The Development of a Magnetic Paste to Remove Recalcitrant Oil from Feathers

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ABSTRACT

This project explores the utility of so-called “magnetic pastes” (MPs) that combine the use of “magnetic cleansing” (MPT) with pre-treatment agents (PTA) and other additives that could potentially facilitate the removal of recalcitrant contamination from feathers. This concept has been systematically explored via the formulation of 21 such pastes, some with different proportions of iron powder and across various categories of PTAs and additives. Using an established gravimetric methodology, these pastes have been systematically tested for their relative quantitative efficacies for the removal of Bua Ban (BB-medium) and Bunker 380 (B380 - heavy) crude oils from clusters of domestic duck feathers. All experiments have been conducted in five-fold replicate. As the physical properties of oil are influenced by temperature, selected MPs were heated to 35°C to test the effect of paste temperature on contaminant removal.

Oil contamination of wildlife, particularly birds, presents a threat to their survival and it is important to develop appropriate methods for efficient removal of a wide variety of contaminants. MPT has shown potential to work as an effective cleaning method of oiled wildlife.

This project has shown that MPT can be developed into MPs that have the potential for the removal of medium to heavy contaminants, that might be otherwise recalcitrant. Thus, it has been shown that some MPs are more efficient at removing a heavy contaminant (B380) from duck feathers than iron powder alone. Valuable insights into the potential usefulness of such magnetic cleansing agents have been gleaned from these experiments. Notable is the effectiveness of the 4% v/v acetic acid (i.e., vinegar) paste for the removal of both medium and heavy contaminants from duck feather clusters. It has also been demonstrated that MPs are contaminant specific, suggesting that such pastes can be tailored to specific contaminants. In this regard, the experiments conducted with two different vegetable oils as additives, for which the relative fatty acid compositions are known, demonstrate that it is feasible to rationally design pastes that are more specific for heavier contaminants. It is evident that some MPs are more efficient overall than iron powder alone. For example, pastes made from conventional PTAs such as methyl soyate, mineral oil, esterol and olive oil are more efficient for the removal of B380 than iron powder alone. Counterintuitively, removal experiments conducted with the pastes heated to a higher temperature (35 C°) show that the effectiveness of some pastes have an inverse relationship to temperature. This suggests a potential application for lower

temperature regimes. Heated MPs have also highlighted the important interaction between the physical chemistry of a paste additive and iron powder on removal efficacy. Finally, these studies help to delineate the effects of various physical properties such as the relative proportion of iron power in a formulation, the effect of additive and contaminant viscosity and iron powder adhesion on oil removal efficacy.

More work is warranted to formulate and test a wider range of pastes to further delineate and improve their removal efficacy and capacity. Since removal is contaminant dependent, a wider range of contaminants should also be explored. Of particular importance is the further investigation of the temperature dependency of paste removal.

Declaration

I, Angela Shewan, declare that the Master of Applied Research thesis entitled "The development of a magnetic paste to remove recalcitrant oil from feathers" is no more than 50,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

I have conducted my research in alignment with the Australian Code for the Responsible Conduct of Research and Victoria University's Higher Degree by Research Policy and Procedures.

Signature: .... Date: ....

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List of Abbreviations

4gFe/g	Represents 4 grams of iron powder for every 1 gram of PTA*
5gFe/g	Represents 5 grams of iron powder for every 1 gram of PTA*
6gFe/g	Represents 6 grams of iron powder for every 1 gram of PTA*
7gFe/g	Represents 7 grams of iron powder for every 1 gram of PTA*
AA	Acetic Acid
BB	Bua Ban Crude Oil
B380	Bunker 380 Crude Oil
BD1	De-oiler (Unspecified) PTA*
CO	Virgin Coconut Oil PTA*
DW	Distilled Water PTA*
EO	Eucalyptus Oil PTA*
EST	Esterol PTA*
EtOH	Ethanol
FAIRY	Fairy® Dishwashing Detergent
MAYO	Praise® Mayonnaise PTA*
MO	Mineral Oil (Johnson's® Baby oil)
MP	Magnetic Paste
MPT	Magnetic Particle Technology
N	Number of treatments
NIVEA	Nivea® Eye Makeup remover
OO	Extra Virgin Olive Oil PTA*
PAH	Polycyclic Aromatic Hydrocarbon
PG	Perfect Gel® Facial Cleanser PTA*
P%	percentage removal of contaminant from feather clusters
P_0%	Maximum percentage removal of contaminant from feather clusters
VOC	Volatile Organic Compound

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Chapter 1: Introduction

1.1 History of crude oil

Crude oil has been known to man from as early as c. 1875 B.C in ancient Samaria but it was not until the mid-19th century that it infiltrated every aspect of industrialised nations when large oil reserves were discovered (Vassillou, 2018). The demand for oil grew as it was a cheap and efficient energy source which fuelled the rapid technological growth of the industrial revolution and accelerated during World War I. Oil has become a major strategic geopolitical objective for many industrialised nations (Vassillou. 2018). These politically driven exploitations of natural oil reserves and the depletion of accessible oil reserves has contributed to further technological developments to exploit more out of reach oil deposits such as oil sands, shale oil and remote deep ocean oil reserves (Vassillou. 2018). Exploration of the offshore Gippsland Basin began in the mid-1960s and by 1967 Australia's largest oil field was discovered, the Kingfish 1 (Geoscience Australia 2023). The amount of oil mined from deep water offshore oil reserves increased from 5% of all conventional oil in 1972 to 35% in 2000 (Vassillou, 2018). Within this time the depths of offshore mines also increased from roughly 240 meters (800ft) in the 1980s to 460 meters (1500ft) in 2007 (Vassillou, 2018), indicating that more remote and isolated parts of the ocean are being exploited to match the global demand of oil and combat the depletion of oil from more accessible reserves. Whole economies are influenced by the availability and price of oil. It is mined for on land and offshore where it is pumped through extensive networks of pipes under the sea floor to refineries where it is turned into high quality hydrocarbon products to be sold and transported across the globe by large petroleum fuelled marine vessels.

Today, processed crude oil i.e., petroleum products, are omnipresent. They are used to power cars, trucks, planes and marine vessels, to pave extensive networks of roads, to manufacture textiles, packaging, utensils, kitchen appliances, medical devices, electronic devices, and infrastructure, and even to make fertilisers to grow food crops.

The environmental problems we face today are largely due to the exploitation of crude oil from burning fossils fuels to power locomotive vehicles contributes to climate change, and plastics made from petroleum products pollute the marine environment. The availability of cheap petroleum products has also made it possible to rapidly clear land and expand urban environments. The drilling for oil and its transportation are major causes of marine oil spills. Nonetheless, the exploration of new oil reserves continues in order to meet the demands of industrialisation and economic development. Petroleum products are ubiquitous and as a result so too is the risk of an oil spill. Oil spills will continue to remain a potential hazard to the environment for as long as we rely on petroleum products (Fingas, 2000).

1.2 Chemical and physical properties of crude oil/petroleum products

By weight, crude oil is composed of 10-14% hydrogen and 83-87% carbon. These elements combined make up ≥90% of the components of crude oil, classing crude oil as a hydrocarbon. Hydrocarbons are hydrophobic and cannot dissolve in water. Crude oil has a lower density than water and when oil spills in the marine environment the oil will sit above the surface and spread outwards. As the oil spreads, a physical barrier is created between the marine environment and the atmosphere preventing photosynthesis and the movement of oxygen between the water and the atmosphere. Oil is attracted to hydrophobic substrates such as shorelines, skin, feathers and fur. Once the oil attaches to these substrates, the oil becomes very difficult to remove. Physical properties vary between oils and affect the strength of the adherence of the oil to a substrate.

Generally, all crude oils contain the same chemical compounds, but proportions vary depending on the location and the condition of the reservoir the oil was mined from giving crude oils a unique fingerprint (Overton et al., 2016). Crude oils typically contain less than 1mg/L of soluble non-hydrocarbon compounds (Keramea et al., 2021) such as the heteroatoms nitrogen ≤2%, oxygen ≤1.5%, and sulphur ≤6% (Overton et al., 2016). Lighter oils contain higher levels of both water-soluble and lower molecular weight compounds which absorb and degrade in the environment (Overton et al., 2016). Heavier crude oils have fewer water-soluble compounds. They contain larger non-soluble molecular compounds which adhere more readily to hydrophobic substrates. Heavier oils are also more likely to form oil-in-water emulsions which persist in the environment decades after an oil spill (Overton et al., 2016; Bodkin, Ballachey et al., 2012).

Crude oil contains toxic compounds, notably Volatile Organic Compounds (VOCs) which readily evaporate, and Polycyclic Aromatic Hydrocarbons (PAHs) which persist in the environment long term (Overton et. al., 2016). The harm caused by these toxic compounds depends on the amount of oil an animal is exposed to and the duration of oil exposure. VOCs readily evaporate and give oil its distinctive odour. In poorly ventilated and tightly packed spaces, inhalation of VOCs can be fatal and this likely contributed to the death of 35% of the oiled African penguins transported to treatment facilities following the oil spill in South Africa caused by the ship the Apollo Sea (Wolfaardt et al., 2009). VOCs can also become trapped in plumage and ingested through preening.

PAHs are carcinogenic, mutagenic and disruptors of hormonal regulation (Albers, 2006). They constitute 5% to 10% of crude oil (Overton et. al., 2016) and absorb into the body via the skin and mucous membranes. Four to six ringed PAHs are the most toxic and cause reproductive problems in marine birds (Albers 2006). The PAHs found in heavier crude oils are too large to be absorbed but are potentially more toxic (Overton et al., 2016). PAHs remain in the environment long term and have been detected in the intertidal zone at Prince William Sound, Alaska, more than 20 years after the 1989 Exxon Valdez oil spill (Bodkin et al., 2012).

1.3 Marine Oil Spills

Oil spills are a persistent hazard to the environment. An oil spill in the marine environment is particularly pervasive as the oil can spread over multiple ecological and geographical regions. Almost half of marine oil spills are caused by crude oil seeping out of natural vents in the sea floor. These types of spills are not considered problematic because the oil seeps out at such a slow rate that natural processes can degrade it and clean-up interventions are not typically required (Razaz, 2020). Larger oil spills are not natural and release huge volumes of oil into the marine environment in a relatively short period of time which overwhelms the natural processes to degrade the oil (Razaz, 2020). These spills are usually caused by shipping or drilling accidents and require large scale clean-up interventions to minimise the damage caused to the environment. Smaller accidental spills occur daily but are not given media coverage and go largely unnoticed whereas major oil spills, although less frequent, receive extensive media attention and become ingrained in the public consciousness (Keramea et al., 2021).

The huge volumes of oil released from offshore mining accidents related to drilling or poor maintenance of infrastructure such as the Montara and Deepwater Horizon oil spills has impacted the environment in unprecedented ways compared to the more common oil spills caused by shipping accidents (e.g., refuelling, poor ship maintenance, and collisions) (Keesing, Gartner, Westera, Edgar, Myers Hardman-Mountford & Bailey, 2018). 71% of all oil spills recorded worldwide come from marine vessels (Chilvers, Morgan & White, 2021). Shipping accidents caused by tanker spills have steadily declined overtime while the volumes of oil that the tankers carry continue to increase (ITOPF, 2022) as seen in **Figure 1.1**. Smaller spills, account for 80% of tanker spills but no data is currently available on the accumulative impact of these smaller spills (ITOPF 2022).

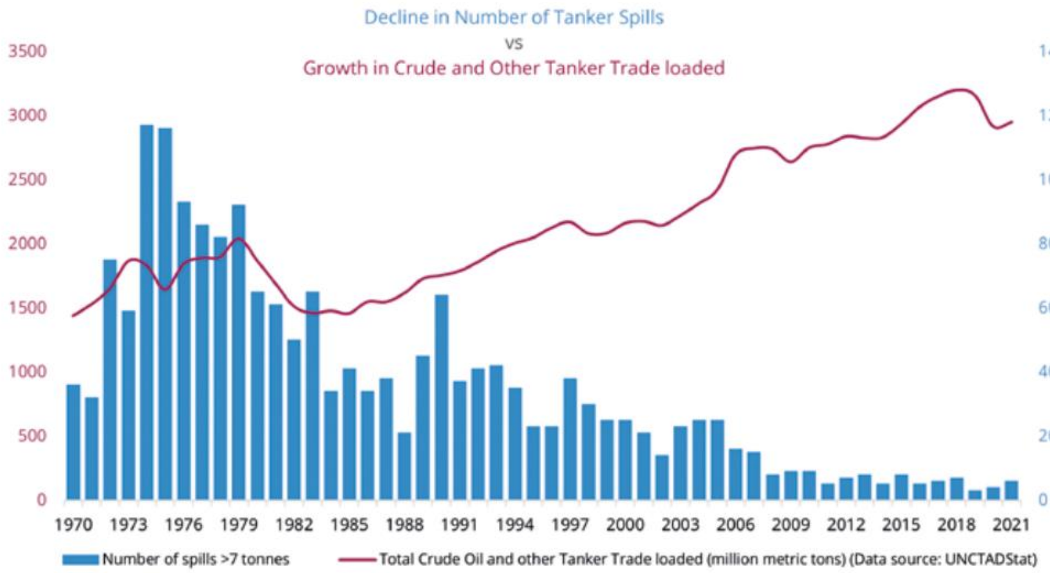


Figure 1.1. The number of oil spills caused by tankers and the volume of oil spilled has declined overtime despite the volume of crude oil transported by tankers increasing (ITOPF 2022)

Large oil spills caused by offshore mining are especially problematic to the environment. The oil continues to be released into the marine environment until the wellhead is capped and this can take months. The deepwater horizon spill, 2010, lasted three months from 20th April 2010, until the well head was capped on 15th July 2010. Within this time, the oil spread 149,000 km² but the geographical spread varied overtime. **Figure 1.2** shows how the area covered by the oil varied over time and that the peak spread occurred on June 18th, 2010, two months after the spill began (Berenshtein et al., 2020)

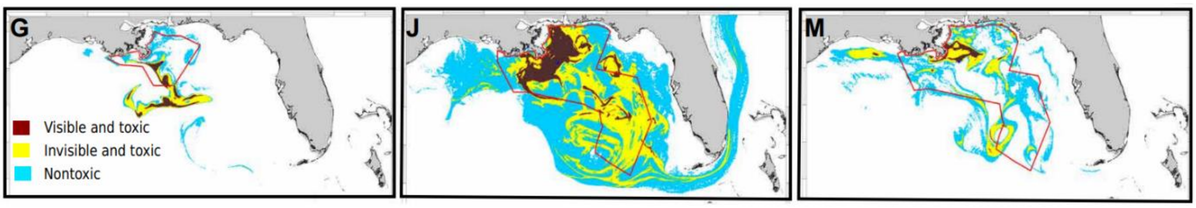


Figure 1.2 The spread of the Oil Spill changed throughout this period. **G** shows the spread of oil on the 15th May 2010, **J** shows the spread of oil on 18th June 2010, and **M** shows the spread of oil on 2nd July 2010. (Berenshtein et. al., 2020).

The extent of environmental damage caused by an oil spill is dependent on many factors such as the proximity of the spill to coastlines, habitat types, protected marine parks, fishing zones and recreational areas (Keesing et. al, 2018). However, weather conditions such as tides and winds can propel oil hundreds to thousands of kilometres from the site of the spill, spreading the oil over multiple ecosystems, geographical regions, and across international and state borders (Ryan & Parry, 2021).

1.4 Oil Weathering

Natural processes alter the composition of oil and the trajectory of an oil spill overtime (Keramea et al., 2021). These natural processes are also called "oil weathering processes" which begin as soon as oil enters the environment and spreads across the surface of the water. Wind and heat accelerate the evaporation of the smaller volatile components and both wind and wave action disperse the oil. Emulsions of oil and sea water are formed, and the soluble components are pushed down the water column. Within a few hours, the sun and atmospheric oxygen oxidise the oil (i.e., photo-oxidation). This introduces oxygen atoms to create tar mats/balls (Ward et al., 2019). Waves mix the sand suspended in the water together with the oil, trapping toxic PAHs, forming tar mats which sink to the sea floor. Tar mats are difficult to locate and remove from the environment. Wave action breaks tar balls off from tar mats and the tar balls persistently wash up along coastlines years after the spill (Clement & John, 2022). The change in oil composition from photo-oxidation reduces the effectiveness of chemical dispersants (Vaz et al., 2021). Biodegradation of crude oil by certain microorganisms is increased after photo-oxidation (Keramea et al., 2021) with complete mineralisation of alkanes and naphthalene derivatives into carbon dioxide and water (Dutta & Harayama, 2000). However, higher-molecular-weight compounds reacting to photo-oxidation can cross link to create heavier compounds that are more resistive to biodegradation (Overton et al., 2016). To make matters more complex, solar radiation alters the composition of biodegrading microorganisms and this impacts the rate of biodegradation (Vaz et al., 2021). Biodegradation is a slow process. Photo-oxidation increases oil degradation from 28% to 36% over an 8-week period (Dutta & Harayama, 2000). The final stage of the weathering process is sedimentation when the remaining components sink to the bottom of the ocean or sea (Keramea et al., 2021).

The rate of oil weathering is variable and is determined by the interaction between the chemical composition of the oil and the variable conditions of the environment. These conditions affect the rate of spreading, evaporation, and emulsification of the oil (Keramea et al. 2021). The rate of spreading is determined by the interaction between the viscosity and density of the oil against the temperature of the water's surface, wind speed and wave action (Keramea et al. 2021). The rate of evaporation is heavily influenced by the temperature of the oil itself which is determined by the vapor pressure and the concentration of volatile components within the oil, as well as the temperature of the surface water, the wind speed and spill coverage (Keramea et al. 2021). The rate of emulsification increases with the intensity of wave action and the viscosity of the oil (Keramea et al. 2021). Evaporation indirectly increases the rate of emulsification by increasing the oil viscosity.

1.5 Notable Oil spills in Australia

Oil spills are a global issue and have affected many countries either directly or indirectly. Australia has experienced many oil spills within the last decade. These spills were caused by both accidents related to shipping and offshore mining.

MV Tycoon, Christmas Island 2012.

In 2012 the MV Tycoon cargo ship broke free from its mooring and crashed into a seawall on Christmas Island. The ship spilled 102 tonnes of bunker fuel oil, 32 tonnes of diesel oil, and 11,000 Litres of lubricant oil. The ship also released the 260 tonnes of the phosphate it was transporting (Australian Maritime Safety Authority [AMSA], 2020a). It is thought that most of the spilled oil dissolved into the local water column which pushed the oil onto nearby beaches and further out to sea where rough weather was able to disperse the oil. The clean-up was coordinated by AMSA and the Christmas Island Emergency Management Committee. It took 8 days using heavy machinery to clean the oil from contaminated beaches (AMSA, 2020a).

Pacific Adventurer, Moreton Bay 2009

On March 5th, 2009, Cyclone Hamish formed in the coral sea and travelled south along the coast of Queensland until March 12th, 2009 (Bureau of Meteorology, 2022). On March 11th, 2009, a cargo ship called the Pacific Adventurer, spilled an estimated 270 tonnes of heavy fuel oil and 31 containers of ammonium nitrate into the sea near Cape Morton. Most of the leaked heavy fuel oil washed up along the beaches of the south-eastern coast of Queensland. It took two months and 2,500 personnel to clean up the spill. Fortunately, despite the size of the spill, the number of wildlife affected was relatively low and this was most likely because the marine birds had migrated to avoid Cyclone Hamish. The spill occurred while docked, allowing clean-up personnel to access the source of the spill more easily. The clean-up effort was given high priority by the local municipality and the State Government due to the spill impacting the tourism industry and the local community (AMSA 2020b). The cost of the clean-up exceeded the predicted $25 million.

Montara wellhead, Timor Sea 2009

On the 21st of August 2009, an uncontrolled oil spill occurred at the Montara wellhead in the Timor Sea off the coast of the Northern Territory. The spill continued for more than 10 weeks. Approximately 64 tonnes of a light crude oil were released into the sea per day. The closest terrestrial habitats to the Montara wellhead are Cartier Island Commonwealth Marine Reserve, Ashmore Reef and Browse Island Nature Reserve, all of which are inhabited by seabirds and shorebirds. Ashmore Reef is a Ramsar wetland of international significance (Clarke & Herrod, 2016). An initial survey of the oil affected areas observed species specific changes. Some marine birds appeared to avoid the area however the absence of the Red-footed Booby and Lesser Frigate Bird from the sea strip surveys could be due to restricted movement during their breeding season. Other absent marine bird species may also prefer to feed in deeper waters not covered by the area surveyed. Conversely, other marine bird species, larger fish, mammals and sea snakes were seen in higher numbers around oil slicks. The schools of fish appeared to be attracted to the oil sheen and the marine birds were attracted to the area by the higher concentration of fish (Watson et al., 2009). A scientific monitoring study of seabirds and shorebirds conducted as part of the Montara environmental monitoring program by Monash University spanning 5 years, found that the Montara spill had no significant impact on the population of seabirds and shore birds at Ashmore Reef (Clarke & Herrod, 2016).

Despite no long-term impact on marine birds, 15,500 seaweed farmers in Indonesia experienced crop damage and financial losses as a direct result of the oil spill (Ryan & Parry, 2021). The landmark case Sanda v PTTEP Australasia (Ashmore Cartier) Pty Ltd, (2021) is the first time a foreign claimant has won against an Australian company for cross-border pollution (Ryan & Parry, 2021).

The class action determined that the risk of another major oil spill in Australia remains high due to the decommissioning risks and liabilities in the offshore gas and oil industry and the industries ongoing lax regulation. A decommissioned offshore floating production facility 'The

Northern Endeavour' is at high risk of spill oil as it has advanced corrosion and major structural problems like the Montara wellhead (Ryan & Parry, 2021).

The iron baron oil spill, Bass Strait 1995

Approximately 325 tonnes of bunker fuel oil spilled from the *Iron Baron,* a chartered bulk ore carrier, in Bass Straight as it ran aground at Hebe Reef on the Tasmanian coast (National Plan Strategic Coordination Committee, 1996). The spilled oil contaminated the Little Penguin habitat along the shores of Ninth and Waterhouse islands (Goldsworthy, Gales, Giese & Brothers, 2000). The volume of oil was relatively small but had a huge impact on the Little Penguin population directly killing between 10,000 and 20,000 Little Penguins (Goldsworthy, Gales, Giese & Brothers, 2000). **Figure 1.3** shows the location of the Iron Baron Spill on Hebe Reef and the locations, mainly islands, along the Tasmanian coastline where oiled penguins were collected from.

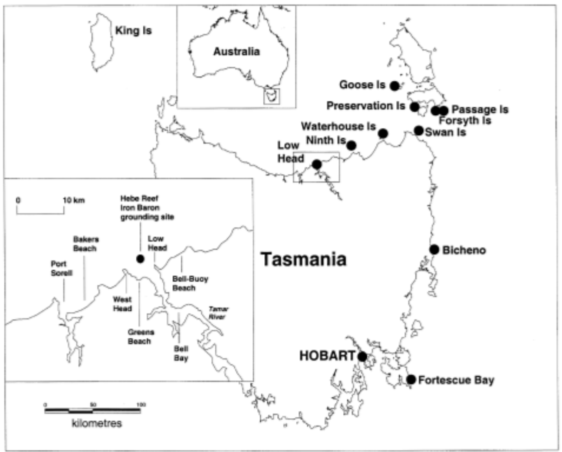


Figure 1.3. This map of Tasmania indicates where the Iron Baron ran aground at Hebe reef and spilt its oil. Oiled penguins were collected from the locations indicated on the map: Low head, Ninth Island, Waterhouse Island, Preservation Island, Goose Island, Passage Island, Forsyth Island, Swan Island, Bicheno and Fortescue Bay. (Goldsworthy, Gales, Giese & Brothers, 2000).

The success of rehabilitated penguins following the Iron Baron Spill was largely determined by the degree of oiling, the mass and condition of the penguin at the time of capture. Penguins with less oiling, higher mass and better overall health were more likely to survive post rehabilitation. An oiled penguin can rapidly lose mass as the oiling disrupts thermoregulation and increases metabolic rate and this affect is exacerbated with increased oiled surface area and prolonged exposure (Goldsworthy, Giese, Gales, Brothers, & Hamill, 2000).

The timing of the Iron Baron Spill and the length of time oiled penguins spent in captivity interrupted important milestones to prepare for the approaching breeding season. Penguins who lost a pair bond partner from the oil spill, did not breed during the upcoming breeding season. Rehabilitated oiled female penguins had lower egg success than non-oiled penguins by the end of the 1995-96 breeding season. For two seasons following the spill, the health of the young of rehabilitated oiled penguins were compromised (Giese, Goldsworthy, Gales, Brothers & Hamill, 2000).

1.6 Offshore Oil Mining in Victoria

ExxonMobil has 23 offshore platforms in the Bass Strait and has pumped 4 billion barrels of crude oil through 600km of underwater pipelines to mainland Victorian refineries located in Williamstown and Altona (Port Phillip Bay), Hastings at Long Island point (Western Port Bay) and Longford in Gippsland. Although Exxon Mobile works closely with government and local jurisdictions to mitigate potential environmental effects of extracting and transporting crude oil and gas, the risk of an oil spill is ever present due to the scale of the operation (Australian Maritime Safety Authority National Plan for Maritime Environmental Emergencies, 2020)

The offshore mining platforms and the extensive petroleum networks in Bass Strait are in close proximity to the Little Penguin colonies shown in **Figure 1.5**. Penguin colonies extend easterly to the Gippsland Basin which is internationally recognised as a giant oil and gas province and the location of Australia’s largest oil field (Geoscience Australia, 2023).

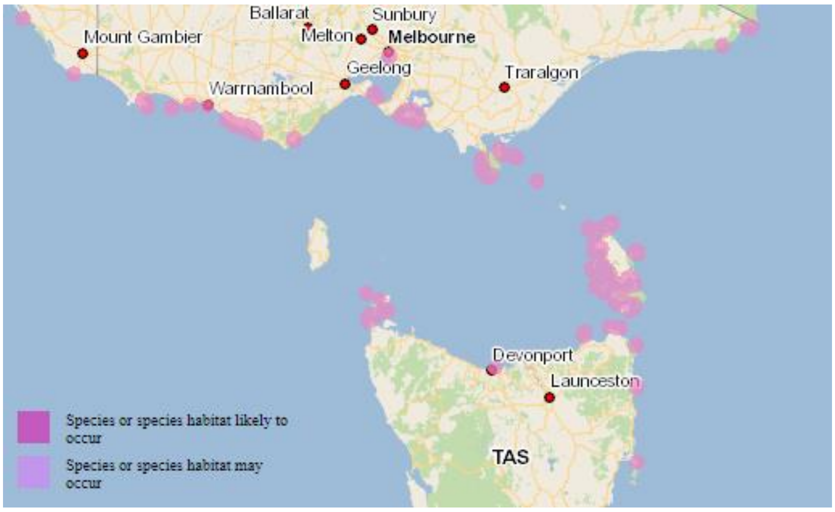


Figure 1.5 Little Penguin colonies, represented in pink, surround Bass strait along the Victorian and the northern Tasmanian coastlines (Department of Climate Change, Energy, the Environment and Water, 2022).

The Gippsland Basin oil field has reached maturity, and its output is declining. However, the Gippsland Basin is considered underexplored and under drilled. Deep-water seismic tests and modelling studies have shown promising oil reserves in the deeper areas of the Gippsland Basin (Bernecker et al., 2001).

Offshore exploration of oil continues in Australian waters as the Federal Government considers Australia to have “the world’s most highly prospective areas for oil and gas” (Australian Government, 2017). The federal government continues to grant permits to assess for underwater oil reserves. Offshore oil and gas contributed $31 billion in 2015 and 2016 to the Australian economy and employed 29,000 people (0.18% of the Australian workforce). Oil and Gas Companies such BP, Chevron, Karoon Energy, Equinor, Santos and Murphy Oil have been encouraged by the Federal Government to explore the Australian Bight for oil and gas (Morton 2020), all of which have abandoned drilling in the area. Support for the drilling was mainly driven by the belief that such a project would create more jobs. However, the project modelling showed that only 826 jobs would be created over the lifespan of the project and most of these positions would be filled by fly-in fly out (FIFO) workers (Campbell et al., 2019). 60% of the Australian population did not support the exploratory drilling in the Great Australian Bight mainly due to concerns relating to the impact on the environment and the tourism, fishing and aquaculture industries which employ over 10,000 South Australians (Campbell et al., 2019).

Equinor, Santos and Murphy Oil have since pulled out of their deals. Equinor considered the plan to not be commercially competitive compared to other locations around the world (Morton, 2020) and Santos believes that exploring the Great Australian Bight falls outside their "strategy to build and grow their five-core long-life natural gas assets" ("Santos and Murphy Oil" 2021). Despite these failed deals, the Australian Government maintains their support of offshore drilling and oil exploration (Morton, 2020; Australian Government, 2017) by continuing to grant permits for offshore petroleum exploration in the Commonwealth waters of Victoria, Western Australia, Northern Territory, and Ashmore and Cartier islands (Bernecher et al., 2021).

1.7 Oil Contamination and Wildlife

Although large volumes of oil cause extreme environmental damage, the volume does not accurately estimate of the number of oiled wildlife (Chilvers et al. 2021). The worst accidental oil spill in history was the Deepwater Horizon Spill off the Gulf of Mexico (2010) which released 275,114 tonnes of oil which spread approximately 149,000 km² (Berenshtein et al., 2020) and killed 700,000 marine birds (3 birds per ton). The Exxon Valdez oil spill (1989) released 36,400 tonnes of oil and killed an estimated 350,000-390,000 marine birds, approximately 10 birds per ton (Burger, 1993). However, a proportion of these birds died not from direct oiling but from starvation caused by the oil spill which destroyed their food supply (Piatt et al., 1990). In contrast, The Apex Houston, 1986, spilled a modest 87 tonnes and killed 10,577 marine birds, approximately 121 birds per ton. The number of marine bird deaths is dependent on the population density and proximity to the site of the spill rather than the volume of oil spilled (Burger, 1993; Chilvers et al., 2021). Marine bird populations are greatest along coastlines and gradually decline with increasing distances from land (Burger, 1993), but density is also influenced by migration and weather events (AMSA, 2020a). Oiled marine birds closer to land are more easily accounted for and more easily captured and cleaned. The marine birds oiled further from shore are more difficult to account for and capture for rehabilitation (Burger, 1993).

Marine Oil spills are a threat to all marine life but impact certain species more so than others depending on the location of the spill, the size and density of the population, timing of migrations, foraging and social behaviour, biology and morphology (Piatt et al., 1990)**.** The most at-risk taxa for mortality following an oil spill are those that inhabit shorelines were the oil has accumulated after the spill. This oil remains in the sediment long after the spill and can cause delayed recovery to these taxa as they continue to be exposed to toxic compounds known as Polycyclic Aromatic Hydrocarbons (PAHs) (Bodkin et al., 2012). Ten years following the Exxon Valdez oil (1989) spill, 55,600 kg hydrocarbons remained in the intertidal zone (Peterson et al., 2003) continuing to expose pigeon guillemots to PAHs causing elevated transcription in several genes associated with hydrocarbon exposure such as elevated enzyme activity in cytochrome P4501A (CYP1A). aspartate aminotransferase (AST), and lactate dehydrogenase (LDH) (Golet et al., 2002).

1.8 The Little Penguin *Eudyptula minor*

1.8.1 Distribution of Little Penguins in Australia

Little Penguins, *Eudyptula minor*, are the smallest of the 17 Penguin species standing 30-40 centimetres tall and weighing only one kilogram. Little Penguins are the only Penguin species inhabiting the coastlines of Mainland Australia and Tasmania. They are distributed across the southern coastline, stretching across 5 states – Western Australia, South Australia, Victoria, New South Wales, and Tasmania. Little Penguins are also distributed along the coastlines of New Zealand. The largest Little Penguin colonies in Australia are found on islands such as Phillip Island in Victoria, Penguin Island in Western Australia (Parks and Wildlife Service, 2022), the Forsyth Island in Tasmania, (Goldsworthy, Gales, Giese & Brothers, 2000) and Baranguba Island in New South Wales (NSW National Parks and Wildlife Service, 2002). There are smaller colonies on the mainland, living side by side with humans in highly urbanised areas such as St Kilda in Melbourne, and Manly beach in Sydney. Manmade structures in these highly urbanised areas provide adequate alternative shelter and protection for penguins whose former colonies were disturbed by land clearing and introduced predators. Little Penguins have colonised the volcanic rocks of the St Kilda Breakwater (Earthcare St Kilda, n.d), and houses and stairs near Manly Beach in NSW (Bourne & Klomp, 2004) and the close proximity to abundant food sources. This shows that Little Penguins are somewhat resilient and adaptable. Aboriginal middens around Sydney Harbour suggest the distribution of Little Penguin colonies was once robust but due to rapid urban expansion, habitat destruction, and decline in food sources due to commercial fishing and pollution, the current distribution is restricted to 2km of foreshore between Manly and Cannae Point (Bourne & Klomp, 2004), making the Manly colony the only Little Penguin colony on mainland NSW. This colony is protected by the *Biodiversity Conservation Act 2016* (NSW).

1.8.2 Little Penguin Biology and Morphology

Little Penguins are more vulnerable to oil contamination than other marine birds for several reasons. Little Penguins build their nests along coastlines which they retreat to between sun set and sun rise after a whole day spent swimming and foraging for food. Little Penguins occupy the top strata of open waters and break the surface of the water to breathe approximately every 20 seconds. They are social animals and will a share nest with a mate where they nurse their young. Little Penguins can unsuspectingly become oiled because they cannot see oil slicks from afar like aerial flying birds can (Wolfaardt et al., 2000).

Penguins swim in frigid waters and have evolved several anatomical features to regulate body temperature. Their body shape is rotund to lower surface area to volume ratio to prevent heat loss, and fusiform to improve swimming and diving efficiency. They also have highly vascularised long thin wings for flying in water enabling efficient heat loss during bouts of extreme exercise. Heat conservation is also achieved in the wings through a counter current flow between the arteries and veins called the humeral plexus (Thomas & Fordyce, 2012). The humeral plexus limits the amount of heat lost from blood from the tip of the wing (Thomas & Fordyce, 2008). Heat stress mainly occurs terrestrially and is increasing due to climate change. Little Penguins experience heat stress when their nest boxes reach 35°C (Chambers et al., 2013). Little Penguins don’t have physiological adaptations to deal with heat stress in the terrestrial environment and instead resort to changes in behaviour (Frost et al., 2009).

1.8.3 Little Penguin Feathers and Plumage

Little Penguin plumage is composed of densely packed short contour feathers which interlock creating a barrier between the frigid water and the internal body to maintain internal body temperature (Thomas & Fordyce, 2012). The level of water repellency and waterproofing (resistance to water penetration) varies between bird species and this is due to selective pressures on feather microstructure by the environment/habitat. Penguins and other diving birds have low water repellency but a high waterproofing because the barbules are large in diameter and the barbules sit closer together along the barb. Whereas a bird with high water repellency and low resistance to water penetration like the Mallard Duck have smaller barbules which sit further apart along the barb (Rijke & Jesser, 2011).

The contour feathers of Little Penguins can be broken down into three sections – the tip, the pennaceous region, and the Plumulaceous region. Because the contour feathers are so tightly packed together, only the tip is visible. The tip of dorsal contour feathers is blue as seen in **Figure 1.6** and gives Little Penguins their distinctive blue hue. These tips lack or have reduced barbules so are unlikely to be waterproof (D'Alba et al., 2011).

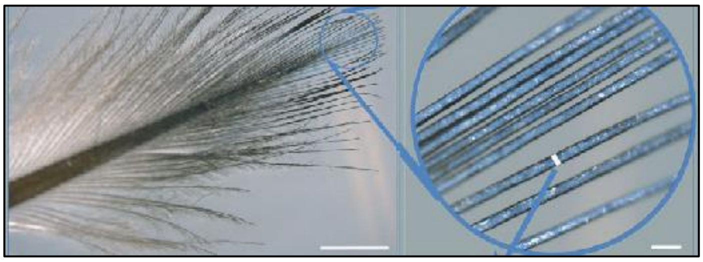


Figure 1.6 The magnification of a Little Penguin contour feather shows that the barbules at the tip of the feather are blue and lack barbules. Image taken from D'Alba et al. (2011) paper. Photo credit given to John Denman, Australia.

The pennaceous region of a contour feather begins from the base of the rachi to below the blue tip (Metwally et al., 2019). Barbs branch from a central rachi and barbules branch from the barbs (King et al., 2021). Each barbule has a series of hooks (hamuli) shown in **Figure 1.7**. The hamuli link together with the hamuli on neighbouring barbules (King et al., 2021) as shown in **Figure 1.8.** This is how a single feather creates a barrier to water.

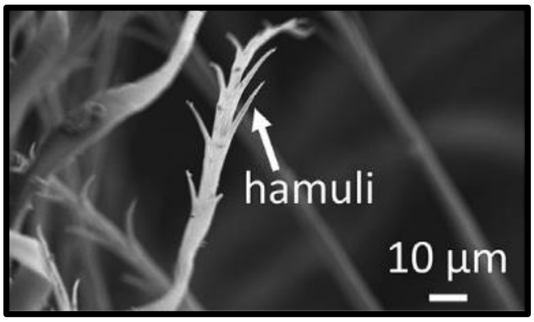


Figure 1.7 SEM micrographs of the hamuli (hooks) on the barbules of ventral contour feathers (Metwally et al., 2019).

Oil contamination disrupts the alignment of the barbules as seen in **Figure 1.8** and waterproofing cannot be maintained. The surface of a feather also has hydrophobic and ice-phobic properties created by the wrinkled surface texture of the barbs and the porous surface of the rachi both of which trap air and decrease surface free energy. The internal structure of the feather is also porous containing keratin matrixes and foamlike structures which contain air (Metwally et al., 2019).

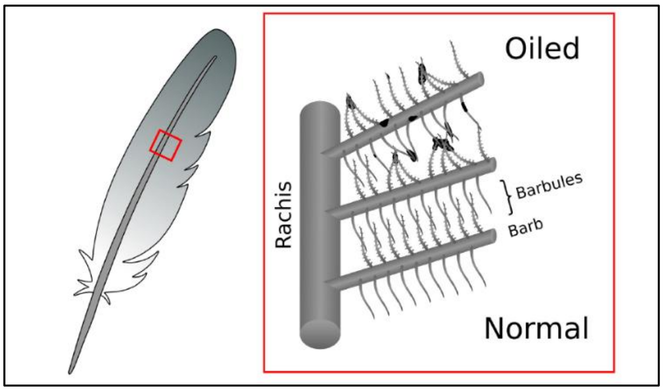


Figure 1.8 An illustration of the microstructures of a typical feather. Under normal conditions, the barbules align to lock together. When feathers become oiled, the oil disrupts the alignment of the feather's barbules, creating gaps for water to seep through (King et al., 2021).

Contour feathers contain plumulaceous afterfeathers connected to the hyporachis which sits between the calamus and the base of the rachi (Metwally et al., 2019). It is assumed that the main function of the afterfeather is insulative as the microstructures are similar to true down (Pap et al., 2020). The afterfeather has long filamentous barbules with sticky nodes of varying sizes and shapes. This creates a loose matrix that traps warm air emanating from the body (Pap et al., 2020). An aquatic habitat selects for aquatic birds to have shorter contour feathers and afterfeathers with longer and denser barbules with a lower density of sticky nodes. This adaptation enables air to easily escape during diving to reduce both buoyancy and drag. Emperor penguins hold 5 Litres of air in their plumage while on land but when submerged in water almost all this air is expelled under the pressure of water except for a small amount close to the skin. As an Emperor Penguin descends, the trapped air expands and diffuses through the plumage to surround the body in a bubble which reduces drag and increases speed. To compensate for the lack of insulation from downy feathers when diving, Emperor Penguins, and potentially all penguins, have a thick layer of subcutaneous fat (Pap et al., 2020).

Penguins as a taxonomic order were thought to not have true down however a study conducted on the feathers of Emperor Penguins by Williams et al. (2015) found that Emperor Penguins downy plumules and filoplumes which are distributed between the contour feathers as seen in **Figure 1.9**. Plumules are insulative feathers that trap warm air and enable penguins to survive in cold climates, just like the afterfeather (Williams et al., 2015). Filoplumes are small feathers that only have barbs and barbules attached at the tip of the rachis. The main function of filoplumes is thought to be sensory. They are sensitive to the changes in ambient temperature and signal feather misalignment (Williams et al., 2015).

Figure 1.9 The distribution of downy feathers and contour feathers of penguin plumage. Illustration by C.N. Cruz. Featured in Williams et al. (2015).

1.9 Oiled Wildlife Clean-up Response

The clean-up response for oiled wildlife is a concerted effort by government, oil companies, and wildlife experts.

There are many steps involved in responding to a marine oil spill. These steps have been divided into 3 parts for the purpose of this thesis. The first part – planning and wildlife recovery (refer to **Chapter 1.9.1 Planning and wildlife recovery**) addresses how the oiling event will be managed. The second part is the cleaning process, and it is this part which MPT could be implemented in the future as an alternative cleaning technology to detergent based methods to clean oiled wildlife (refer to **Chapter 1.9.2 Cleaning oil from wildlife**). The third part refers to rehabilitation which happens post cleaning and using MPT may improve this stage by (refer to **Chapter 1.9.3 Rehabilitation**) (NSW Department of primary industries, 2012).

1.9.1 Planning and wildlife recovery

Planning and preparedness

This assesses the situation and determines the health and safety concerns. At risks species are identified. Response options and resources needed are identified based on the nature of the oil spill.

Reconnaissance and Hazing

The spill site is thoroughly observed for oiled animals. This gives responders an idea of which species have been affected and to what extent. Responders can then implement the correct specialisations for affected species (NSW Department of primary industries, 2012).

Hazing of the affected site attempts to prevent further wildlife contamination. Hazing involves using tactics that will prevent animals from approaching the spill site. The tactics used will vary depending on the species and the location of the spill. (NSW Department of primary industries, 2012). Some species will avoid loud sounds, bright lights, or physical barriers such as bubble curtains. Hazing can cause animals to become distressed and react in ways that can cause harm to themselves and to others in their colonies such as causing a stampede and trampling on their young or push the hazed animals out towards predators or other hazardous environments.

Wildlife recovery

Animals that have already been oiled are identified and captured. Once captured they are given first aid and transported to treatment facilities where a file is started to record each individual animal. These files record the time, date and location of capture, the extent of oiling and health status (NSW Department of primary industries, 2012). The oiled animals are triaged by experienced wildlife personnel to improve the efficiency of the clean-up response. Animals that are deemed more likely to survive the oiling and animals that are rare and endangered are prioritised (Walraven 1992). The oiled animals are given appropriate species-specific care including nutrition, hydration and shelter. They will only proceed to the cleaning stage once their health status is stable. This is because the cleaning processes is an additional stress that can overwhelm a sick animal causing death (NSW Department of primary industries, 2012).

1.9.2 Cleaning oil from wildlife

Procedures are developed to minimise stress to improve survival outcomes. Each animal is cleaned by 2 personnel and takes approximately one hour (Estes, 1998). The cleaning process involves 5 steps listed below:

Step 1: Stabilisation

Before washing begins, the bird is given at least one dose of rehydration and glucose solution, and this is determined and carried out by the veterinarian staff based on species, size and status of the bird (NSW Department of primary industries, 2012).

Step 2: Pre-treatment. 30 to 60 minutes

Firstly, heavier contaminant oils may require application of a pre-treatment agent (PTA). Lighter oils don't necessarily need a PTA application before cleaning. PTAs commonly used in Australia are light oils, either cooking oils or a mineral oil. These light oils are warmed between 35°C and 38°C and massaged into the feathers and left for thirty minutes to soften the hard and tarry contaminant oil (NSW Department of primary industries, 2012). The type of pre-treatment oil and the time needed to massage into the feathers will vary depending on the type of contaminant. This stage can take anywhere between thirty minutes to an hour and requires two personnel to complete, one to hold the animal and the other to massage the PTA into the contaminated feathers.

Step 3: Cleansing. 60 minutes

After pre-treatment the oiled birds are placed in 39°C - 40°C water baths with 2-10% detergent. Dawn ® dishwashing liquid is considered the most effective detergent to remove oil however its accessibility is restricted to North America. Phillip Island Nature Park uses Suma Star Plus D1 (Leung, Morgan, White, Ward & Chilvers, 2015). Leung et al. (2015) found that Dawn ® dishwashing liquid is by far the most effective detergent compared to other more accessible detergents. Of the other detergents tested, Suma Star Plus D1 was the most effective and its effectiveness improves as its concentration increases from 2% to 10% concentration. This stage also requires two personnel, one to hold the bird and the other to wash. Washing is achieved by ladling the bath water over the bird and massaging the feathers under water to minimise damage to the feathers. Once the bath water becomes too oily, the water is gently squeezed out of the feathers and the bird is moved to another bath and the process is repeated until the bathwater contains no oil, indicating that all oil has been removed from the bird's feathers. (NSW Department of primary industries, 2012).

Step 4: Rinsing. 15 to 30 minutes

The cleaned bird is placed in a warm freshwater bath (39°C - 40°C) and the bath water is ladled over the bird until the bath water contains detergent residue. Rinsing of the bird starts from the top downwards. The bird is then moved to another warm water bath and the process is repeated until the bath water contains no detergent residue. The bird is then rinsed again with 39°C - 40°C water using a pressurised waterhead until water can be seen beading and rolling off the feathers and the feathers appear dry and fluffy (NSW Department of primary industries, 2012).

Step 5: Drying. 30 to 180 minutes

The bird is gently patted down with a dry towel and then placed into a drying pen. Only one bird should be placed in a drying pen at any one time. Drying pens are lined with an absorbent material and heated to 35°C - 40°C using heat lamps and warm air blowers. The birds must have access to drinking water when inside the drying pens to prevent overheating and dehydration. The temperature of the pens, and the state of the bird must be closely monitored to prevent heat stress. The time needed to dry depends on the size of the bird. A small bird may only require 30 minutes whereas a large bird may require up to three hours (NSW Department of primary industries, 2012).

1.9.3 Rehabilitation

Rehabilitation is a lengthy process and can take several weeks. Only uninjured, healthy birds with waterproof plumage can be released.

Waterproofing

Once dry, the bird is placed in a warm indoor pre-release accommodation where it can be closely monitored and assessed for waterproofing. A bird that is not waterproof will continue to over preen and avoid going in water. It is normal for birds to preen early at this stage as preening helps the bird to realign the microstructures that have been disrupted not only from oiling but also from the cleansing process. Once waterproofed, the bird is placed in an outdoor setting where it can recover and regain enough strength to be released (NSW Department of primary industries, 2012).

Recovery. Several days to several weeks

A cleaned and waterproofed bird still requires supervision and care before release including adequate nutrition and hydration. This can take between several days to weeks depending on the condition of the bird. Only birds that are fit, healthy, strong, with waterproofed feathers will be released back into the wild. Those that are not fit for release will either remain in captivity or be euthanised (NSW Department of primary industries, 2012).

As an oil spill clean-up can take several months, longer than it takes to rehabilitate wildlife, rehabilitated birds may not be able to be released to their original habitat right away. Little Penguins have been successfully translocated to other colonies not affected by the spill. The Little Penguins will try to return to their original habitat, so it is important to choose a new colony that is far enough away to delay their return to their original habitat (Goldsworthy, Giese, Gales, Brothers & Hamill, 2000).

1.10 Outcomes of the Oiled Wildlife Clean-up Response

Cleaning oiled wildlife is crucial to ameliorate the devastating effects of an oil spill. However, it does not reverse the effects the oil has on affected wildlife and the environment. The cleaning process also poses risks to the safety and wellbeing of oiled wildlife and personnel. The cleaning processes is highly stressful to wildlife, and this can hamper survival rates. Procedures have been developed to fine tune the cleaning process to reduce the stress levels of the affected animals. Personnel also experience high levels of stress as they witness the dying and suffering of several animals. Personnel also need to protect themselves from the toxic effects of crude oil to reduce the risk of personal injury and poor health. The cleaning process also produces a lot of toxic waste which needs to be safely disposed of to reduce re-contaminating the environment.

Protocols recognise that the process rescue and rehabilitation may cause additional harm and reduce the animal’s chance of survival post-cleaning. Factors that cause stress in an animal is species specific however many factors are universal such as human contact (including noise and movement), time spent being held and how they are handled, overcrowding, and exposure to potential predators. The animal needs to be kept in an environment that mimics its natural habitat including a comfortable ambient temperature, natural light levels and a similar physical environment such as a perch for a perching bird or a burrow for a burrowing bird. Introducing any type of container into an enclosure may reduce Little Penguin stress levels by making it feel safe. Nutritional needs must be met for all animals, but the quantity and source are species specific (Walraven 1992).

Hydrocarbon oil is toxic to all lifeforms, including humans. Personnel involved in oil clean-up can be exposed to the toxic compounds of oil for extended periods of time either via contact to the skin or inhalation of toxic VOCs. Appropriate Personal Protective Equipment (PPE) such as protective eye coverings, face masks, gloves, closed toe shoes, and water-resistant/water-proof clothing should always be donned during the clean-up process and appropriately disposed of. Working stations should have appropriate ventilation. Toxicity causes headaches, nausea, drowsiness, burning skin, chest tightness, blurred vision, irritation of the eyes, and tinnitus (Walraven 1992).

The Australian Marine Oil Spill Centre provides clean-up operations with an Oiled Wildlife Response (OWR) Container. These containers provide the equipment needed to safely clean oiled wildlife, such as gas hot-water systems, running water, electricity, air conditioning, and waste disposal (Australian Marine Oil Spill Centre, 2014). The oily grey water cannot simply be poured down a drain and into the sewer system (NSW Department of primary industries, 2012). The local jurisdiction dictates the appropriate treatment and disposal of oily grey water (Australian Maritime Safety Authority National Plan for Maritime Environmental Emergencies 2020).

1.11 Rehabilitated Marine Birds

Waterproofing of feathers in rehabilitated birds is greatly reduced. Contaminants damage the feather microstructures as does the cleaning process. Feather microstructures can be further damaged by over preening. Preening improves the integrity of the feathers by coating the feathers with preen-oil which is produced by the uropygial gland which sits near the tail. Preen-oil does not waterproof the feathers but helps to maintain the feather microstructures so the barbules can interlock. However, preen oil does increase water repellency by increasing the surface tension of the feathers (Bostwick, 2016). The intensity and frequency of preening is one of the important indicators of bird fitness in rehabilitation (Walraven, 1992). Birds in rehabilitation must be hydrated and well-nourished before release and this also takes time (U.S. Fish and Wildlife Service, 2003).

Rehabilitated oiled wildlife can have lower reproductive success with smaller clutch sizes, egg production and lower rates of hatchling success with reduced growth, developmental abnormalities and a higher rate of mortality, and increased clutch/brood abandonment (Albers, 2006). This is especially concerning as an individual animal directly impacted by oiling can pass the effects of contamination down through the generations therefore affecting the entire species. Furthermore, the PAHs also impact the immune system leaving the oiled bird susceptible to infections such as pneumonia and aspergillosis.

1.12 Alternative Clean-up Methods: Magnetic Particle Technology (MPT) and Magnetic Pastes (MP)

Previous research has shown that removing contaminant oils from bird feathers with MPT is comparable to traditional surfactant-based methods (Munaweera, 2015). These projects have established the optimal grade of iron powder, the effectiveness of PTAs, and the optimal ambient temperatures to remove contaminants. However, MPT, as it currently is, struggles to remove the more hard and tarry components of hydrocarbon oil. PTAs are often used advantageously to soften the contaminant oil in both the detergent-based cleaning processes and MPT. Thus, combining PTAs with iron powder is a logical step to improve MPT particularly the removal of the hard and tarry components. Other agents that are not typically used as PTAs may also prove to be exceptional additives to a MP.

The research group at Victoria University is the only group worldwide that is working on the application of MPT to oiled wildlife rescue and rehabilitation. Therefore, the international published literature is limited to this group.

Contaminants such as crude oils, readily adhere to the surface of iron particles. The oil laden iron particles can then be sequestered from a substrate with a magnetic wand (Bigger, Ngeh, Dann, & Orbell, 2017). Iron particles that have a greater surface area are more efficient at removing oil from a substrate. A greater surface area is achieved by reducing the size of the particles and roughening the surface of the particles. In **Figure 1.10**, MH300-29 spongey annealed iron particles are more efficient at removing Arab Medium Crude Oil than other iron grades due to its large surface area which can absorb and adsorb more oil (Dao, Ngeh, Bigger & Orbell, 2006a).

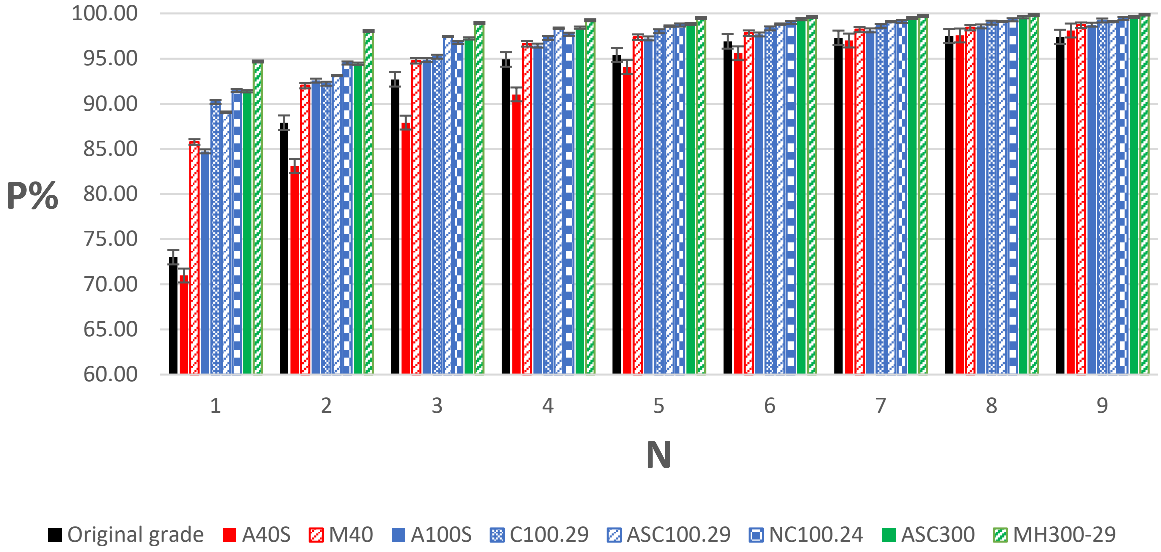


Figure 1.10 The percentage removal of Arab Medium Crude Oil Removal (R%) is represented by each grade of iron powder along the y-axis. The Number of Treatments (N) is represented along the x-axis. Error bars showing a 95% Confidence Interval are included on each bar. The MH300-29 spongy annealed iron powder grade removes more Arab Medium Crude Oil. Adapted from Dao et al. (2006a).

The whole-bird model gives a more accurate picture of how MPT would behave on a live animal. Feather clusters are convenient to test novel techniques and technology due to cost, availability, and ethical reasons (Orbell, Ngeh, Bigger, Zabinskas, Zheng, Healy, Jessop & Dann, 2004). Initial treatments of MPT remove more oil from feather clusters than it does from a whole-bird carcass as shown in **Figure 1.11**. However, with later treatments the amount of oil removal is similar.

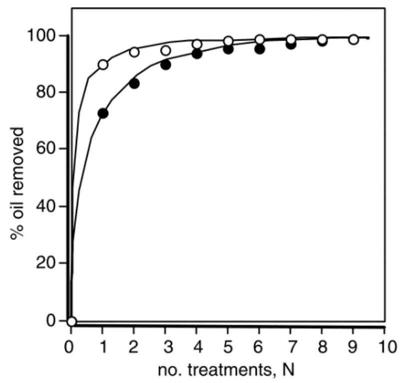


Figure 1.11 A comparison between the oil removal by iron powder on penguin breast feather clusters (open circles) and carcass feathers (closed circles) (Orbell et al., 2004).

Detergents typically used to clean oiled wildlife dry out feathers making them vulnerable to breakage. There is a clear correlation between the concentration of detergents and the level of damage to feather microstructures (Bigger et al., 2017). **Figure 1.12** shows micrograph images of barbule alignment of feathers treated with either detergents or MPT. The alignment of the barbules of the MPT cleaned feathers resemble the virgin feathers. Whereas the detergent cleaned feathers are notably distorted with large gaps between the barbules. MPT has little to no impact on the feather microstructure.

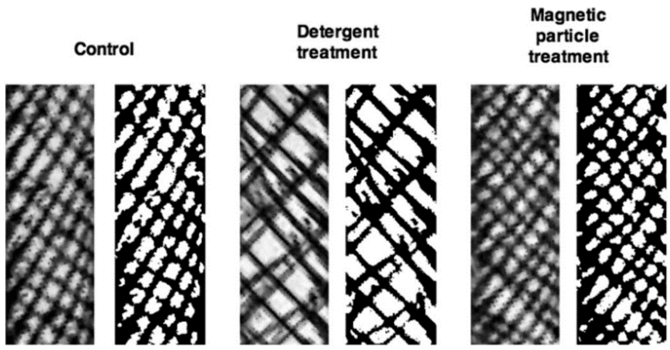


Figure 1.12 Micrograph images of the barbules of Mallard Duck feathers show how different cleaning techniques can alter the alignment of the barbules. Both grey-scale and black and white images are shown for each (Bigger et al., 2017).

Waterproofing is achieved by the interlocking feather microstructures and when these structures become distorted as seen in **Figure 1.12**, waterproofing cannot occur. Cleaned wildlife remain in rehabilitation until waterproofing returns. The more damage to the feather microstructures, the more time it takes to regain waterproofing. The use of MPT as a cleaning agent may accelerate recovery and survival outcomes of rehabilitated oiled wildlife by reducing the level of damage to the feathers.

MPT an effective cleaning technology to remove a variety of oils from a variety of substrates for example, MPT removes 82% of bunker oil from rocks after one treatment but can remove up to 94% after 4 treatments. The amount of iron powder required to remove 94% of bunker oil is 8 times the weight of the bunker oil. Orbell, Dao, Kapadia, Ngeh, Bigger, Healy, Jessop & Dann (2007) suggests that a removal of 100% could be achieved with the use of appropriate PTAs before MPT treatment.

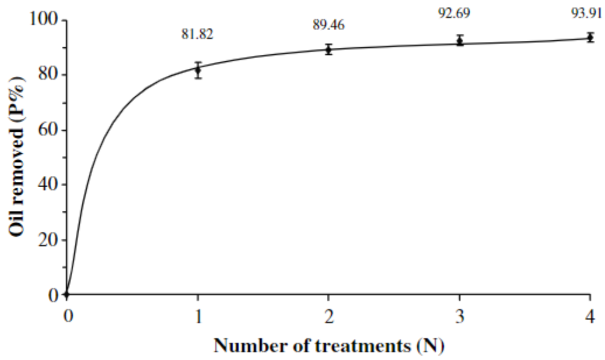


Figure 1.13 An isotherm plotting the percentage by weight of oil removal from a rock substrate after 4 treatments with MPT. Error bars are included, representing 95% confidence interval of 20 replicates (Orbell et al., 2007).

The current methods to clean oil contaminated shorelines use large machinery such as skimmers, vacuums, and bulldozers which are often costly, labour intensive, and time consuming. Contaminated sediments are often removed and disposed of, and this is destructive to the landscape (Fingas, 2000). The use of MPT could treat the contaminated shorelines in situ without altering the physical landscape. The mount of iron powder required to clean is 8 times the weight of the contaminant removed which is far lighter than bulldozers (Orbell et al., 2007).

The effectiveness of a PTA varies depending on certain factors such as the type of contaminant (light/heavy oil, weathered/unweathered), cleaning technology and the contaminated surface (Tegtmeier & Miller 2007; Orbell, Munaweera, Ngeh, Bigger & Dann, 2012). There is no single PTA that is effective on every type of contaminant. In fact, in some cases PTAs can exacerbate the problem (Orbell et al., 2012).

Methyl soyate has been shown to be more effective over other PTAs when Dawn® dishwashing detergent is used to remove crude oils, used-cooking oils, roofing tar, Orimulsion® (a bitumenin-water based fuel similar in appearance to heavy fuel oil), and tanglefoot® (a sticky paste used to trap insects made of vegetable waxes, natural gum resin, and castor oil) (Tegtmeier et al. 2007). Elastol®, a polymer used to solidify spilled oil to assist in skimming marine oil spills, is the most effective PTA to remove silicone (Tegtmeier et al. 2007).

PTAs have also been shown to enhance the removal of crude oils from plumage when MPT is used. **Figure 1.14** shows that when olive oil was used to pre-treat Little Penguin feather clusters cleaned using MPT in an experiment conducted by Dao, Ngeh, Bigger, Orbell, Healy, Jessop & Dann, (2006b), the removal of the contaminant increased.

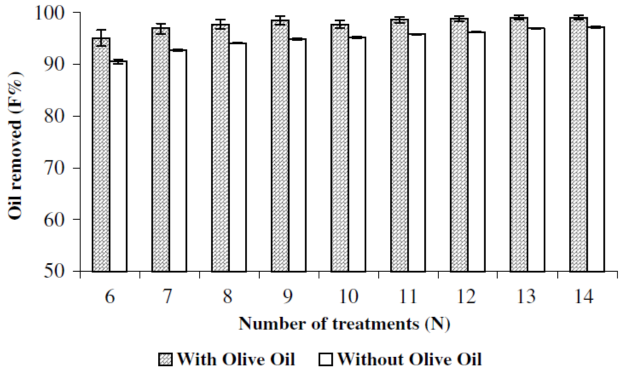


Figure 1.14. A histogram comparing the % removal of oil by weight from Little Penguin feather clusters using MPT with an Olive oil PTA (dark bars) and without a PTA (light bars) (Dao et al., 2006b).

The effectiveness of a PTA also depends on what stage in the cleaning process it is applied. Olive oil performs well as a PTA after several treatments of MPT removal rather than when it is used before MPT treatments begin (Dao et al., 2006b). This is likely due to the physical composition of the contaminant oil changing after each layer is removed. The olive oil is more effective at removing the inner layers of the oil rather than the outer layer. However, this has only been observed when olive oil has been used as a PTA and it is not known if this effect is seen in other PTAs.

Methyl Soyate and Methyl Oleate were found by Orbell et al. (2012) to be a more effective PTA than olive oil to remove crude oil from feather clusters when MPT was used. Methyl soyate worked best as a PTA on Little Penguin feather clusters whereas Methyl Oleate performed best on Mallard Duck feathers (Orbell et al., 2012).

The physical chemistry of crude oil is temperature dependent. Heating a substance increases kinetic and thermal energy of the molecules so they can move more freely, reducing viscosity. Under extreme temperatures, the lighter volatile components evaporate, changing the chemical composition. Orbell, Dao, Ngeh, Bigger, Healy, Jessop & Dann (2005) identified the minimal and optimal temperatures required to remove oil varies between substrates. The minimum temperature to remove oil from Little Penguin feather clusters was 16.2°C and 15.5°C for Mallard duck feather clusters. The optimal temperature for Little Penguin feather clusters was 27°C and 27.5°C for Mallard duck feather clusters.

Lowering the temperature of oil increases the viscosity to a point where the physical chemistry becomes so rigid that iron particles cannot penetrate the surface to magnetically remove the oil. When the temperature of the oil falls below 14 °C, MPT does not remove any oil. The effect temperature has on oil removal differs between substrates as shown in **Figure 1.15**. To remove oil from penguin feather plumage, MPT only begins to remove oil when the temperature reaches 16.3°C. At this temperature 81% of oil is removed. As the temperature continues to rise more oil is removed, with a maximum removal of 96% occurring at 26.4°C (Dao, Maher, Ngeh, Bigger, Orbell, Healy, Jessop & Dann, 2006c).

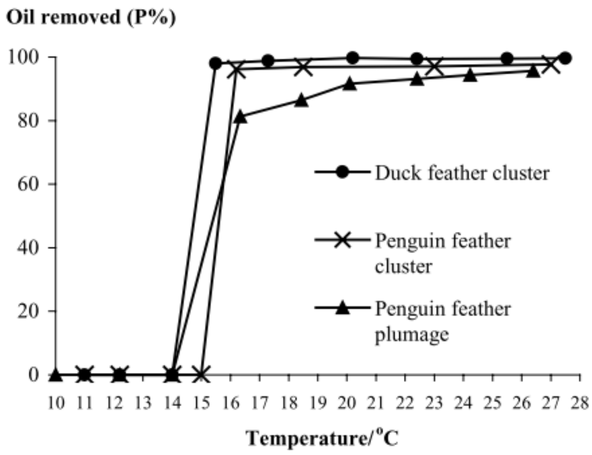


Figure 1.15 A comparison between the optimum removal of oil from penguin feather plumage, and duck and penguin feather clusters as a function of the ambient temperature (Dao et al., 2006c).

The effect of ambient temperature on oil is endothermic with heat transferred to oil and altering the physical chemistry. The van der Waals interaction between the oil molecules weakens as temperature increases, allowing iron particles an opportunity to adsorb the oil (Dao et al., 2006c).

Although ambient temperature influences removal efficacy of oil, the removal of contaminant oil largely depends on the inherent physical characteristics of the contaminant oil. These physical characteristics are initially determined by the species of oil but change overtime due to exposure to the environment which initiates the evaporation of the lighter volatile components of oil, leaving behind the heavier components. Oil that has been exposed to the environment is called “weathered” (Dao et. al 2006b).

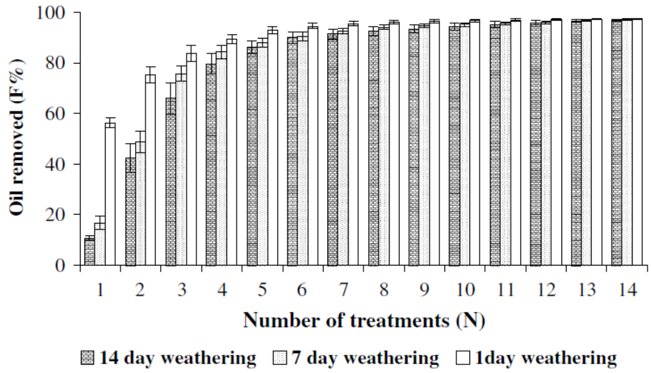


Figure 1.16 A comparison of weathered oil removed *(F%)* from penguin feathers for different weathering times (Dao et al., 2006b).

1.13 MPT and the Oiled Wildlife Clean-up Response Plan

MPT can be incorporated into the current standard protocol used to clean oiled wildlife. MPT is not limited to being used only during the cleaning steps but can also be used during stabilisation and incorporated into pre-clean care (refer to **Table 1.1**). If MPT is used in the stabilisation step, the toxic VOC can be removed before the animals are transported to a treatment facility.

MPT can reduce the time spent on pre-clean care and reduce the wait time between rescue and cleaning. The reduced amount of time spent handled by humans and contaminated by toxic components will reduce time spent in rehabilitation. MPT can therefore can positively influence all stages of clean-up and greatly improve logistics (reduce time and cost) and ultimately the survival rate of oiled birds.

The technology used to clean oiled birds can help minimise stress by reducing the time spent handling. This is a major benefit of using MPT as an alternative to standard surfactant-based methods. An MPT magnetic paste combines both the pre-treatment and cleansing, potentially reducing handling time. MPT does not use water to clean an oiled bird, potentially eliminating time spent rinsing and drying. An additional benefit of MPT is that it can be used to rapidly remove volatiles during the stabilisation of the bird before it is transported to a treatment facility for a more thorough clean.

It can take up to five and a half hours to completely clean an oiled bird using detergent/ water baths. MPT can potentially clean a bird in under 2 hours. Reducing the time spent handling the bird during the cleaning stage may also improve the rehabilitative success of the bird.

Detergents and MPT may have difficulties in removing all the contaminant, especially high molecular weight and tarry components, without the use of PTAs and at lower temperatures. However, considerable success has been achieved in this regard with traditional methods. Current clean-up protocols have been optimised from years of research and have greatly improved the survival outcomes for oiled birds. MPT has the potential to further improve the survival outcomes of oiled birds by removing more oil on capture as well as minimising time and costs involved in the cleaning process to the benefit of first responders.

As MPT is a dry-cleaning method, no wastewater is produced. However, MPT still produces contaminated waste and will need to be disposed of correctly (NPSCC 2017). For isolated areas, MPT may be advantageous over water/detergent methods because of the reduction in waste production, specifically water waste.

MPT can be incorporated into the standard cleaning protocol as presented in **Table 1.1.** MPT can be tactfully used during field stabilisation as a quick clean technology to remove VOCs before transportation to a treatment facility to reduce fatalities related to inhaled VOC toxicity. MPT may also be suitable to use alongside standard techniques during pre-treatment, cleaning, rinsing or drying to improve efficacy for contaminant removal and. Incorporating MPT during these steps could also potentially improve rehabilitative and release success due to MPTs ability to better maintain the feather microstructures and waterproofing the plumage.

Table 1.1 A breakdown of the steps involved in cleaning oiled wildlife and where MPT can be incorporated to improve the process by reducing time spent exposed to the toxic components of oil, and improving survival outcomes post-capture, post-treatment, and post-rehabilitation.

Action	MPT	MPT may improve outcome
Planning & preparedness		
Reconnaissance & hazing		
Wildlife recovery		
Field stabilisation	☑	
Pre-treatment	☑	
Cleansing	☑	
Rinsing	☑	
Drying	☑	
Rehabilitation		☑
Release		☑

1.14 Contribution to Knowledge

As this is a novel technology, the optimal PTA with iron particles is unknown as are the conditions that affect its behaviour. This project seeks to explore how both PTAs and iron particles behave at a chemical and physical level to remove recalcitrant oil from feather substrates. This project can shed light on the physical and chemical properties of substrates, oils and pre-treatments and be of value in science disciplines. The knowledge gained from this project will be of benefit to a wide variety of industries that seek out non-toxic cleaning methods either to reduce cost or to improve their environmental impact.

The reliance of oil across the world and the continued exploration and mining of new oil deposits in our oceans and seas, continues to pose the risk of marine oil spills. A successfully developed paste, a paste that can remove recalcitrant oil more efficiently than detergent-based methods, can be used on any animal in any climate with reduced or little additional harm to wildlife. The paste aims to be easily administered in-field without the need to transport the animals to a treatment centre before initiating clean-up procedures. The longer an animal is exposed to a contaminant oil, the poorer its rehabilitation outcomes. The paste could also extend to treating both biotic and abiotic elements of the physical environment and assist in cleaning up habitat such as nesting sites and surrounding vegetation (Orbell et al., 2007). Ultimately, this project will contribute to the conservation of Victoria's Little Penguin population in the event of oil spill contamination.

1.15 Aims and Objectives

This project aims to explore the utility of so-called "magnetic pastes" that combine the use of MPT ("magnetic cleansing") with PTAs (pre-treatment agents) and other additives that could potentially facilitate the removal of recalcitrant contamination from feathers. This concept will be systematically explored via the formulation of a series of such pastes with different proportions of iron powder and different categories of PTAs and additives. These pastes will be systematically tested on clusters of domestic duck (*Anas Platyrhynchos Domesticus)* feathers that have been contaminated with Bua Ban (medium) and Bunker 380 (heavy) crude oils. Thus, removal isotherms will be constructed and compared according to an existing methodology. In this way, the feasibility of this concept may be assessed, and new directions established. More specifically:

Aim 1: Nominate PTAs that could be used in a magnetic paste. Research additives, apart from known PTAs that have potential oil removing or softening abilities.

Aim 2: Design and formulate pastes suitable for testing with varying consistencies and proportions of iron powder. Refine the consistency and 'spreadability' of each paste in terms of the proportion of iron powder.

Aim 3: Utilizing a methodology previously developed by this research group, carry out five-fold replicate experiments for the removal of both Bua Ban (BB) (medium) and Bunker 380 (B380) (heavy), from contaminated duck feather clusters, by a range of magnetic pastes (MPs). The results will be represented by comparative "removal isotherms" - in histogram and/or curve form. The removal of both BB and B380 from duck feather clusters will be referenced to two controls – iron powder alone and iron powder mixed with distilled water (effectively another paste, with a 5:1 g ratio of iron particles to water.

Aim 4: Use the data from above gravimetric method, and a previously derived efficacy parameter, to quantitatively compare the relative effectiveness of the different kinds of MPs towards both oil types, with respect to the initial, final and overall removal.

Aim 5: To assess the effect on removal efficacy of heating a MPs to a temperature of 35 °C.

Thus, the project will test the percentage removal of a contaminant oil from duck feathers by 24 different MP formulations. The consistency and iron particle content within each paste will be tested for usability in terms of how the paste is applied and spread across the feathers. As the physical properties of oil are influenced by temperature, selected MPs will be heated to 35°C to test the effects on contaminant removal.

An important consideration in the above is for the magnetic paste to be non-toxic to animals. Also, the disposal of contaminant-laden paste is best achieved by incineration since the iron powder (low cost) is converted to iron oxide (a natural component of earth) and only a small amount of CO_2 would be produced.

Chapter 2: Materials and Methods

2.1 The formulation of a magnetic paste

Each magnetic paste (MP) was formulated by mixing MH300 grade iron powder (Höganäs Pty. Ltd.) with a potential pre-treatment agent (PTA). Many of the potential PTAs selected to formulate the MPs where commercially sourced from a supermarket (Woolworths) and include Praise® mayonnaise, Johnson & Johnson® Baby oil (Mineral oil), vinegar (4% acetic acid), "extra strength" vinegar (8% acetic acid), virgin olive oil, coconut oil, Nivea® eye make-up remover, and Bosistos® Eucalyptus oil. Other potential PTAs such as Methyl Soyate, Esterol, and 70% Ethanol were sourced from stock at Victoria University (Werribee Campus). In all, 17 different pastes were formulated and tested. The specific PTAs that were used in the formulation of these pastes are listed in **Table 2.1**.

Table 2.1 The PTAs selected for the formulation of the MPs used in this project.

Selected PTA	Brand/Source	Ingredients
White Vinegar	Coles White Vinegar sourced from Coles	2~4% Acetic Acid in Water
Double Strength Vinegar	Coles Double Strength Vinegar sourced from Coles	8% Acetic Acid in Water
Acetic Acid	Glacial Acetic Acid sourced from stock at Victoria University (Werribee Campus)	Glacial Acetic Acid
Mayonnaise	Praise Traditional Mayonnaise Squeeze Bottle 490g sourced from Woolworths	Sunflower oil [Antioxidant (320)], water, sugar, free range whole egg (4%), white vinegar, malt vinegar (barley & wheat), salt, vegetable gums (415 from soy, 405), food acid (330), natural colour (carrot extract), flavours

Fairy Dishwashing Liquid	Fairy Platinum Original Dishwashing liquid 625mL sourced from Woolworths	15-30% Anionic surfactants, 5-15% nonionic surfactants, perfume, geraniol, limonene
Nivea Eye Makeup Remover	Nivea Gentle Eye Makeup Remover 125mL sourced from Woolworths	Agua, poloxamer 124, PEG-8, PEG-40 hydrogenated, castor oil, glycerin, isosteareth-20, panthenol, trisodium, EDTA, phenoxyethanol, benzyl alcohol, benzethonium chloride, pantolactone, citric acid, sodium hydroxide, geraniol, linalool, alpha-isomethyl ionone, parfum
Perfect Gel Facial Cleanser	Shiseido Sengansenka Perfect Gel Makeup Cleansing Gel 160g sourced from unknown	Mineral oil, trioctanoin, sorbitol, water, pentaerythrityl, tetraoctanoate, glycerin, sucrose, stearate, poloxamer 184, PEG-60, hydrogenated castor oil, sodium methyl cocoyl taurate, phytosteryl/octyldodecyl lauroyl glutamate, algin, dimethicone copolyol, sodium citrate, citric acid, fragrance

Eucalyptus Oil	Bosisto's Eucalyptus oil 175ml sourced from Chemist Warehouse	Eucalyptus oil 1mL/mL
Methyl Soyate	Methyl soyate sourced from stock at Victoria University (Werribee Campus)	
Esterol	Esterol sourced from stock at Victoria University (Werribee Campus)	
Mineral Oil	Johnson's Baby oil 200ml sourced from Woolworths	Mineral oil, fragrance
Ethanol	70% ethanol sourced from stock at Victoria University (Werribee Campus)	70% ethanol, 30% water
Coconut Oil	Coco Earth Premium Liquid Coconut Oil 500ml sourced from Coles	100% Coconut oil. "Medium-chain Triglycerides – Potent part of coconut oil''
Olive Oil	Coles Extra Virgin Olive Oil sourced from Coles	Extra virgin olive oil (product of Spain)
BD1	A trialled PTA sourced from stock at Victoria University (Werribee Campus)	Unknown

2.1.1 Rationale for the Choice of the PTAs/additives used in the MPs

So-called pre-treatment agents (PTAs) are universally used in the cleaning of oiled wildlife (Walraven, 1992; NSW Department of primary industries, 2012; Tegtmeier et al., 2007) but the choice of which PTA to use varies between rehabilitators. However, the reason for using them is universal. PTAs are used to improve the efficacy of removing the contaminant oil in conjunction with a cleaning agent, usually a detergent diluted in warm water. The choice of the PTA ranges from light vegetable oils, mineral oils, biodiesel and even mayonnaise (cleaning the digestive tract of sea turtles in Israel (Joyner 2021). There are usually physical and chemical similarities between these PTAs. Many contain components with long hydrocarbon chains, and this is why they function as effective softeners since they have an affinity for the hydrocarbons in contaminants ("like attracts like"), forming Van der Waals interactions with the hydrocarbon chains in the contaminant, hence weakening the overall physical structure of the contaminant (softening). Light vegetable oils, biodiesels and mineral oils are liquid at room temperature because they contain shorter chain hydrocarbons compared to a thick tarry contaminant which often contain longer unsaturated hydrocarbon chains. Vegetable oils are triglycerides, which are made up of three fatty acids (hydrocarbon chains) connected to the alcohol glycerol. The alcohol glycerol is a hydrophilic moiety. However, the hydrophobic fatty acid hydrocarbon chains tend to dominate the overall chemistry. The hydrocarbon chains of the fatty acids in vegetable oils and biodiesels are not uniform as they are in mineral oil, making them more likely to form intermolecular Van der Waals interactions.

Traditional methods for cleansing oiled wildlife uses dishwashing detergent (1-5% v/v) diluted in warm water (Walraven 1992). With the highest concentration 5% v/v used in the first bath to treat hard and tarry oil followed by a dilution of 3% v/v for the second bath and then 1% v/v for each subsequent bath (Walraven 1992). In U.S based protocols, the Dawn® dishwashing liquid, produced by Procter & Gamble, is recommended but this brand of dishwashing liquid is not stocked in Australian supermarkets. The Procter & Gamble dishwashing liquid available in Australian supermarkets is Fairy®. For this reason, in this project, 5% v/v Fairy® dishwashing liquid, diluted in distilled water, was used as one of the PTAs for one of the MPs.

The Australian Government describes a cosmetic product as a substance that has been designed to cleanse, protect, change the odour or appearance of any part of the external body (skin, hair, nails, lips) and inside the mouth (Australian Industrial Chemicals Introduction Scheme 2021). Cosmetic cleansers are a mixture of active ingredients used to remove oil and grime but also to moisturise the skin. They contain surfactants, solvents, emulsifying agents, humectant and monoterpenes to remove oil - with many also having antimicrobial abilities. They also contain aromatic alcohols, fragrances, hydrocarbons, and chelating agents (Beiersdorf 2024) which are used to produce a marketable cosmetic product for consumers. Hence these are quite complex potential PTAs for incorporating into pastes.

Methyl soyate is primarily used as a biodiesel but it has also proved to be an effective alternative to organic solvents when cleaning environments contaminated by oil. Methyl soyate functions in a similar way to organic solvents but does not produce toxic by-products that could adversely impact aquatic lifeforms. Methyl soyate works by emulsifying heavy crude oil, hence lowering its viscosity and specific gravity. This causes the crude oil to float to the surface of the water where it can be collected by skimming the surface of the water (Pereira & Mudge, 2004). Lowering the viscosity of a contaminant on plumage by using a biodiesel could soften the oil and make it more pliable for easier removal by iron particles. Using a biodiesel as a medium for a MP could facilitate removal of the contaminant by softening and loosening the contaminant from the substrate.

Mineral oil (baby oil) is a by-product of the refinement of crude oil, and it is the most purified form of petroleum (Rawlings & Lombard, 2012). The process of producing mineral oil products removes polycyclic aromatic hydrocarbons (volatile components) which are well known carcinogens (Rawlings & Lombard, 2012). As mineral oil is miscible with volatile components, it could assist in removing the toxic volatiles from the contaminant (Rawlings & Lombard, 2012). Mineral oil is also used in the pharmaceutical, cosmetic and food industries. Mineral oil is commonly used to treat conditions affecting the skin, eyes, and ears, and is safe to use on infants which is why it is also marketed as 'baby oil'. Mineral oil is also used to medically treat constipation (Rawlings & Lombard, 2012) and is therefore safe for consumption. Therefore, Mineral oil is safe to use on animals and is unlikely to causes irritation to a bird's eyes, ears, skin, or feathers. Mineral oil has a density of $0.83 - 0.86\ \mathrm{g.mL^{-1}}$ enabling it to hold a higher density of iron particles than water-based liquids (Rawlings & Lombard, 2012). This could be beneficial in paste formulation as it is already known that a higher proportion of iron particles removes more oil. Mineral oil has many other industrial uses such as protecting metal appliances from rust as it does not oxidise the metal and acts as a barrier to reducing agents in the environment (Rawlings & Lombard, 2012). This is a favourable trait as other pre-treatment agents may oxidise the zero valent iron (ZVI), thereby altering the chemical and physical composition of the MP and potentially impacting on its efficacy. Mineral oil is used to maintain the flow of crude oil through pipelines as it dilutes the viscous crude oil without disturbing the chemical properties of the crude oil (Kulkarni & Wani, 2016). Mineral oil is an ideal candidate to use in a MP as it protects the iron powder chemically from rusting, it decreases viscosity, it is safe to use on humans and animals both internally and externally and it has a low density compared to other pre-treatment agents enabling it to hold more iron powder.

"Vegetable" oils are cooking oils made from plants either vegetables, fruits, or seeds. They are cheap and accessible, costing as little as $0.22/L for a blended vegetable oil and $6.00/L for the Woolworths® extra virgin olive oil (Woolworths 2021). Extra virgin olive oil is often used as a pre-treatment agent when cleaning oiled wildlife as it is believed to soften the contaminant oil making it easier to remove. Extra Virgin Olive oil and Extra Virgin coconut oil were the two vegetable oils selected as MP additives for this project. Vegetable oils are composed of variable triglyceride components and this composition varies between vegetable oils. In contrast, Mineral oil, a highly refined hydrocarbon is relatively uniform in composition (Rawlings & Lombard, 2012), *vide supra*. Both mineral oils and vegetable oils are light oils with low viscosities which can be used to dilute highly viscous crude oils as their non-polar moieties are attracted to the non-polar moieties of crude oil disrupting the forces between the crude oil's hydrocarbon chains, decreasing the viscosity of the crude oil. The shape of a triglyceride is irregular, and this physical characteristic may further assist in interfering with the dispersion forces between hydrocarbon chains, *vide supra*. Dispersion or Van der Waals force increase with the length of a hydrocarbon chain. More viscous oils, such as those that are tarry or solid at ambient temperature, are typically composed of long hydrocarbon chains with strong dispersion forces holding the chains in place. The most obvious benefit for using vegetable oils is that they are a common food product and hence non-toxic - with low boiling points.

Essential oils such as eucalyptus oil ($C_{10}H_{18}O$; 1,8-Cineole) have solvent properties making them effective cleaning agents. At high concentrations, eucalyptus oil is toxic, but it is an effective solvent to remove grease and stains. At lower concentrations, eucalyptus oil is safe to use and has a wide variety of medical uses. It is used topically to treat skin aliments as either a disinfectant or an antifungal, and as a decongestant and to treat respiratory disorders. Concentrated Eucalyptus oil is toxic. Like most essential oils, eucalyptus oil absorbs easily through skin and mucous membranes and does not change its composition once absorbed. For an adult ingesting >5 mL of undiluted eucalyptus oil is life-threatening as it interferes with the nervous system causing CNS depression with coma (Royal Childrens Hospital, n.d). In this regard, eucalyptus-based commercial products sold in Australia such as Eucalyptus rubs contain 6-12% w/w of eucalyptus oil. For this project, four different dilutions of eucalyptus oil were incorporated into MPs: 5% 10%, 20% and 25% w/w.

Ethanol (EtOH) is an effective cleaning agent as it can dissolve in both polar (water) and non-polar (oil) compounds due to its amphiphilic structure. EtOH mixed with oil disrupts the dispersion forces between the hydrocarbon chains and this can make the oil less viscous and decrease the boiling point. Ethanol blended fuel is made by mixing EtOH with petroleum and increases the octane level preventing early combustion. This makes the fuel more efficient and more environmentally friendly as it has lower toxic emissions than standard petrol (U.S Department of Energy, n.d). In Australia ethanol fuel is not common but a concentration of 10% EtOH and 90% petrol % v/v is standard (Eze & George, 2020). The amphiphilic structure of EtOH also makes it an effective disinfectant/antimicrobial by dissolving the lipid membranes (non-polar) and denaturing proteins of microorganisms and viruses (Kampf, 2018). Low concentrations of EtOH are commonly found in cosmetics, pharmaceuticals, and food products. 70% v/v EtOH is readily available in most laboratories as it a safe, economical and an effective cleaning agent to disinfect surfaces and appliances.

Vinegar (acetic acid ~4% v/v) is an everyday, cheap household item available in all supermarkets for approximately 60^{c} per litre (Woolworths 2021). It is a staple cooking ingredient due to its chemistry. Vinegar acts as an emulsifier by mixing polar and non-polar ingredients together to form an emulsion. Vinegar is a dilution of acetic acid in water making it a weak acid which speeds up cooking reactions by denaturing proteins. Glacial acetic acid (99.7% v/v) is toxic. Vinegar preserves food by inhibiting the growth of bacteria and fungi. Vinegar’s antimicrobial and emulsifying ability has led people to use vinegar as a non-toxic alternative household cleaning agent.

Mayonnaise is an emulsion of oil, vinegar, and egg components. Each one of these ingredients has abilities to change the composition of a contaminant oil. The vegetable oil can dilute the tarry contaminant oil and lower its viscosity. The vinegar can dissolve oil by interacting with the non-polar ends of hydrocarbons. The egg components contain lecithin which is amphiphilic with both emulsifying and surfactant abilities. Lecithin is used in the food industry to smooth out textures. Mayonnaise was recently used in Israel to clean the digestive system of oiled sea turtles (BBC, 2021).

2.1.2 Formulation of the MP

To formulate each MP, ~20 g of a potential PTA is weighed into a beaker. A quantity of MH300 iron powder is then blended-in using a spatula to achieve an even consistency (spreadable). The amount of iron powder varies from 80g, 100g, 120g and 140g. The relative (optimized) proportions of the components for each formulation are given in **Table 2.1.** To achieve each of the formulations, the following optimization procedure was carried out:

Iron powder itself has previously demonstrated a high capacity to remove oil contaminants from feather clusters, pelt and plumage. This suggests that maintaining the highest possible level of iron powder in the paste formulation is desirable, whilst not compromising the role of the PTA component. This also helps to maintain the magnetic susceptibility of the paste for efficient magnetic harvesting. In this regard, it is important to distinguish the role of each component in a MP. The PTA's role is to combine with and soften the recalcitrant contamination so that it can adsorb more easily to the iron powder.

The practical challenge in formulating such pastes was found to be in the determination of the ideal ratio of iron powder to pre-treatment agent (by weight) so as to create a smooth and even paste that is homogeneous and 'spreadable' with respect to the contaminated substrate[1]. This optimization procedure is described as follows for the PTA Olive Oil (OO) - *as a representative example.*

20 g of OO was weighed into a plastic container and MH300 grade Fe powder was added with mixing in 1 g increments. Initially, up to 20 g of the iron powder was added to achieve a 1:1 ratio and the mixture was stirred to ensure a good blend. The resulting paste was then subjected to a magnetic field using the magnetic tester device. At this ratio, the harvested material left behind a considerable residual of the OO. It was also observed that when the suspension of iron particles in olive oil was left to settle the larger iron particles sank to the bottom and a similar amount of residual OO remained on the top. It was subsequently found that as a higher proportion of iron powder was added to the mix, the less this separation occurred. At 100g of iron powder to 20g of olive oil (a 5:1 ratio, designated 5gFe/1g), there was only a trace amount of residual OO left behind that left a slight sheen on the surface of the plastic container upon magnetic harvesting. Excessive residual PTA is potentially problematic as it will effectively become another contaminant. At 120g of iron powder in 20 olive oil (6Fe/1g), the surface of

[1] The substrate for these investigations is duck feather clusters (*Anas platyrhynchos*)

the container appeared free of any OO suggesting that the iron powder to olive oil ratio was close to optimum. However, the resulting paste cracked and crumbled and could not be spread evenly across a substrate at room temperature. Therefore, the concentration of 6gFe/1g paste was not considered tenable as a workable paste and the 5gFe/1g was adopted, **Figure 2.1.**

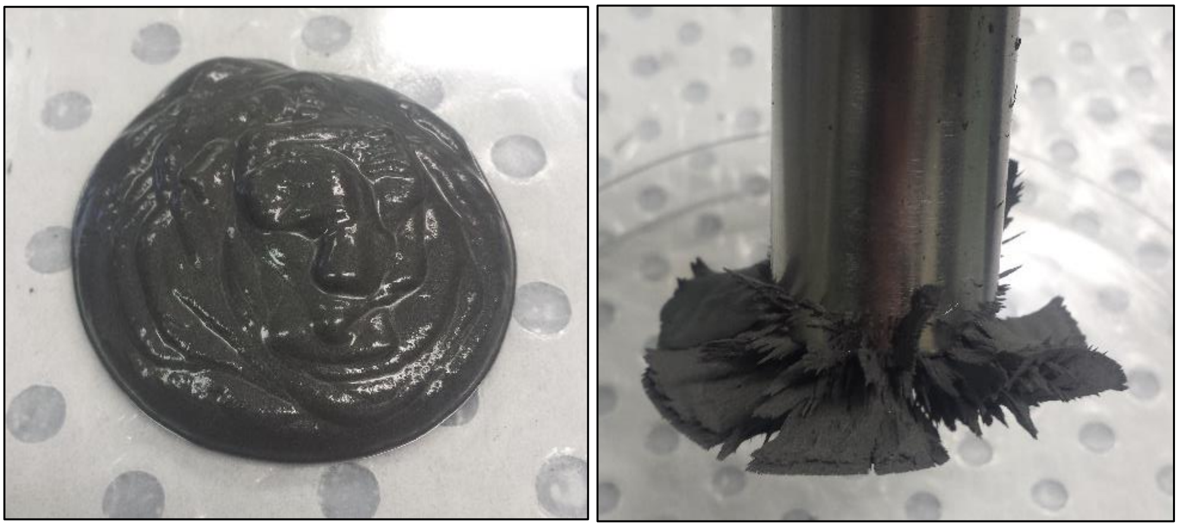


Figure 2.1 The virgin olive oil (OO)/iron powder (MH300) paste produces a spreadable paste with the formulation of 100g Fe powder and 20g of OO (5gFe/g). When magnetically harvested the OO (5gFe/g) MP attaches to the magnetic tester.

The same optimization procedure was carried out for all the other types of pre-treatment agents used in this study. For essential oils, water, acetic acid, the non-gel cleansers, and detergents, 5gFe/1g also created an optimal spreadable paste. For other pre-treatment agents such as methyl soyate, esterol, mineral oil, and BD1, more iron powder (6g/g) could be added before the paste became unsuitable for spreading easily over a substrate. For EtOH, up to 7gFe/g was acceptable. For PTAs with a gel-like consistency such as sodium alginate, mayonnaise, and perfect-gel (face cleanser), only maximum of 4gfe/g produced a workable paste.

2.2 Paste categories

The 17 different pastes that were formulated and trialed as recalcitrant oil removal agents may be summarized, categorized and abbreviated as follows:

i. **Pastes with an acetic acid (AA) component.** White vinegar/iron powder paste designated **AA ~4% v/v (5gFe/g)**; 'extra strength' vinegar paste designated **AA ~8% v/v (5gFe/g)**; 10% acetic acid paste designated **AA 10% v/v (5gFe/g)**; 20% acetic acid paste designated **AA 20% v/v (5gFe/g)**, and mayonnaise paste designated **MAYO (4gFe/g)**. **Note:** 5gFe/g indicates a ratio of 5g of Fe powder to 1g of acetic acid and 4gFe/g indicates a ratio of 4g of Fe powder to 1g of mayonnaise to formulate the paste.

ii. **Pastes with a commercial cleansing product.** Fairy® dishwashing detergent diluted in water, designated **Fairy 5% v/v (5gFe/g)**; Nivea® eye makeup remover designated **Nivea (5gFe/g)**, and Perfect Gel® facial cleanser designated **Perfect Gel (4gFe/g)**. **Note:** Fairy 5% v/v of Fairy dishwashing liquid is diluted in distilled water, 5gFe/g indicates a ratio of 5g of Fe powder to 1g of 5% diluted Fairy dishwashing or Nivea eye makeup remover, and 4gFe/g indicates a ratio of 4g of Fe powder to 1g of Perfect Gel facial cleanser to formulate the paste.

iii. **Pastes with a eucalyptus oil component.** These pastes are made with varying concentrations of eucalyptus oil emulsions. Eucalyptus Oil 5% v/v in deionized water, designated **EO 5% v/v (5gFe/g)**; Eucalyptus Oil 20% v/v, designated **EO 20% v/v (5gFe/g)**; Eucalyptus oil 25% v/v, designated **EO 25% v/v (5gFe/g)**. **Note:** the %v/v of Eucalyptus Oil is the percentage suspended as an emulsion in deionized water; 5gFe/g indicates a ratio of 5g of Fe powder to 1g of Eucalyptus Oil emulsion.

iv. **Pastes with a "conventional" pre-treatment agent.** Methyl Soyate, **designated MS (6gFe/g)**; Esterol designated **EST (6gFe/g)**; Mineral Oil designated **MO (6gFe/g)** and Ethanol designated **ETOH (7gFe/g). Note:** 6gFe/g indicates a ratio of 6g of Fe powder to 1g of Methyl Soyate/Esterol/Mineral Oil to formulate the paste; 7gFe/g indicates a ratio of 7g of Fe powder to 1g ethanol to formulate the paste.

v. **<u>Pastes with a vegetable oil</u>.** Coconut Oil designated **CO (5gFe/g)** and Olive Oil designated **OO (5gFe/g)**. Note: 5gFe/g indicates a ratio of 5g of Fe powder to 1g of vegetable oil to formulate the paste.

<u>Controls</u>

1. **Control Fe**. This is the neat iron powder itself – a non-paste.

2. **Control DW (5gFe/g)**. This is an iron powder/water paste, with a ratio of 5g Fe powder to 1g deionized water.

2.2.1 The Effect of the Proportion of Iron Powder in a MP on Contaminant Removal

4 additional formulations of MPs were concocted to measure the effect the proportion of iron powder has on contaminant removal. Methyl soyate, esterol, mineral oil, and BD1 additives were found to maintain a paste like consistency when the proportion of iron powder was increased from 5gFe/g to 6gFe/g. Thus, the following additives were used to test the effect the proportion of iron powder has on removal efficacy:

- **Methyl soyate/iron powder MPs: 5gFe/g and 6gFe/g**
- **Esterol/iron powder MPs: 5gFe/g and 6gFe/g**
- **Mineral Oil/iron powder MPs: 5gFe/g and 6gFe/g**
- **BD1/iron powder MPs: 5gFe/g and 6gFe/g**

2.2.2 The Effect of MP Temperature on Contaminant Removal

All MPs were removed under ambient temperature conditions at approximately 21℃. The removal of crude oil from a substrate using standard MPT has been shown from previous research to be temperature dependent. However, animals are also sensitive to temperature and there is a limit to the maximum temperature that is safe. For penguins, prolonged exposure to temperatures above 35℃ increase heat stress. Therefore, it was decided that 35℃ would be the ideal temperature to test the effects of increasing the temperature of a paste (Chambers, Dann, Cannell, & Woehler, 2013).

- **Heated Mineral Oil, MO (6gFe/g)**
- **Heated Olive Oil, OO (5gFe/g)**
- **Heated Mayonnaise, MAYO (4gFe/g)**

2.3 "Removal Isotherms" for Assessing Relative Removal Efficacies of the MPs

The efficacy of contaminant removal by MPT from a particular substrate may be assessed using an established gravimetric method that measures the percentage removal of contaminant, **P%**, as a function of the number of treatments, **N**. The resulting curve (which may also be represented by a set of histograms) is referred to as a "Removal Isotherm" (Dao, 2007; Orbell, Tan, Coutts, Bigger & Ngeh, 1999). An example of such an isotherm is shown in **Figure 2.2.**

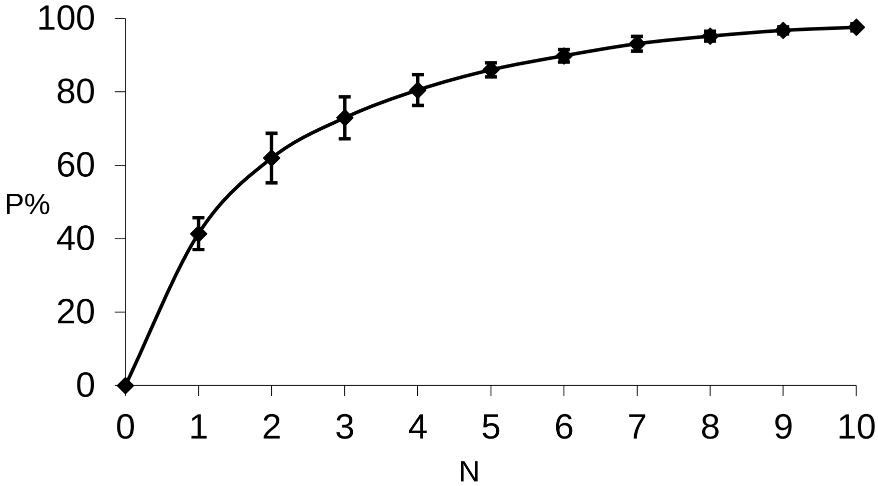


Figure 2.2 A typical gravimetric ab(d)sorption "isotherm" showing the removal (P%) of crude oil from penguin feathers as a function of the number of treatments (N). Here, the error bars represent 95% confidence intervals for five replicates and, typically, such experiments are highly reproducible (Orbell et al., 1999)

Mallard duck (*Anas platyrhynchos*) breast feathers were sourced from a poultry farm and three feathers of comparable size were tied together into a cluster and weighed, $\mathbf{f_1}$. The feather cluster was then immersed in a contaminant (here, either **Bua Ban Crude (BB) or Bunker Oil 380 (B380)** to achieve saturation. The cluster was allowed to drain on a tarred petri dish for 10 min prior to being re-weighed, $\mathbf{f_2}$. The cluster was then removed from the dish and the residual quantity, **r**, was recorded. Hence, the weight of the contaminant-laden feathers, $\mathbf{f_3}$, for further experimentation is given by: $\mathbf{f_3 = f_2 - r}$. The contaminated feathers were then completely covered with iron powder (for the control) or a particular MP and left for around 2 min to ensure maximum ad(b)sorption of the contaminant.[2] The contaminant-laden magnetic particles or MP were then harvested from the feathers using a "magnetic tester", **Figure 2.3**. The stripped feather cluster was then re-weighed, $\mathbf{f_4}$. The percentage removal of the contaminant, **P%**, was calculated using the following equation and this was recorded as treatment **N1.**

$$\mathbf{P\ \% = [(f_3 - f_4)/(f_3 - f_1)] \times 100\%}$$

This process was then repeated on the contaminated feather cluster until a constant value of **P%** was achieved, as shown in **Figure 2.2**.

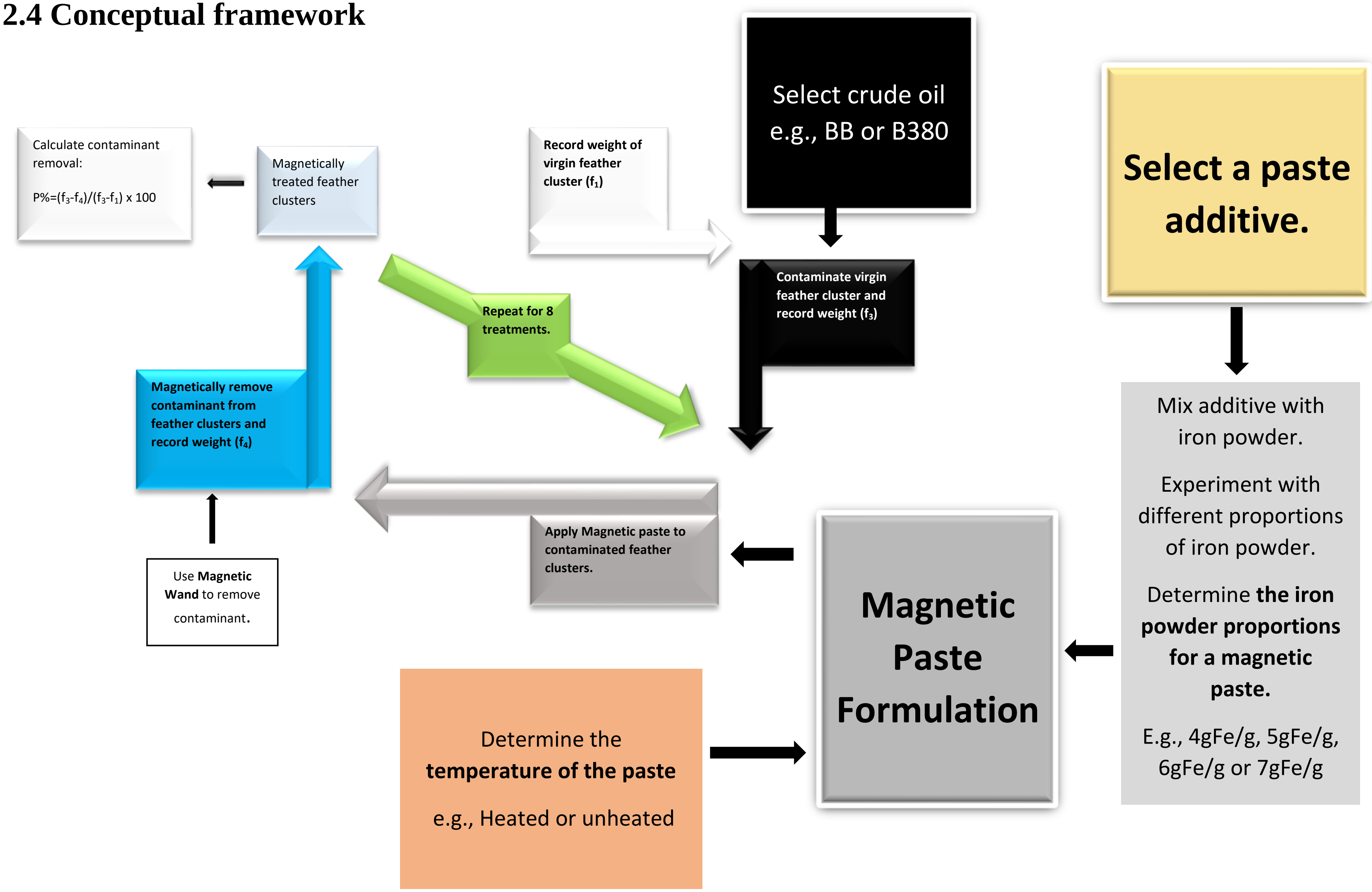
Figure 2.3 Laboratory "magnetic tester" for harvesting contaminant-laden magnetic material that can then be released by mechanically removing the magnetic field via the plunger.

Table 2.2 The ratios of iron powder to PTA for the formulation of each paste.

[2] Some jiggling and massaging are employed to ensure maximum coverage and penetration.

w/w ratio of Fe:PTA	80 g of Fe powder to 20 g of PTA Designated **(4gFe/g)**	100 g of Fe powder to 20g of PTA Designated **(5gFe/g)**	120g of Fe powder in 20g of PTA Designated **(6gFe/g)**	140g of Fe powder in 20g of PTA Designated **(7gFe/g)**
PTA	Praise Mayonnaise **(MAYO)**	Methyl Soyate **(MS)**	Methyl Soyate **(MS)**	70% Ethanol **(ETOH70%)**
	Perfect Gel facial cleanser **(PG)**	Esterol **(EST)**	Esterol **(EST)**	
		Mineral oil **(MO)**	Mineral oil **(MO)**	
		Distilled water **(DW)**		
		Acetic acid conc. **(%AA)**		
		Nivea eye makeup remover **(NIVEA)**		
		Fairy dishwashing liquid **(FAIRY)**		
		Eucalyptus oil conc. **(%EO)**		
		Virgin olive oil **(OO)**		
		Virgin coconut oil **(CO)**		

2.4 Conceptual framework



Chapter 3: Results and Discussion

3.1 Paste categories[3]

The different pastes that were trialed as oil removal agents are categorized as follows:

i. **Pastes with an acetic acid (AA) component.** White vinegar/iron powder paste designated **AA ~4% v/v (5gFe/g)**; 'extra strength' vinegar paste designated **AA ~8% v/v (5gFe/g)**; 10% acetic acid paste designated **AA 10% v/v (5gFe/g)**; 20% acetic acid paste designated **AA 20% v/v (5gFe/g)**, and mayonnaise paste designated **MAYO (4gFe/g)**. **Note:** 5gFe/g indicates a ratio of 5g of Fe powder to 1g of acetic acid and 4gFe/g indicates a ratio of 4g of Fe powder to 1g of mayonnaise to formulate the paste. The detailed preparation of these pastes is given in **Material and Methods, Chapter 2**.

ii. **Pastes with a commercial cleansing product.** Fairy® dishwashing detergent diluted in water, designated **Fairy 5% v/v (5gFe/g)**; Nivea® eye makeup remover designated **Nivea (5gFe/g)**, and Perfect Gel® facial cleanser designated **Perfect Gel (4gFe/g)**. **Note:** Fairy 5% v/v of Fairy dishwashing liquid is diluted in distilled water, 5gFe/g indicates a ratio of 5g of Fe powder to 1g of 5% diluted Fairy dishwashing or Nivea eye makeup remover, and 4gFe/g indicates a ratio of 4g of Fe powder to 1g of Perfect Gel facial cleanser to formulate the paste.

iii. **Pastes with a eucalyptus oil component.** These pastes are made with varying concentrations of eucalyptus oil emulsions. Eucalyptus Oil 5% v/v in deionized water, designated **EO 5% v/v (5gFe/g)**; Eucalyptus Oil 20% v/v, designated **EO 20% v/v (5gFe/g)**; Eucalyptus oil 25% v/v, designated **EO 25% v/v (5gFe/g)**. **Note:** the %v/v of Eucalyptus Oil is the percentage suspended as an emulsion in deionized water; 5gFe/g indicates a ratio of 5g of Fe powder to 1g of Eucalyptus Oil emulsion.

iv. **Pastes with a "conventional" pre-treatment agent.** Methyl Soyate, **designated MS (6gFe/g)**; Esterol designated **EST (6gFe/g)**; Mineral Oil designated **MO (6gFe/g)** and Ethanol designated **ETOH (7gFe/g). Note:** 6gFe/g indicates a ratio of 6g of Fe powder

[3] This listing has been duplicated from a previous section for the convenience of the reader.

to 1g of Methyl Soyate/Esterol/Mineral Oil to formulate the paste; 7gFe/g indicates a ratio of 7g of Fe powder to 1g ethanol to formulate the paste.

v. **Pastes with a vegetable oil.** Coconut Oil designated **CO (5gFe/g)** and Olive Oil designated **OO (5gFe/g)**. Note: 5gFe/g indicates a ratio of 5g of Fe powder to 1g of vegetable oil to formulate the paste.

3.2 Relative Paste Efficacy Analysis

To assess the relative removal efficacies of a contaminant from a particular substrate (here, feather clusters) using different MPs, the first step is to construct the removal "isotherms", whereby the % contaminant removal (by weight), P%, is plotted against the number of treatments, N, **Chapter 2, Section 2.3**. The resulting "removal isotherm" may be represented by a curve or a set of histograms. To compare the relative removal efficacies of different pastes, such plots may be represented as nested curves or sets of block histograms, with appropriate error bars included. For this project, sets of block histograms have been chosen for this task, since differences are more easily discerned. Thus, sets of histograms are presented in the following discourse to compare relative efficacies within each category. For example, see **Figure 3.1**, that compares the isotherms for the **Category (i)** pastes. Overall, of particular interest are the relative *initial removal* efficacies (**N = 1 to 3**) and the *final removal* efficacies (**N = 4 to 8**). In relation to the initial removal efficacy, a parameter $\mathbf{N_x}$ may be defined, where **x** represents an arbitrary percentage removal, usually **90%** or **95%**[4]. This parameter gives the "effective number of treatments" required to reach the chosen **x** percentage level. Thus, the more efficient the initial removal, the lower the value of $\mathbf{N_x}$. This parameter is readily determined from the intercept of a particular isotherm curve with a horizontal line corresponding to the chosen x percentage level on the vertical axis, see **Figure 3.2** for the **Category (i)** pastes. In relation to the *final removal* efficacy, this is given by the value of **P%** on the vertical axis that correspond to the plateau of the curve. This is designated as $\mathbf{P_0\%}$ and

[4] The removal benchmark chosen depends on the overall removal of the MPs within a category being analysed. For example, if the final removal only reaches 84%, an x value of 80% will be chosen.

the higher this number, the more efficient is the *final removal*. The parameters **P_0%** and **N_x** may be combined into a new parameter, **E_x**:

$$E_x = \frac{P_0\%}{N_x}$$

that represents the *overall* removal efficacy. Note that the higher the value of **E**, the higher the overall removal efficacy. Values for these parameters for the data represented by **Figure 3.1** are given in **Table 3.1** for x values of **90%** and **95%**. This method has been applied to all paste categories as follows.

3.2.1 Pastes with an acetic acid component (Category i.)

Contaminant: **Bua Ban (BB)**

Duck Feather clusters contaminated with Bua Ban crude oil (BB) were treated 8 times with each of the MPs with a different acetic acid containing component, (i.e., white vinegar, extra strength vinegar, 10% acetic acid v/v, 20% acetic acid v/v, and mayonnaise). After each treatment, the weight of the feather cluster was recorded, and the percentage removal of the BB was calculated according to the gravimetric methodology. 5 replicates were conducted in each case to determine the average and the standard error (SE). **Figure 3.1** shows the relative removal efficacies of Bua Ban (BB) crude oil from duck feather clusters using varying concentrations of the acetic acid/iron powder MPs, including data for two controls (i.e., iron powder and iron/water paste).

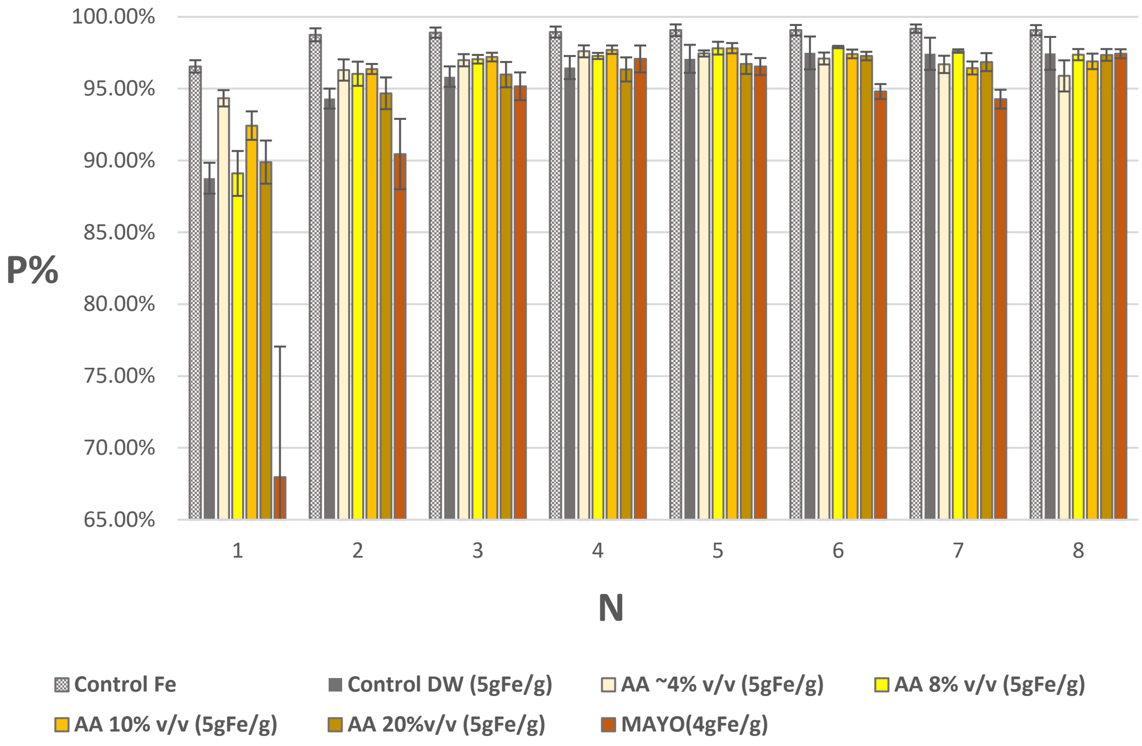


Figure 3.1. The % Removal, P%, of the Bua Ban (BB) crude oil from duck feather clusters using varying concentrations of acetic acid/iron powder magnetic pastes, as a function of the Number of Treatments, N. The two controls are iron powder alone and an iron powder/water paste.

The iron powder (alone) control removes significantly more BB than any of the MPs from N= 1 to N= 8. The iron powder/distilled water paste, DW control, removes significantly less than the iron powder itself and is generally comparable to the effectiveness of all the other pastes, apart from AA 4% and MAYO at N=1. Thus, there does not appear to be any significant difference between the distilled water, AA ~8% and AA 20% at N=1. Notably, white vinegar (AA 4%) removes significantly more BB at N=1 than Control DW (5gFe/g) and all the other AA% MPs, despite having the lowest concentration of acetic acid (4%). AA 10% removes the second highest amount of BB at N=1. By N=2, AA ~4, 8 and 10% do not appear to be statistically different from one another, but all three remove more BB than distilled water and AA 20%. Mayonnaise performs poorly at N=1 but the difference in removal from N=1 to 2 is extremely large relative to the other pastes. By N=4, MAYO removes approximately the same amount as the other AA concentrations. As the treatments progress from N=4 to 7, the percentage removal begins to decline in MAYO. This indicates that the MAYO MP is re-contaminating the feathers with itself after it has removed most of the BB.

In summary, at initial removal (N=1), AA~4% MP outperforms all other MPs with an acetic acid component as well as the control DW. The increase in acetic acid concentration does not appear to convey an advantage for the removal of BB. MAYO (4gFe/g) does not perform well at the initial removals of N=1, 2. MAYO (4gFe/g) shows that it has limitations as a cleaning agent for this contaminant. Oiled feathered clusters treated with MAYO (4gFe/g) will begin to gain weight from N=4 and continue to do so with each subsequent treatment. Therefore, MAYO (4gFe/g) is not suitable to use as a sole cleaning agent as additional measures will be needed to remove the mayonnaise from the feathers. However, because mayonnaise is a domestic food product and domestic dishwashing detergents are designed to remove this type of residue, mayonnaise is likely far easier to remove than a hard tarry hydrocarbon contaminant using a standard domestic detergent.

Figure 3.2 shows the implementation of the "**E_x** method", *vide supra*, for delineating the relative *initial*, *final*, and *overall* removal efficacies, for the representative **N_{95}** case. The plots for the determination of other **N_x** values and the data for the other categories are provided in the **Appendix. Table 3.1** summarizes the relevant parameters for the **Category i** series. Note that where both the 90% and 95% values are available, either may be selected for a relative efficacy assessment and are expected to yield equivalent outcomes.

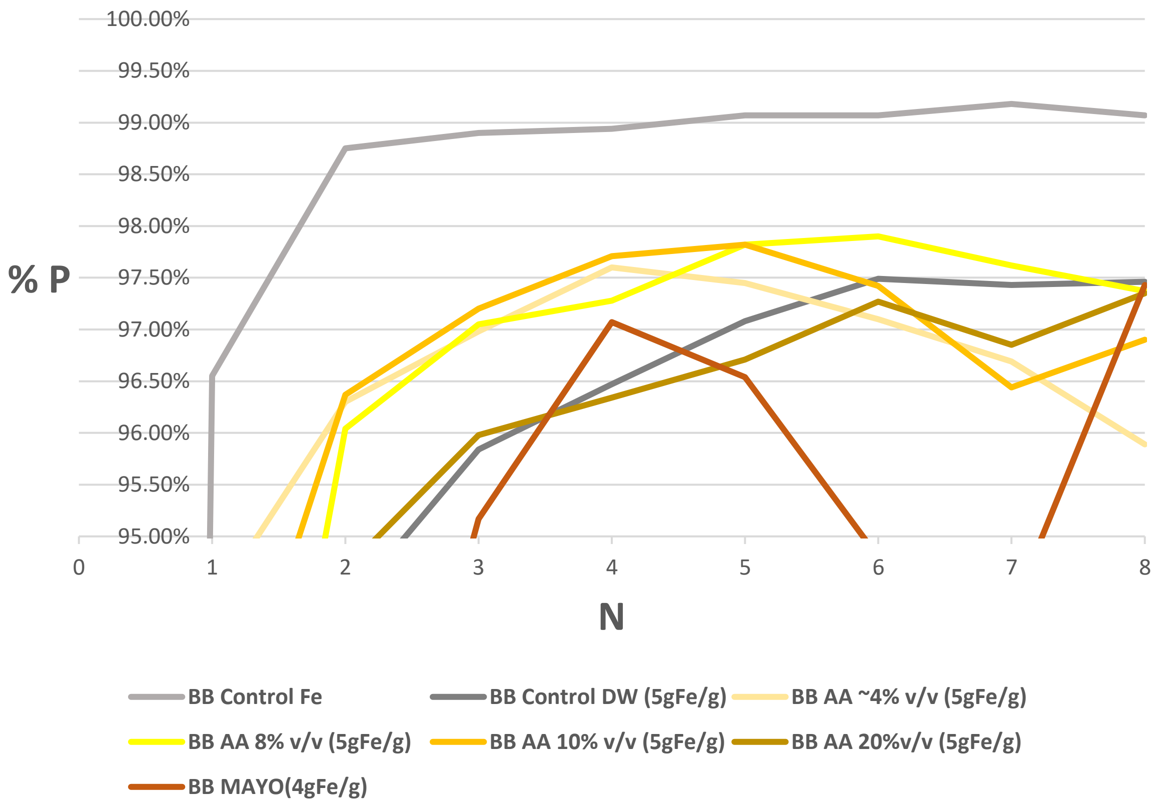


Figure 3.2. Representative removal isotherms for magnetic pastes with an acetic acid component, **Category i**, show the effective number of treatments required to achieve 95% removal, i.e., N_{95}. The lower the value of N_x (intercept on the horizontal axis)) the more efficient the paste.

Table 3.1. Relative removal efficacy parameters for **Category i**. magnetic paste, calculated at x = 90 and 95%.

Magnetic Paste with an acetic acid component	**P_0%**	**N_{90}**	**E_{90}**	**N_{95}**	**E_{95}**
CONTROL Fe	99.18	0.93	106.65	0.98	101.20
CONTROL DW (5gFe/g)	97.49	1.22	79.91	2.45	39.79
AA ~4% (5gFe/g)	97.60	0.95	102.74	1.35	72.30
AA ~8% (5gFe/g)	97.90	1.13	86.64	1.85	52.92
AA 10% (5gFe/g)	97.82	0.97	100.85	1.65	59.28
AA 20% (5gFe/g)	97.35	1.02	97.35	2.25	43.27
MAYO (4gFe/g)	97.43	1.98	97.43	2.97	32.80

From the data in **Table 3.1**, MPs with an acetic acid component remove similar optimal amounts of BB. However, AA ~8% v/v (5gFe/g) has a slightly higher P_0%. AA ~4% v/v (5gFe/g) has the highest $E_{90,95}$ ratios of all the MPs with an acetic acid component, making it the most efficient of these pastes at removing 90% and 95% of the BB contaminant. AA 10% (5gFe/g) is the second most efficient MP at both 90% and 95% removal of the BB. The efficacies of the other MPs vary. At 90% removal MAYO (4gFe/g) is more efficient than AA ~8% (5gFe/g) and AA 20% (5gFe/g). At 95% removal of the BB AA ~8% (5gFe/g) is more efficient than AA 20% (5gFe/g) and MAYO (4gFe/g) becomes the least efficient paste. All the MPs with an acetic acid component are more efficient at 90% removal of the BB than the control DW (5gFe/g). At 95% removal of the BB only MAYO (4gFe/g) is less efficient than the control DW (5gFe/g). No MP with an acetic acid component is more efficient than the iron powder alone at 90 and 95% removal of the BB. Therefore, the most efficient MPT to use in this category is iron powder itself, not a MP.

An alternative representation of relative efficacies has been developed by the author and is shown in **Figure 3.3**. Thus, the visual representation of efficacy produces a set of histograms using a series of bars that contain 3 components – a coloured section, a white section, and a white circle. The coloured section of each bar represents *initial* removal, the white section represents the deficit to maximum removal. The white circle represents the number of treatments required to reach the plateau.

AA ~4% v/v (5gFe/g) removes more of the BB after initial treatment and removes the maximum amount of BB after 4 treatments. AA 10% v/v (5gFe/g) only requires 3 treatments to reach its maximum removal of the BB however the amount of the BB removed is less than

AA ~4% v/v (5gFe/g). MAYO (4gFe/g) is the least efficient paste as the initial removal of the BB is significantly less. Although MAYO (4gFe/g) does end up removing a similar amount of the BB overall as the other MPs with an acetic acid component is only does so after 8 treatments. The most efficient paste with an acetic acid component is AA ~4% v/v (5gFe/g) followed by AA 10% v/v (5gFe/g), then either AA 8% v/v (5gFe/g) or AA 20% v/v (5gFe/g), and lastly MAYO (4gFe/g). Such plots have been calculated for each category and the remainder are shown in the **Appendix.** These are meant to provide another perspective on the relative efficacies.

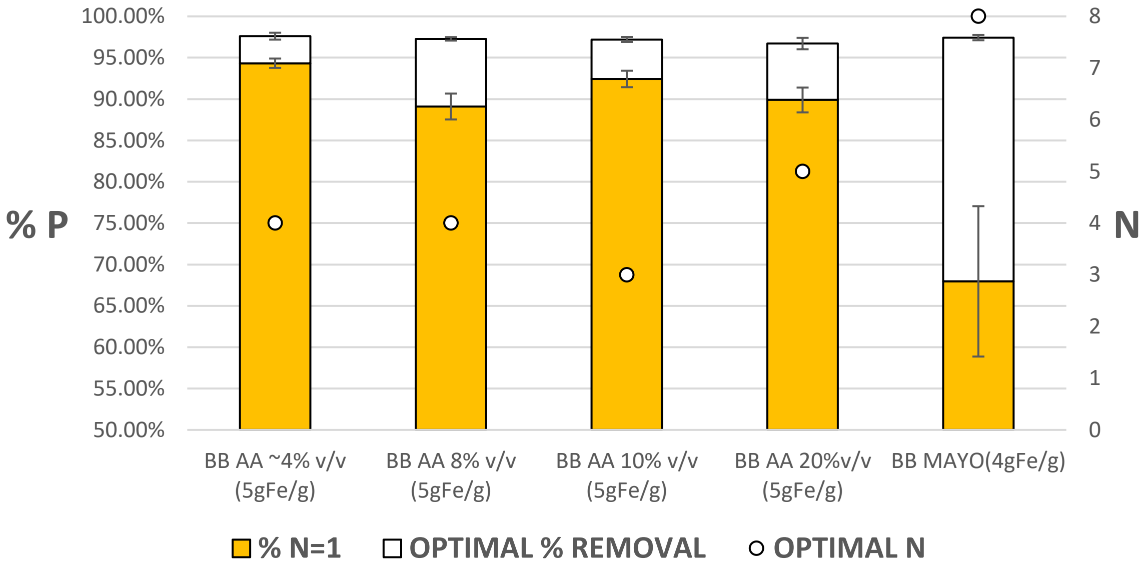


Figure 3.3 A representation of the relative efficacies of contaminant removal of BB from feather clusters by a series of acetic acid based magnetic pastes, **Category i**. Initial removal – yellow section, deficit to maximum removal – white section, number of treatments to reach plateau (maximum removal) – white dot.

<u>Contaminant:</u> Bunker 380 (B380)

Duck Feather clusters contaminated with Bunker 380 (B380) were treated 8 times with each MP with a different acetic acid containing component (i.e., with white vinegar, extra strength vinegar, 10% acetic acid v/v, 20% acetic acid v/v, and mayonnaise). After each treatment, the weight of the feather cluster was recorded, and the percentage removal of the B380 was calculated according to the gravimetric methodology. 5 replicates were conducted in each case to determine an average and the standard error (SE). **Figure 3.4**. Shows the relative removal efficacies of Bunker 380 (B380) crude oil from duck feather clusters using varying concentrations of acetic acid/iron powder MPs, including data for the two controls (i.e., iron powder and iron/water paste).

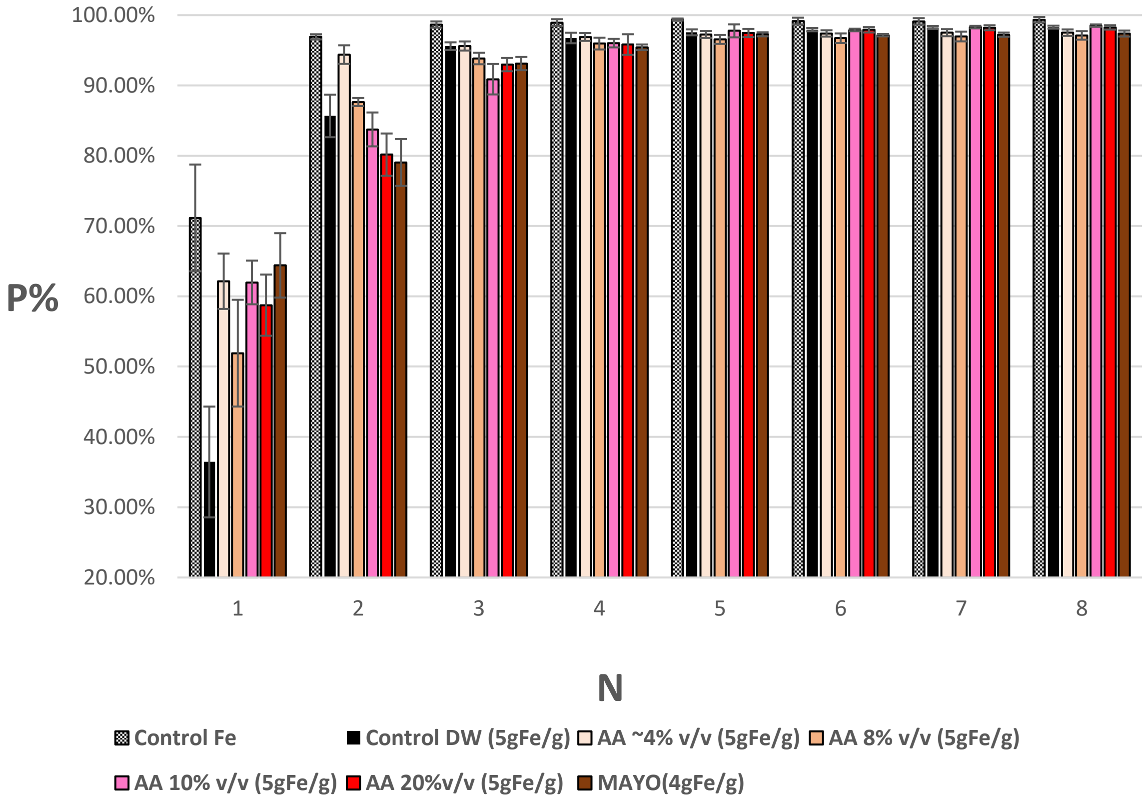


Figure 3.4 The % Removal, P%, of the Bunker 380 (B380) crude oil from duck feather clusters using varying concentrations of acetic acid/iron powder magnetic pastes. The two controls are iron powder alone and an iron powder/water paste.

The iron powder (alone) control removes significantly more B380 than any of the MPs from N= 1 to N=8. The iron powder/distilled water paste, DW control, removes significantly less than the iron powder itself from N= 1 to N= 8. At N= 1, DW control removes significantly less B380 than any of the acetic acid pastes, showing that an acetic acid additive does improve the removal of B380 however, the higher the concentration of acetic acid does not translate as higher removal of B380. The highest average percentage removal of B380 at N= 1 is MAYO, which contains the lowest concentration of acetic acid, less than 4%, as it only contains a portion of vinegar. However, the error bars show that with one treatment, the removal of B380 by a MP with an acetic acid are not significantly different. By N= 2, the differences between the MPs becomes more evident. AA ~4% paste removes significantly more B380 than the DW control and any of the other acetic acid pastes and the percentage removal of B380 declines as the concentration of acetic acid increases. At N= 3 the DW control and AA ~4% are comparable whereas the MPs with higher concentrations of acetic acid have a lower percentage removal of B380. From N= 6 to 8 the removal power of AA~4% declines and is overtaken by the higher acetic acid concentrations AA 10% and AA 20% and are comparable to the DW control.

In summary, at first removal all MPs with an acetic acid component are more effective at removing B380 than the DW control. AA~4% Removes significantly more B380 after 2 treatments and the higher concentrations of acetic acid remove less than the DW control. MAYO continues to remove more B380 with each treatment, its capacity to remove as much at N= 2 is significantly less than the other pastes although the removal by MAYO from N=3 to 8 is similar to AA~4% and AA~8%. In the final treatments (N= 6 to 8) the MPs with the higher concentrations of acetic acid AA 10% and AA 20% remove more than the other MPs including the DW control. Therefore, MPs with a lower concentration of acetic acid are effective at removing the outer layers of B380 and MPs with a higher concentration of acetic acid are more effective at removing the inner layers of B380 although not as effective as the iron powder alone.

Table 3.2. Relative removal efficacy parameters for **Category i** magnetic paste, calculated at x = 90 and 95%.

Magnetic Paste with an acetic acid component	**P_0%**	**N_{90}**	**E_{90}**	**N_{95}**	**E_{95}**
CONTROL Fe	99.38	1.73	57.45	1.93	51.49
CONTROL DW (5gFe/g)	98.29	2.44	40.28	2.94	33.43
AA ~4% (5gFe/g)	97.51	1.87	52.14	2.54	38.39
AA ~8% (5gFe/g)	97.12	2.39	40.64	3.56	27.28
AA 10% (5gFe/g)	98.51	2.88	34.20	3.80	25.92
AA 20% (5gFe/g)	98.26	2.77	35.47	3.72	26.41
MAYO (4gFe/g)	97.38	2.78	35.03	3.83	25.43

Although AA~4% does not achieve the highest P_0% B380 removal of all the MPs with an acetic acid component and the DW control, it is the most effective MP in this category. **Table 3.3** shows that AA~4% as the lowest N_x and the highest E_x values, both indicators of efficacy.

The remaining MPs all have a similar efficacy except at E_{90} where AA ~8% (5gFe/g) is clearly the second most efficient paste. When comparing this category of MP against the 2 controls, AA ~4% (5gFe/g) is the only MP that is consistently more efficient than the DW control. AA ~8% (5gFe/g) has a slightly higher efficacy at 90% removal of B380 as CONTROL DW (5gFe/g) but a lower efficacy at 95% removal of B380. Iron powder alone is more efficient at removing B380 than any MP from category i.

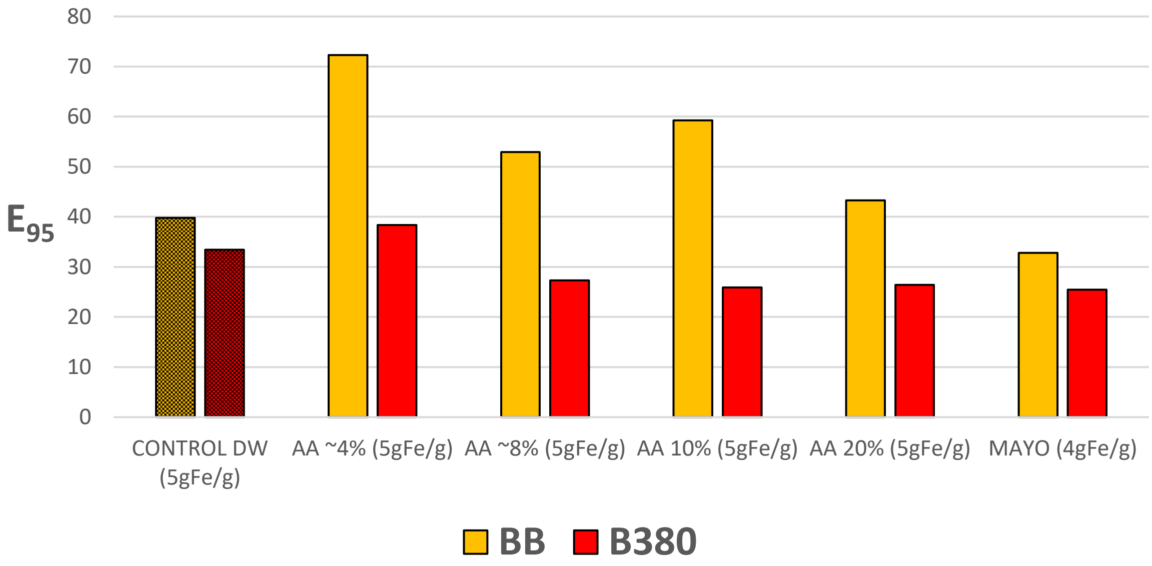


Figure 3.5 The E_{95} values of **Category i** magnetic pastes on **BB** and **B380** contaminants. Yellow bars represent Bua Ban, designated BB. Red bars represent Bunker 380, designated B380.

As all MPs with an acetic acid component reach 95% removal of contaminant, E_{95} is used to measure the efficacy of this category of MPs. All MPs with an acetic acid component work more efficiently to remove BB than for B380. AA ~4% (5gFe/g) is more efficient at removing both contaminants than the other MPs with an acetic acid component although the difference in BB removal efficacy between the pastes is less significant. For B380 removal, AA ~4% (5gFe/g) is significantly more efficient than the other MPs in category i. AA 10%, AA 20% (5gFe/g) and MAYO (4gFe/g) all have similar efficacies on both BB and B380 removal.

Generally, MPs with an acetic acid component are more efficient at removing BB, a medium crude oil, than B380, a heavy crude oil.

3.2.2 Pastes with a Commercial Cleansing Product (category ii)

<u>Contaminant</u>: Bua Ban (BB)

Duck Feather clusters contaminated with Bua Ban (BB) and were treated 8 times with each of the MPs with different commercial cleansing products (i.e., 5% v/v Fairy dishwashing liquid, Nivea eye make-up remover, and Perfect gel cosmetic cleanser). The percentage removal of the BB and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.6**. shows the relative removal efficacies of BB from duck feather clusters using MPs containing a commercial cleansing product, including data from two controls (i.e., iron powder and iron/water paste).

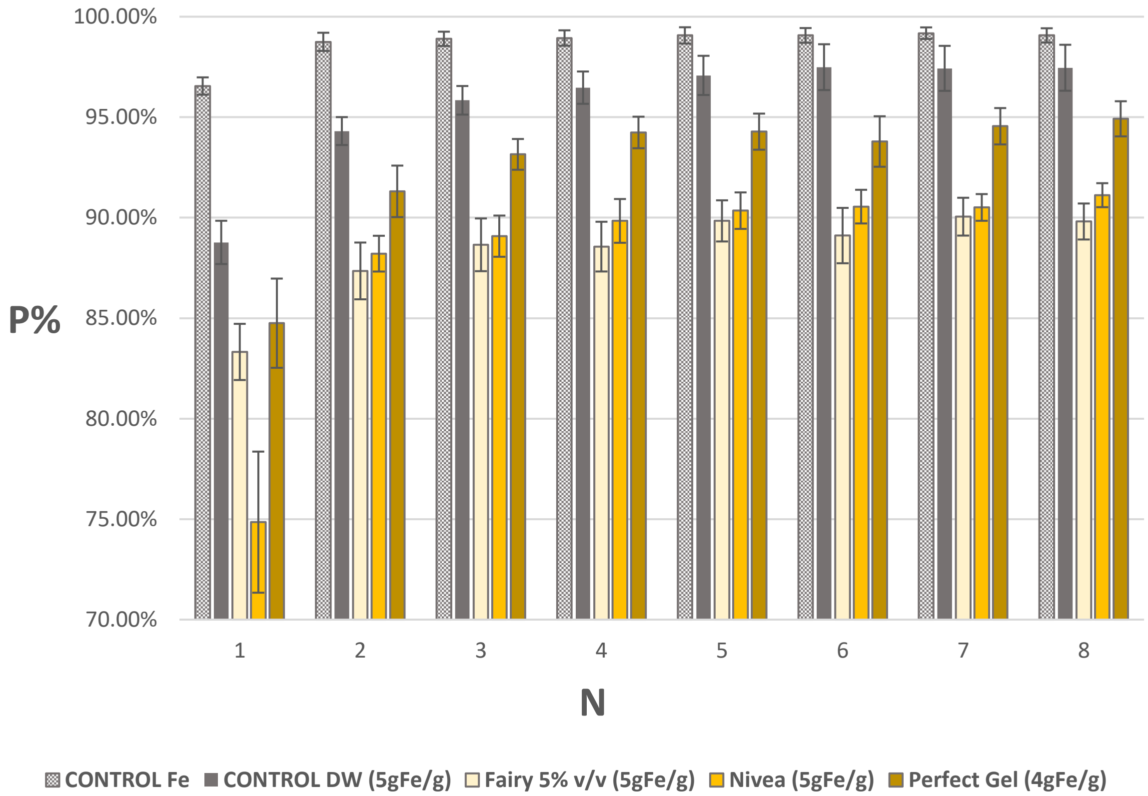


Figure 3.6 The % Removal, P%, of the Bua Ban (BB) crude oil from duck feather clusters using different types of commercial cleansing detergents/iron powder magnetic paste. The two controls are iron powder alone and an iron powder/water paste.

The commercial detergent/iron powder MPs do not remove more BB than the two controls. Both controls remove more BB than any MP from this category.

Between the MPs in category ii, Perfect Gel (4gFe/g) has a higher average removal at N= 1 although not statistically dissimilar to Fairy 5% v/v (5gFe/g). Nivea (5gFe/g) clearly removes the least BB at N= 1. From N=2 to 8, Perfect Gel (4gFe/g) removes significantly more BB than the other pastes in this category. Nivea (5gFe/g) has the second highest average removal from N=2 to 8 but the difference with Fairy 5 % v/v (5gFe/g) is not significant. By N= 8 Nivea (5gFe/g) removes significantly more BB than Fairy 5 % v/v (5gFe/g).

As Perfect Gel is already a paste and cannot hold as much iron powder as more aqueous agents Nivea and Fairy, its superior removal capacity cannot be attributed to its iron content but rather to the Perfect Gel itself.

The aqueous pastes from this category contain water like the DW control but also contain detergents. Therefore, the detergent additives inhibit the removal of BB when in the form of a MP. This is counterintuitive as commercial detergents diluted in water are used as the standard oil cleanser on oiled wildlife. These experiments show that adding a detergent to a MP has a negative impact on the removal of medium crude oils such as BB.

Table 3.3 Relative removal efficacy parameters for **Category ii** magnetic paste, calculated at x = 90. Efficacy is not calculated at x = 95 because no paste achieves a P_0% of at least 95%.

Magnetic Paste with a Commercial Cleansing Product	**P_0%**	**N_{90}**	**E_{90}**
CONTROL Fe	99.18	0.93	106.65
CONTROL DW (5gFe/g)	97.49	1.22	79.91
Fairy 5% v/v (5gFe/g)	90.05	6.90	13.05
Nivea (5gFe/g)	91.12	4.22	21.59
Perfect Gel (4gFe/g)	94.92	1.79	53.03

Category ii MPs do not reach 95% removal of BB. The efficacy of these pastes is measured using their efficacy at 90% removal of BB. From the data in **Table 3.3** Perfect Gel (4gFe/g) is the most efficient paste followed by Nivea (5gFe/g) then Fairy 5% v/v (5gFe/g). No MP from this category is more efficient at removing BB than either of the controls. Therefore, MPs from category ii are recommended to use on removing BB contamination.

<u>Contaminant:</u> Bunker (B380)

Duck Feather clusters contaminated with Bunker 380 (B380) and were treated 8 times with each of the MPs with different commercial cleansing products (i.e., 5% v/v Fairy dishwashing liquid, Nivea eye make-up remover, and Perfect gel cosmetic cleanser). The percentage removal of the B380 and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.7**. shows the relative removal efficacies of B380 from duck feather clusters using MPs containing a commercial cleansing product, including data from two controls (i.e., iron powder and iron/water paste).

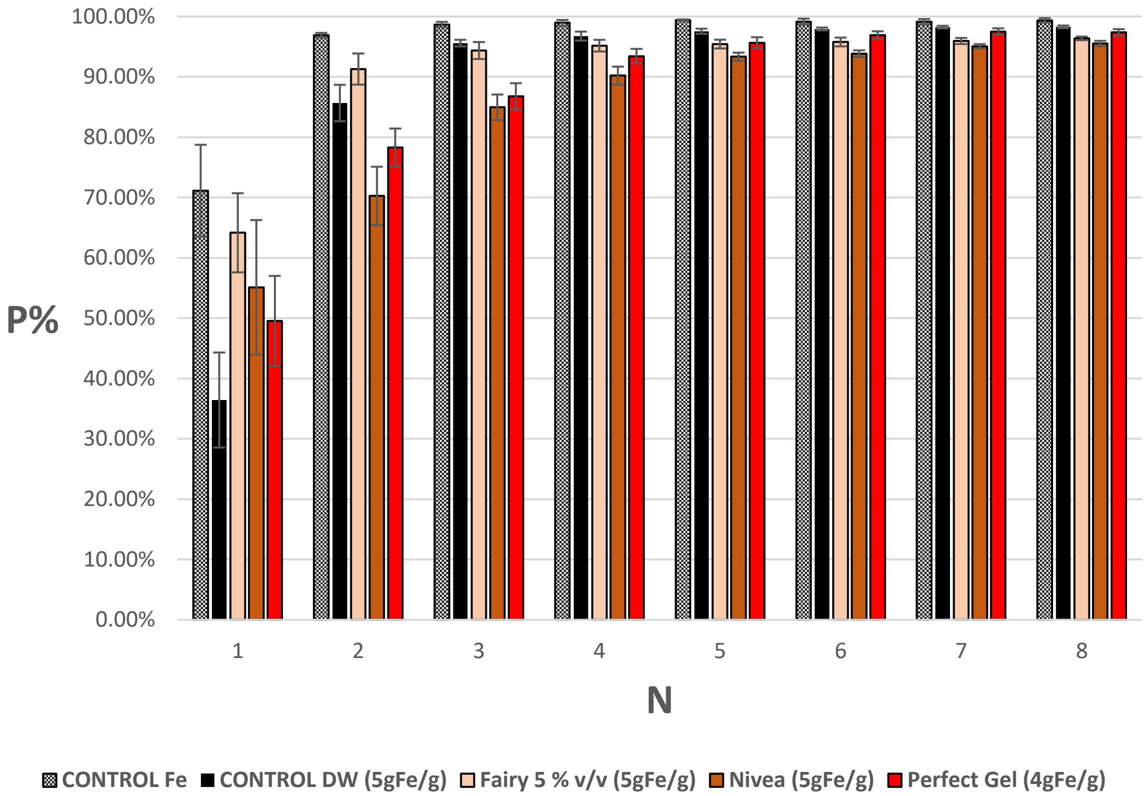


Figure 3.7 The % Removal, P%, of the Bunker 380 (B380) crude oil from duck feather clusters using different types of commercial cleansing detergents/iron powder magnetic paste. The two controls are iron powder alone and an iron powder/water paste.

The iron powder (alone) control removes significantly more B380 than any of the MPs from N= 1 to 8. The MPs from this category remove more B380 at N=1 than the DW control. At N= 2 only Fairy 5% v/v (5gFe/g) removes more than the DW control. From N= 3 to 8 the DW control removes more B380 than any category ii paste. Fairy 5% v/v (5gFe/g) removes more B380 than the other MPs in this category from N=1 to 4. In later treatments (N= 6 to 8) Perfect Gel (4gFe/g) removes more B380 than the other MPs. Although Nivea has the second highest removal of B380 after one treatment, for each subsequent treatment it removes the least amount of B380.

Table 3.4 Relative removal efficacy parameters for **Category ii** magnetic paste, calculated at x = 90 and 95%.

Magnetic Paste with a Commercial Cleansing Product	P_0%	N_{90}	E_{90}	N_{95}	E_{95}
CONTROL Fe	99.38	1.73	57.45	1.93	51.49
CONTROL DW (5gFe/g)	98.29	2.44	40.28	2.94	33.43
Fairy 5% v/v (5gFe/g)	96.37	1.96	49.17	2.94	32.78
Nivea (5gFe/g)	97.50	3.97	24.56	6.96	14.01
Perfect Gel (4gFe/g)	95.52	3.49	27.37	4.73	20.19

All three of the MPs with a commercial cleansing agent reached 95% removal of B380. These same three MPs did not reach 95% removal of BB. From the data in **Table 3.4**, Fairy 5% v/v (5gFe/g) is the most efficient MP in this category to remove B380. However, it is not the MP which has the highest overall removal. The MP with the highest percentage removal is Nivea. Nivea also happens to be the least efficient paste in this category. Fairy 5% v/v (5gFe/g) is more efficient than the DW control to remove 90% B380 however the DW control is marginally more efficient at 95% B380 removal.

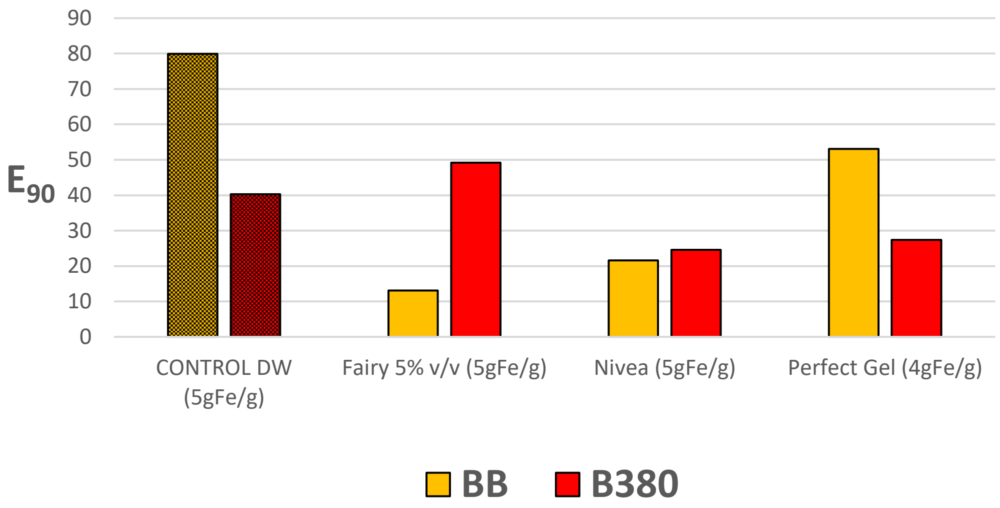


Figure 3.8 The E_{90} values of **category ii** magnetic pastes on **BB** and **B380** contaminants. Yellow bars represent Bua Ban, designated BB. Red bars represent Bunker 380, designated B380.

Comparing the removal efficacies of category ii pastes on BB and B380 as illustrated in **Figure 3.8,** shows that Fairy 5% v/v (5gFe/g) has potential as a MP to remove heavier crude oils such as Bunker 380

These efficacy results at 90% contaminant removal show that each paste with a commercial cleansing component does not behave in the same way to remove BB and B380. Fairy 5% v/v (5gFe/g) and Nivea (5gFe/g) are both more efficient at removing B380 than BB although the difference is extreme in Fairy 5% v/v (5gFe/g). Whereas Perfect Gel (4gFe/g) is more efficient at removing BB than B380. This demonstrates that a MP can be tailored to specific contaminants. For example, to remove heavier crude oils Fairy 5% v/v (5gFe/g) would be used and a MP like Perfect Gel (4gFe/g) would be used on lighter crude oils.

3.2.3 Pastes with a eucalyptus oil component (category iii)

Contaminant: **Bua Ban (BB)**

Duck Feather clusters contaminated with Bua Ban (BB) were treated 8 times with each of the MPs with a different eucalyptus oil containing component, (i.e., Eucalyptus oil (EO) 5% v/v, EO 20% v/v, EO 25% v/v). The percentage removal of the BB and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.9** shows the relative removal efficacies of BB from duck feather clusters using varying proportions of the eucalyptus oil/iron powder MPs, including data for two controls (i.e., iron powder and iron/water paste).

During this experiment it was noted by the researcher that the feathers clusters treated with a eucalyptus oil MP took on a strong odor of eucalyptus oil although the feathers appeared clean. The intensity of the odor, brittleness, and stickiness appeared to increase as the proportion of eucalyptus oil in a MP increased. The feathers also became brittle and sticky. The treated feathers easily adhered to equipment which led to breakage of the feather structures when attempting to remove.

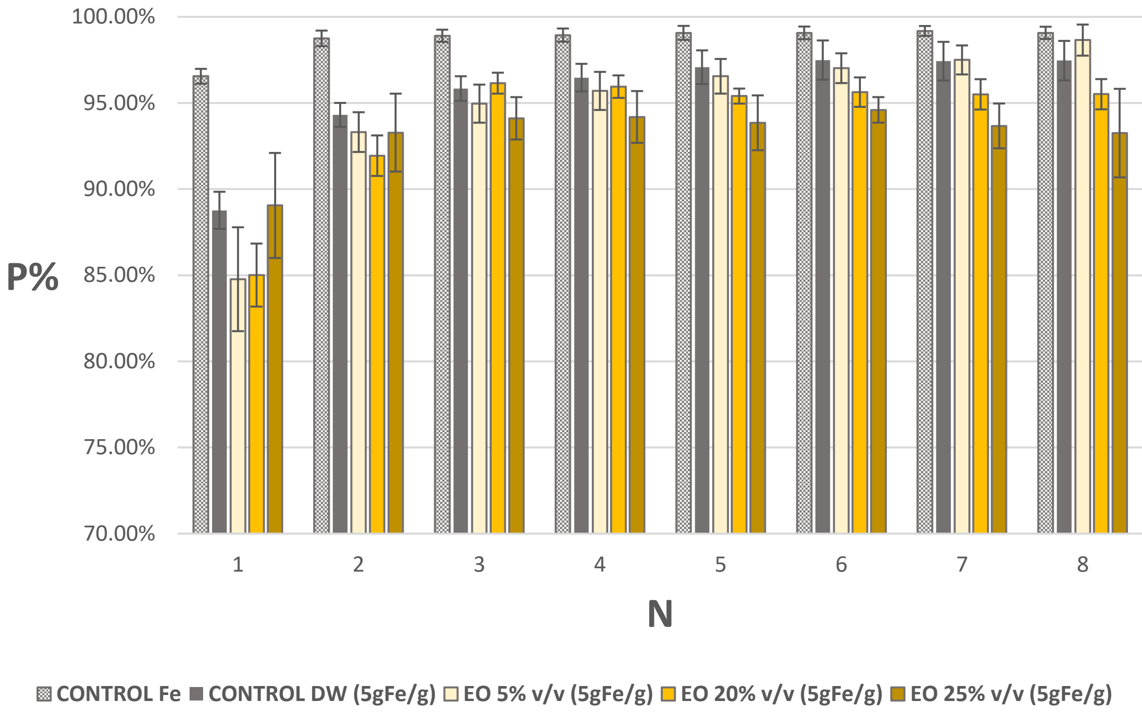


Figure 3.9 The % Removal, P%, of the Bua Ban (BB) crude oil from duck feather clusters using Eucalyptus oil/iron powder magnetic pastes with different concentrations of eucalyptus oil. The two controls are iron powder alone and an iron powder/water paste.

From N=1 to 7 the iron powder (alone) removes more BB than any category iii paste. At N= 8 both the iron powder (alone) and EO 5% v/v (5gFe/g) remove the most BB. Of the MPs at N=1, EO 5% v/v (5gFe/g) and EO 20% v/v (5gFe/g) remove less than the DW control, and EO 25% v/v (5gFe/g) has a slightly higher average removal than the DW control but this not statistically significant. From N=5 to 8 the proportion of eucalyptus oil in a MP is inversely related to BB removal with the lowest proportion of eucalyptus oil removing more and the highest proportion of eucalyptus oil removing less. The removal of BB by both EO 20% v/v (5gFe/g) and EO 25% v/v (5gFe/g) does not progressively increase from N= 3 to 8. Instead, the feather clusters treated with these two MPs begin to gain weight, indicating that these MPs begin to contaminate the feather clusters. There does not appear to be an improvement in initial BB removal by incorporating eucalyptus oil into a magnetic paste. However, eucalyptus oil does appear to improve BB removal at the final treatment but only at a low proportion of eucalyptus oil. EO 5% v/v (5gFe/g) which removes a comparable amount of BB to the iron power alone. Although eucalyptus shows that it can remove crude oil, it also becomes a contaminant when a higher proportion is mixed with iron powder in later treatments. Proportions lower than 5% eucalyptus oil may be even more effective at removing BB when mixed with another component other than water.

Table 3.5 Relative removal efficacy parameters for **Category iii** magnetic paste, calculated at x = 90 and 95%.

Magnetic Paste with a eucalyptus component	**P_0%**	**N_{90}**	**E_{90}**	**N_{95}**	**E_{95}**
CONTROL Fe	99.18	0.93	106.65	0.98	101.20
CONTROL DW (5gFe/g)	97.49	1.22	79.91	2.45	39.79
EO 5% (5gFe/g)	98.65	1.62	60.90	3.11	31.72
EO 20% (5gFe/g)	96.15	1.73	55.58	2.73	35.22
EO 25% (5gFe/g)	94.60	1.23	76.91	N/A	N/A

Although **Figure 3.9** shows that EO 5% (5gFe/g) has a similar BB removal as iron powder alone and a higher BB removal than the DW control, the data presented in **Table 3.5** shows that EO 5% (5gFe/g) is not as efficient as either control. In fact, the more efficient eucalyptus oil MP at E_{90} is EO 25% (5gFe/g) which removes the least amount of BB overall.

The data in **Table 3.5** reiterates that EO 25% (5gFe/g) is effective at initial removal from N=1 to 2 (ie., N_{90} = 1.23) but is ineffective to remove contamination from feather clusters with additional treatments. This is supported from the data in **Figure 3.9** that shows that EO 25% (5gFe/g) treated feather clusters begin to gain weight from N=3 to 8.

<u>Contaminant:</u> Bunker 380 (B380)

Duck Feather clusters contaminated with Bunker (B380) were treated 8 times with each of the MPs with a different eucalyptus oil containing component, (i.e., Eucalyptus oil (EO) 5% v/v, EO 20% v/v, EO 25% v/v). The percentage removal of the B380 and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.10** shows the relative removal efficacies of B380 from duck feather clusters using varying proportions of the eucalyptus oil/iron powder MPs, including data for two controls (i.e., iron powder and iron/water paste).

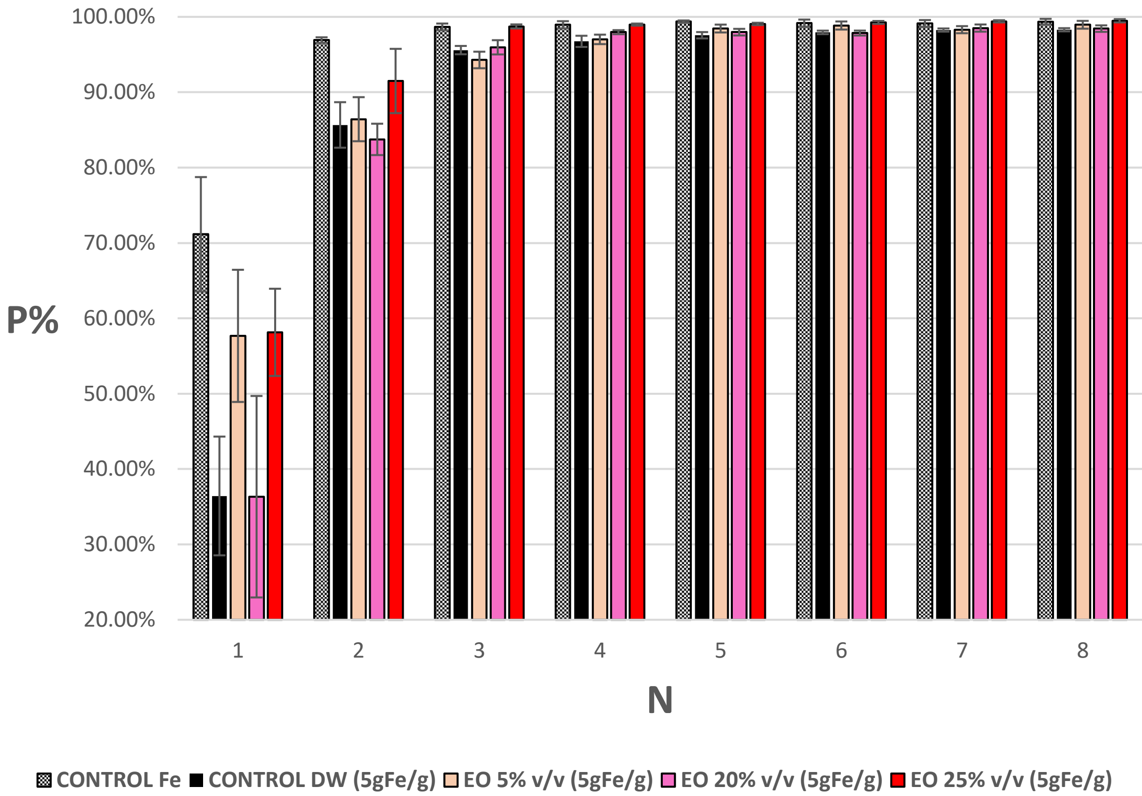


Figure 3.10 The % Removal, P%, of the Bunker 380 (B380) crude oil from duck feather clusters using Eucalyptus oil/iron powder magnetic pastes with different concentrations of eucalyptus oil. The two controls are iron powder alone and an iron powder/water paste.

Iron powder (alone) removes more B380 at N=1 and 2. From N=3 to 8 EO 25% v/v (5gFe/g) removes marginally more B380 than the iron powder control although it is not statistically significant. At N=1 EO 5% v/v (5gFe/g), and EO 25% v/v (5gFe/g) remove similar amounts of B380 and remove significantly more B380 than the DW control. Meanwhile the DW control and EO 20% v/v (5gFe/g) remove a similarly low amount of B380. From N= 2 to 4 the DW control, 5% v/v (5gFe/g), and EO 20% v/v (5gFe/g) alternate between how much they remove B380. From N=5 to 8, both EO 5% v/v (5gFe/g) and EO 25% v/v (5gFe/g) remove more B380 than the DW control with EO 25% v/v (5gFe/g) removing the most.

From the data in **Table 3.6**, EO 25% v/v (5gFe/g) is the most efficient MP in this category with higher P_0%, E_{90} and E_{95} values which are also higher than the DW control. All category iii pastes remove more B380 than the DW control. Only EO 25% v/v (5gFe/g) is more efficient with higher E90 and E95 values. The other category iii pastes have similar efficacy values as the DW control. EO 25% v/v (5gFe/g) removes more B380 than the iron powder (alone) although the iron powder (alone) is more efficient.

Table 3.6 Relative removal efficacy parameters for **Category iii** magnetic paste, calculated at x = 90 and 95%.

Magnetic Paste with a eucalyptus component	P_0%	N_{90}	E_{90}	N_{95}	E_{95}
CONTROL Fe	99.38	1.73	57.45	1.93	51.49
CONTROL DW (5gFe/g)	98.29	2.44	40.28	2.94	33.43
EO 5% v/v (5gFe/g)	98.95	2.46	40.22	3.28	30.17
EO 20% v/v (5gFe/g)	98.51	2.52	39.09	2.92	33.74
EO 25% v/v (5gFe/g)	99.48	1.96	50.76	2.49	39.95

The mere presence of eucalyptus oil in a MP does not improve the removal of B380. The proportion of eucalyptus oil in a MP must be ~ 25% for an improved B380 removal. The stickiness of the feathers seen on BB contaminated feather clusters treated with category iii pastes did not occur on the feathers contaminated with B380. Therefore, the interaction between the contaminant and eucalyptus oil varies depending on the physical composition of the contaminant.

MPs with a eucalyptus component do improve contaminant removal but this is dependent on the type of contaminant. Low proportions of eucalyptus oil in a MP improve the removal of medium crude oils overall but higher proportions of eucalyptus oil are most effective for initial treatments but not for later treatments as eucalyptus oil/iron particles likely become an additional contaminant. High proportions of eucalyptus oil in a MPimprove the removal of heavy crude oils and do not appear to negatively interact with the heavy crude oil.

MPs with a eucalyptus oil component work more efficiently on BB rather than B380, shown in **Figure 3.11**. On both contaminants EO 25% (5gFe/g) is the most efficient and EO 20% (5gFe/g) is the least efficient. The efficiencies of MPs with a eucalyptus oil component do no correspond exactly with the proportion of eucalyptus oil in the MP although the highest concentration is the most efficient at removing 90% of both contaminants. The lower concentrations, EO 5% (5gFe/g) and EO 20% (5gFe/g) are relatively similar in their removal efficacies of both contaminants despite their substantial difference in eucalyptus oil concentration.

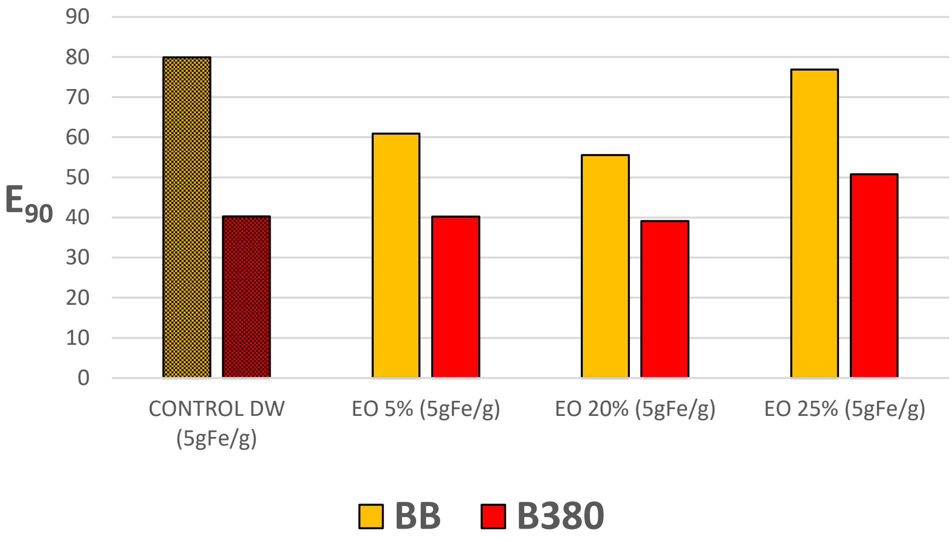


Figure 3.11 The E_{90} values of **category iii** magnetic pastes on **BB** and **B380** contaminants. Yellow bars represent Bua Ban, designated BB. Red bars represent Bunker 380, designated B380.

3.2.4 Pastes with a conventional pre-treatment agent (PTA) (category iv)

Contaminant: Bua Ban (BB)

Duck Feather clusters contaminated with Bua Ban (BB) were treated 8 times with each of the MPs with a different PTA containing component, (i.e., Methyl Soyate (MS 6gFe/g), Esterol (EST 6gFe/g), Mineral Oil (MO 6gFe/g), and Ethanol (ETOH 70% v/v 7gFe/g)). The percentage removal of the BB and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.12** shows the relative removal efficacies of BB from duck feather clusters using varying types of PTA/iron powder MPs, including data for two controls (i.e., iron powder and iron/water paste).

Unlike the other paste categories with iron powder proportions of 5g to 1g of a component/agent, the proportion of iron powder is higher for MPs with a conventional PTA at 6gFe/g. The MP with ETOH 70% has a proportion of 7g of iron powder to 1g of ETOH 70%. The histogram compares the percentage removal of each MP with a conventional PTA against the controls after each treatment to evaluate the effect conventional PTAs in a MP has on BB removal.

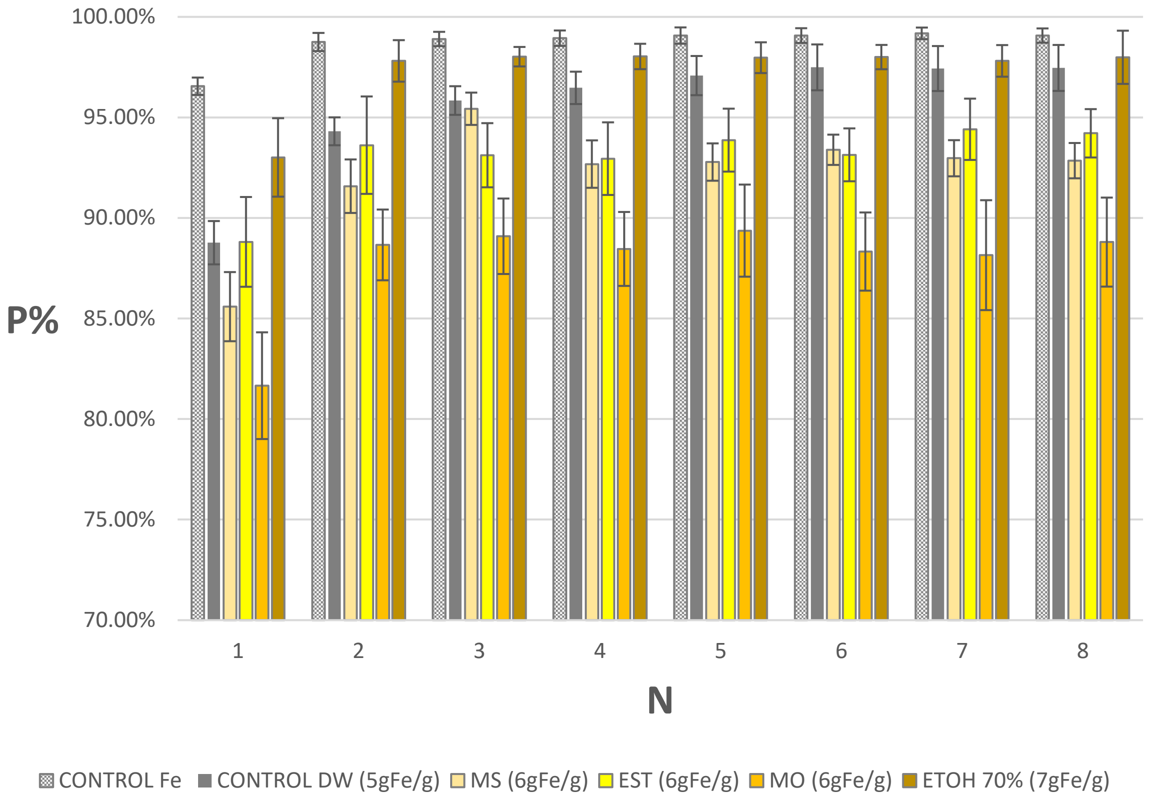


Figure 3.12 The % Removal, P%, of the Bua Ban (BB) crude oil from duck feather clusters using varying pre-treatment agents (PTA)/iron powder magnetic pastes. The two controls are iron powder alone and an iron powder/water paste.

The iron powder (alone) control removes significantly more BB than any of the MPs from N= 1 to N= 8. ETOH (7gFe/g) is the only MP in this category iv that removes significantly more BB than the DW control from N=1 to 8 although there is little to no improvement in BB removal by ETOH (7gFe/g) from N=3 to 8. The least effective MP from N=1 to 8 is MO (6gFe/g). MO (6gFe/g) only removes BB from N=1 to 3. From N=4 to 8 the weight of the feather cluster remains unchanged. Both MS (6gFe/g) and EST (6gFe/g) remove similar amounts of BB. EST (6gFe/g) appears to remove more BB in the first 2 treatments but at N=3 MS (6gFe/g) removes more than EST (6gFe/g). At N=4 the weight of the MS (6gFe/g) treated feather cluster increases and weighs a similar amount to EST (6gFe/g). There is not improvement in MS (6gFe/g) from N=4 to 8.

No MP in category iv appear to improve BB removal beyond N=3 whereas both controls continue to remove more BB with every treatment from N=1 to 8. The only paste in category iv to improve initial removal of BB is ETOH (7gFe/g).

Table 3.7 Relative removal efficacy parameters for **Category iv** magnetic paste, calculated at x = 85, 90 and 95%.

Magnetic paste with a conventional PTA	**P_0%**	**N_{85}**	**E_{85}**	**N_{90}**	**E_{90}**	**N_{95}**	**E_{95}**
CONTROL Fe	99.18	0.88	112.70	0.93	106.65	0.98	101.20
CONTROL DW (5gFe/g)	97.49	0.96	101.55	1.22	79.91	2.45	39.79
MO (6gFe/g)	89.37	1.48	60.39	N/A	N/A	N/A	N/A
MS (6gFe/g)	95.43	0.99	96.39	1.75	54.53	2.9	32.91
EST (6gFe/g)	94.41	0.96	98.34	1.26	74.93	N/A	N/A
70%ETOH (7gFe/g)	98.03	0.91	107.73	0.97	101.06	1.42	69.04

From the data in **Table 3.1**, ETOH (7gFe/g) is the only MP from this category that is more efficient than the DW control at all benchmarks (E_{85}, E_{90}, and E_{95}). MO (6gFe/g) does not reach 90% removal, so the 85% removal (E_{85}) benchmark is used for all pastes in this category. At E_{85} MO (6gFe/g) is significantly less efficient. When the benchmark is increased to 90% BB removal, EST (6gFe/g) is the second most efficient MP behind ETOH (7gFe/g). Only ETOH (7gFe/g) and MS (6gFe/g) reach BB removal above 95%. The most salient points from the data in **Table 3.1** are that ETOH (7gFe/g) improves the efficacy of BB removal, MO (6gFe/g) inhibits the efficacy of BB removal, and no category iv paste is more efficient than iron powder (alone).

<u>Contaminant:</u> Bunker (B380)

Duck Feather clusters contaminated with Bunker (B380) were treated 8 times with each of the MPs with a different PTA containing component, (i.e., Methyl Soyate (MS 6gFe/g), Esterol (EST 6gFe/g), Mineral Oil (MO 6gFe/g), and Ethanol (ETOH 70% v/v 7gFe/g)). The percentage removal of the B380 and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.13** shows the relative removal efficacies of B380 from duck feather clusters using varying types of PTA/iron powder MPs, including data for two controls (i.e., iron powder and iron/water paste).

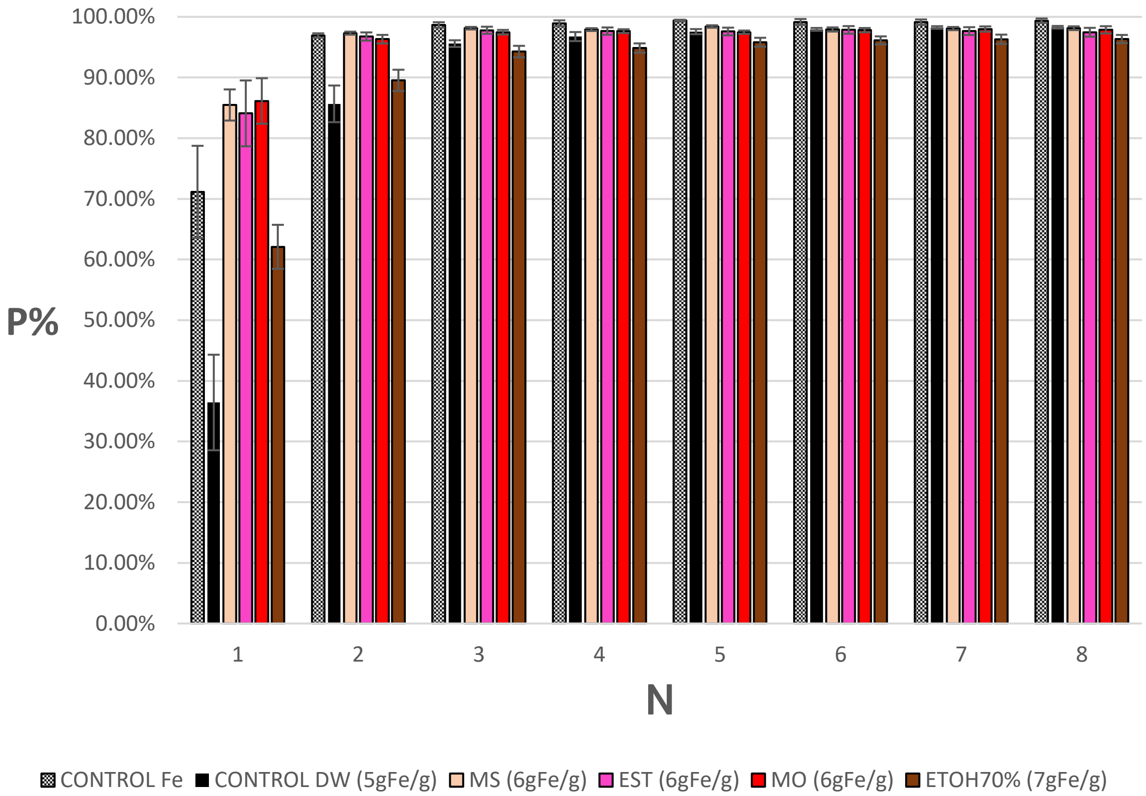


Figure 3.13 The % Removal, P%, of the Bunker (B380) crude oil from duck feather clusters using varying pre-treatment agents (PTA)/iron powder magnetic pastes. The two controls are iron powder alone and an iron powder/water paste.

Iron powder (alone) does not remove more B380 than three out of the four PTA MPs at N=1. This is the only category of MPs to do so. MS (6gFe/g), EST (6gFe/g) and MO (6gFe/g) remove similar amounts of B380 to each other from N= 1 to 8. At N=2, these three MPs remove a similar amount of B380 as iron powder (alone). From N=3 to 8, iron powder (alone) removes more B380. Meanwhile to appears the removal of B380 by MS (6gFe/g), EST (6gFe/g) and MO (6gFe/g) comes to a standstill. All category iv MPs remove more B380 than the DW control from N=1 to 2. From N=3 to 8 the DW control removes more B380 than ETOH (7gFe/g). From N=6 to 8 B380 removal by MS (6gFe/g), EST (6gFe/g) and MO (6gFe/g) is comparable to the DW control.

The results in **Figure 3.13** show that MS (6gFe/g), EST (6gFe/g) and MO (6gFe/g) are similarly effective to remove B380 after two treatments with MS (6gFe/g) being the most effective. Although ETOH (7gFe/g) is the less effective, it does improve the removal of B380 after 2 treatments when compared against the DW control.

Category iv prove to be effective when used initially. Continued treatments using these pastes do not show any improvement to B380 when compared to the iron powder (alone).

Table 3.8 Relative removal efficacy parameters for **Category iv** magnetic paste, calculated at x = 85, 90 and 95%.

Magnetic paste with a conventional PTA	**P_0%**	**N_{85}**	**E_{85}**	**N_{90}**	**E_{90}**	**N_{95}**	**E_{95}**
CONTROL Fe	99.38	1.54	64.53	1.73	57.45	1.93	51.49
CONTROL DW (5gFe/g)	98.29	1.99	49.52	2.44	40.28	2.94	33.43
MO (6gFe/g)	97.99	0.99	99.48	1.38	71.01	1.97	49.74
MS (6gFe/g)	98.41	1.00	98.90	1.38	71.31	1.81	54.37
EST (6gFe/g)	97.85	1.07	91.45	1.47	66.56	1.86	52.61
ETOH 70% (7gFe/g)	96.35	1.83	52.65	2.1	45.88	4.17	23.11

The data in **Table 3.8** shows that MS (6gFe/g) is the most efficient MP at E_{90} and E_{95} but at E_{85} MO (6gFe/g) is the most efficient. All pastes in this category are more efficient than the DW control at E_{85} and E_{90}. At E95 ETOH 70% (7gFe/g) is the only MP less efficient than the DW control. MS (6gFe/g), EST (6gFe/g), and MO (6gFe/g) are more efficient than the iron powder alone at E_{85} and E_{90}. At E_{95} only MS (6gFe/g) and EST (6gFe/g) are more efficient than iron powder (alone). Iron powder (alone) is not more efficient at removing B380 that MPs from category iv despite it removing slightly more B380 overall (Po%).

To include the efficacy value for MO (6gFe/g) the 85% removal parameter was used. **Figure 3.14** shows that MO (6gFe/g) and MS (6gFe/g) work more efficiently on B380 than BB although the removal efficacy for MS (6gFe/g) on both contaminants is almost the same. The two controls and ETOH 70% v/v (6gFe/g) share similar profiles with all more efficiently removing BB than B380.

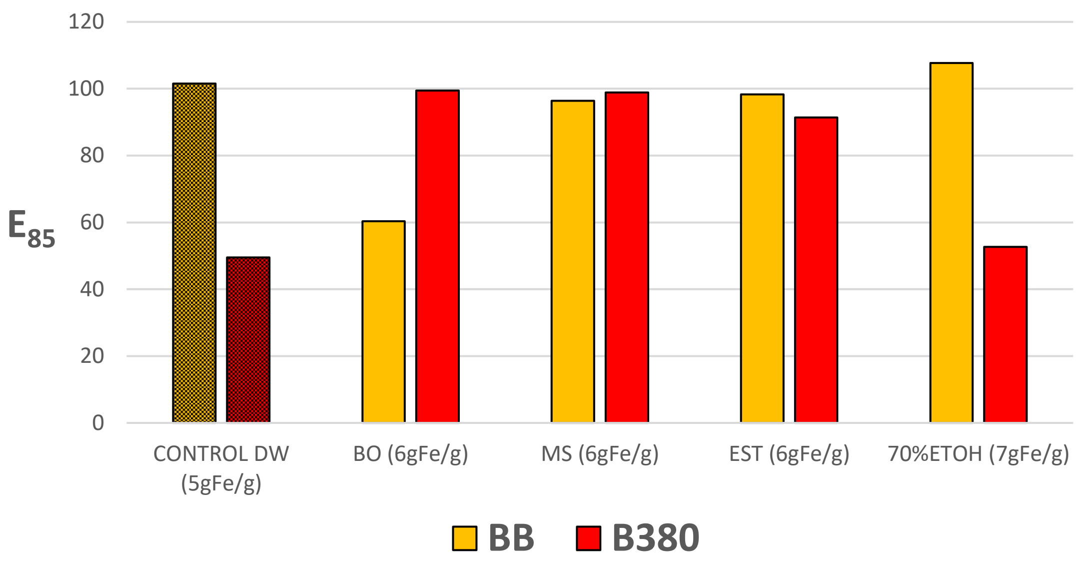


Figure 3.14 The E_{85} values of **category iv** magnetic Pastes on **BB** and **B380** contaminants. Yellow bars represent Bua Ban, designated BB. Red bars represent Bunker 380, designated B380.

The chemical and physical compositions of the PTAs in this category are not similar to each other. Mineral Oil (BO) is a refined hydrocarbon, esterol (EST) and methyl soyate (MS) are both biodiesels, and ethanol (ETOH) is an alcohol. This explains why their removal efficacies vary considerably.

3.2.5 Pastes with a Vegetable Oil Component (Category v)

<u>Contaminant:</u> Bua Ban (BB)

Duck Feather clusters contaminated with Bua Ban (BB) were treated 8 times with each of the MPs with two different vegetable oil containing component, (i.e., Extra virgin Olive Oil (OO) and extra virgin Coconut Oil (OO)). The percentage removal of the BB and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.15** shows the relative removal efficacies of BB from duck feather clusters using varying types of vegetable oil/iron powder MPs, including data for two controls (i.e., iron powder and iron/water paste).

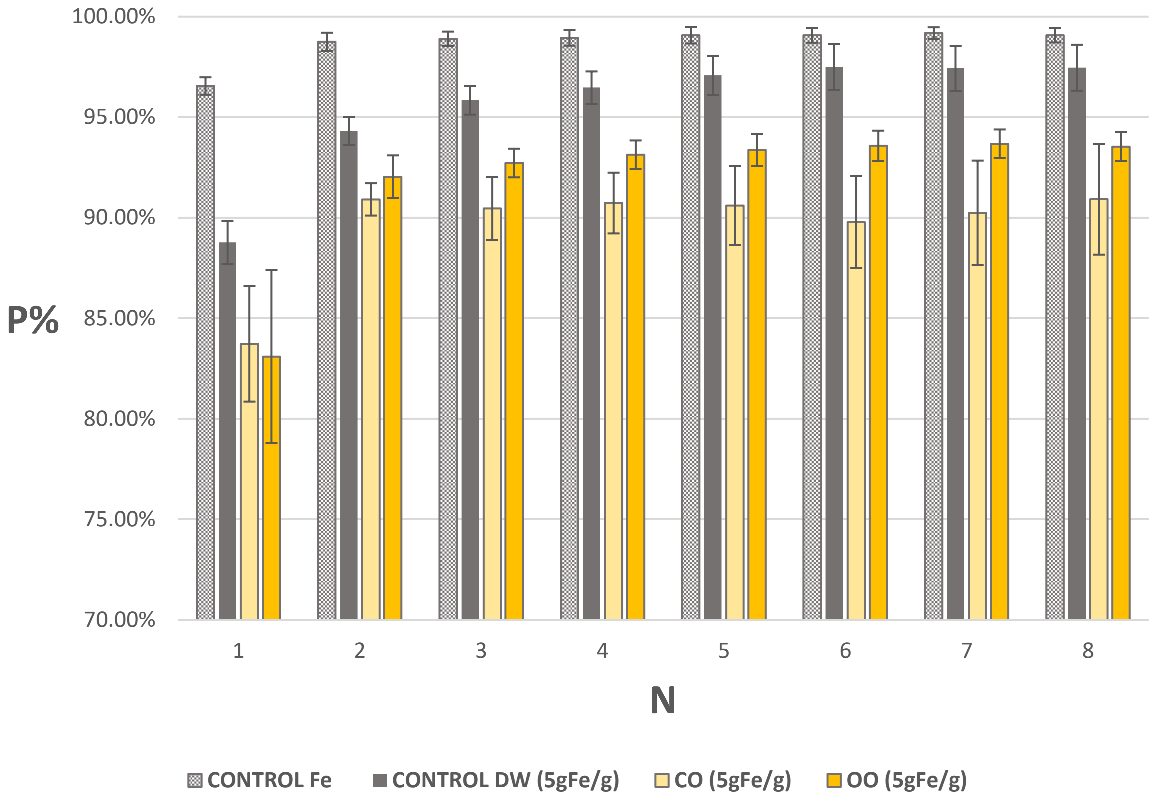


Figure 3.15 The % Removal, P%, of the Bua Ban (BB) crude oil from duck feather clusters using different vegetable oils/iron powder magnetic pastes. The two controls are iron powder alone and an iron powder/water paste.

Neither of the MPs with a vegetable oil component remove more BB than iron powder (alone) or the DW control. The removal of BB from N=1 to 2 is comparable for both MPs in category v. From N=3 to 8, OO (5gFe/g) removes more BB than CO (5gFe/g). Removal of BB by CO (5gFe/g) does not improve from N=3 to 8, in fact it appears that feather clusters treated with CO (5gFe/g) are prone to gaining weight with additional treatments suggesting that CO (5gFe/g) itself becomes a contaminant with 3 or more treatments.

Data from **Table 3.9** shows that MPs with a vegetable oil component do not improve BB removal when compared to the DW control and this is more noticeable for the CO (5gFe/g) MP which has a significantly lower overall removal (P_0%) than the DW control. OO (5gFe/g) does not negatively impact the overall removal or the removal efficacy of BB as much as the CO (5gFe/g).

Table 3.9 Relative removal efficacy parameters for **Category v** magnetic paste, calculated at x = 90 and 95%.

Magnetic paste with a vegetable oil component	P_0**%**	N_{90}	E_{90}	N_{95}	E_{95}
CONTROL Fe	99.18	0.93	106.65	0.98	101.20
CONTROL DW (5gFe/g)	97.49	1.22	79.91	2.45	39.79
OO (5gFe/g)	93.68	1.78	52.63	N/A	N/A
CO (5gFe/g)	90.92	1.89	48.11	N/A	N/A

<u>Contaminant:</u> Bunker (B380)

Duck Feather clusters contaminated with Bunker (B380) were treated 8 times with each of the MPs with two different vegetable oil containing component, (i.e., Extra virgin Olive Oil (OO) and extra virgin Coconut Oil (OO)). The percentage removal of the B380 and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.16** shows the relative removal efficacies of B380 from duck feather clusters using varying types of vegetable oil/iron powder MPs, including data for two controls (i.e., iron powder and iron/water paste).

At N= 1 both OO (5gFe/g) and CO (5gFe/g) remove more B380 than the DW control but only OO (5gFe/g) removes more than iron powder (alone). From N= 2 to 8 iron powder (alone) removes more B380 than both MPs in this category. From N= 2 to 3 OO (5gFe/g) removes more than the DW control. From N= 5 to 8 the DW control removes more than both category v MPs. OO (5gFe/g) is more effective at removing B380 than CO (5gFe/g) from N=1 to 8. Both category v MPs improve removal of B380 at N= 1 with OO (5gFe/g) being far more effective as it removes significantly more than the iron powder (alone). Therefore, for initial treatment for B380 removal OO (5gFe/g) is effective and treatment by iron powder (alone) is more effective for later treatments.

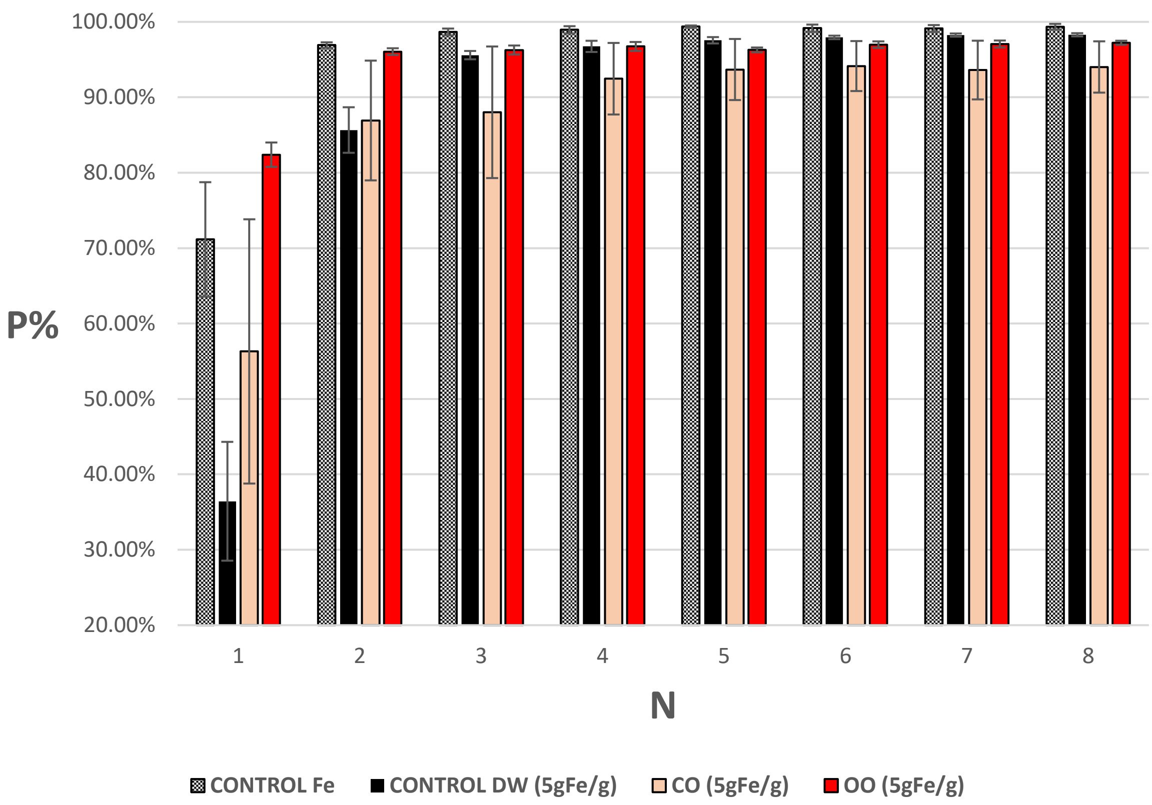


Figure 3.16 The % Removal, P%, of the Bunker 380 (B380) crude oil from duck feather clusters using different vegetable oils/iron powder magnetic pastes. The two controls are iron powder alone and an iron powder/water paste.

Table 3.10 Relative removal efficacy parameters for **Category v** magnetic paste, calculated at x = 90 and 95%.

Magnetic Paste with a vegetable oil component	**P_0%**	**N_{90}**	**E_{90}**	**N_{95}**	**E_{95}**
CONTROL Fe	99.38	1.73	57.45	1.93	51.49
CONTROL DW (5gFe/g)	98.29	2.44	40.28	2.94	33.43
OO (5gFe/g)	97.23	1.56	62.33	1.92	50.64
CO (5gFe/g)	94.14	3.46	27.21	N/A	N/A

From the data presented in **Table 3.10**, OO (5gFe/g) is the most efficient of the category v MPs. At 90% B380 removal OO (5gFe/g) is more efficient than the iron powder (alone) but when the benchmark is increased to 95% B380 removal, iron powder is the most efficient. CO (5gFe/g) is not efficient at removing B380 at either 90 or 95% removal when compared to the iron powder (alone) or the DW control.

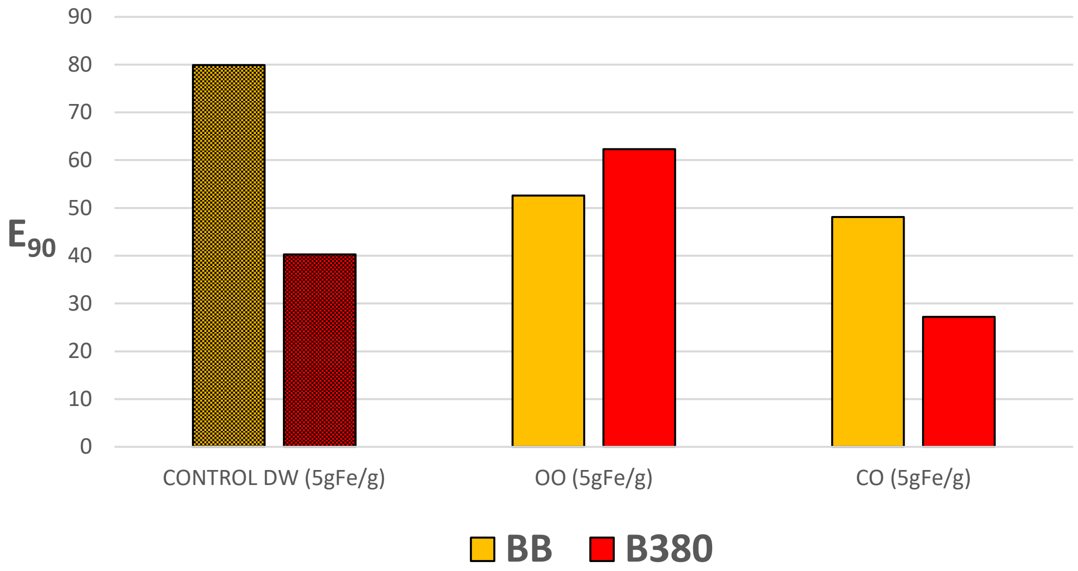


Figure 3.17 The E_{90} values of **Category v** magnetic pastes on **BB** and **B380** contaminants. Yellow bars represent Bua Ban, designated BB. Red bars represent Bunker 380, designated B380.

OO (5gFe/g) is the more efficient MP with a vegetable oil component to remove BB and B380. However, it is more efficient at removing B380 than it is at removing BB. This the opposite for CO (5gFe/g) which is more efficient at removing BB than B380.

When these pastes are compared against the controls, OO (5gFe/g) is more efficient than the CONTROL DW (5gFe/g) to remove B380 but less efficient than the iron powder alone.

3.3 Proportion of Iron Particles: The Effects of Increasing Proportion of Iron Particles from 5gfe/g to 6gfe/g in a MP

Foundational studies into how iron particles sequester crude oil from penguin feather and pelt have proven that iron particles are an effective agent to remove almost 99% of crude oil after a series of treatments. Iron particles will remove oil however adding an additional agent may either improve overall contaminant removal by targeting the tarrier components of a contaminant that are otherwise more difficult to remove. A MP has two components – the contaminant conditioner (additive in the paste) and the contaminant remover (the iron powder). The proportions of these components will affect the removal of the contaminant, and the ideal proportions are unknown.

The MP control using deionised water and iron powder was made using 5 grams of iron powder per gram of water. This was the maximum amount of iron powder that could be added to water to form a spreadable paste. More iron powder resulted a texture that was like wet sand and less iron powder resulted in a non-uniform paste with residual water. 5 grams of iron powder per gram of agent therefore became the standard. However, there were certain MPs such as the perfect gel and mayonnaise, both paste-like in nature, that did not produce spreadable pastes with 5 grams of iron powder per gram. Perfect gel and mayonnaise MPs were made using 4 grams of iron powder per gram instead. Meanwhile, there were some MPs using aqueous solutions that would produce 'runny' MPs at 5 grams of iron powder per gram, and the iron powder and agent would separate when left to rest. These MPs required a higher proportion of iron powder to produce uniform spreadable MPs- 6 grams rather than 5 grams of iron powder per gram. These pastes were Methyl soyate, Esterol and Mineral oil and these are the MPs that have been used to compare the effect the proportion of iron powder has on the removal of a contaminant.

The same methods described in **Chapter 3.2** were used to assess the effect the proportion of iron powder in a MP has on removing a contaminant. The contaminant used in this experiment was Bua Ban (BB). The comparisons include deionised water/iron powder MP as a control.

3.3.1 Methyl soyate/iron powder MPs: 5gFe/g and 6gFe/g

Duck Feather clusters contaminated with Bua Ban (BB) were treated 8 times with a Methyl soyate MP containing either 5 or 6 grams of iron powder per gram of methyl soyate, to magnetically remove B380. The percentage removal of the BB and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.18** shows the relative % Removal, P%, of the BB contaminant from duck feather clusters by both MS 5gFe/g and MS 6gFe/g and the deionised water/iron powder paste as a control.

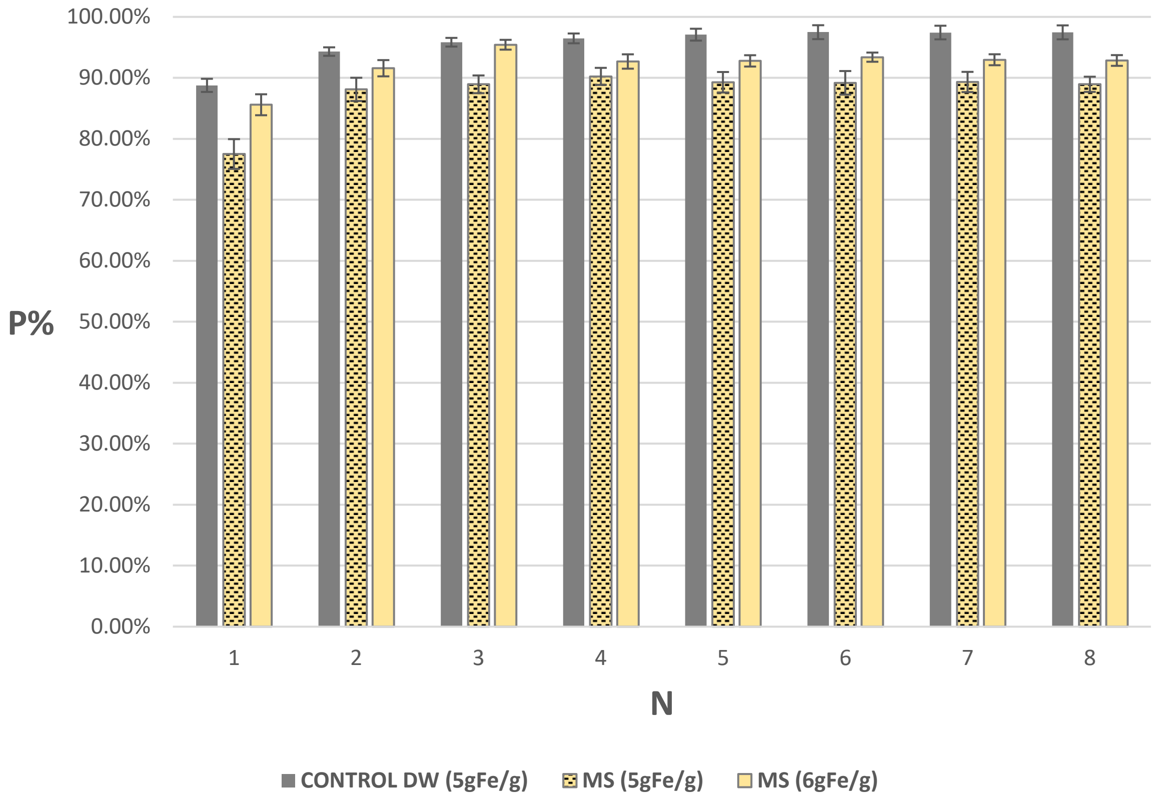


Figure 3.18 The % Removal, P%, of the Bua Ban (BB) crude oil from duck feather clusters using two proportions of iron powder in a Methyl Soyate/iron powder magnetic paste, as a function of the Number of Treatments, N. The two proportions are, 5g of iron powder per gram of Methyl Soyate (5gFe/g) and 6 grams of iron powder per gram of Methyl Soyate (6gFe/g). The control is iron powder/water paste (DW 5gFe/g).

The DW control removes more BB than MS 5gFe/g and MS 6gFe/g at N=1 to 8, except at N=3 when the removal of BB by the DW control is comparable to MS 6gFe/g. Although the proportion of iron powder in the DW control and the MS 5gFe/g is the same., the DW control, removes significantly more BB. This shows that methyl soyate has an inhibitory effect on BB removal. When the proportion of iron powder is increased to 6gFe/g, the % removal of BB increases but not enough to remove more of the BB than the DW control.

The MS (5gFe/g) MP does not reach 95% removal of BB whereas MS (6gFe/g) does. The E_{90} values show that a higher proportion of iron powder also significantly improves the removal efficacy of BB although it is still not enough to be more efficient than the DW control (5gFe/g). To remove 90% of the BB, the N_{90} values show that MS (5gFe/g) requires roughly twice as many treatments (N_{90}=3.84) as the MS (6gFe/g) (N_{90}=1.75). At E_{80}, the difference between the DW control and the MS (5gFe/g) is not as great, but both are clearly more efficient than the

MS (5gFe/g). Note that the E_{80} is significant as this will be the value used to compare all the MP with different iron proportions as not all could reach an overall removal of 90% BB.

Table 3.11 Relative removal efficacy parameters for **5g** and **6g** of iron powder in a Methyl Soyate/iron powder magnetic paste, calculated at x = 80, 90 and 95%.

Magnetic pastes with varying proportions of Fe	**P_0%**	**N_{80}**	**E_{80}**	**N_{90}**	**E_{90}**	**N_{95}**	**E_{95}**
CONTROL Fe	99.18	0.83	119.51	0.93	106.65	0.98	101.20
CONTROL DW (5gFe/g)	97.49	0.90	108.32	1.22	79.91	2.45	39.79
MS (5gFe/g)	90.24	1.23	73.37	3.84	23.50	N/A	N/A
MS (6gFe/g)	95.43	0.93	102.61	1.75	54.53	2.9	32.91

3.3.2 Esterol/Iron Powder MPs: 5gFe/g and 6gFe/g

Duck Feather clusters contaminated with Bua Ban (BB) were treated 8 times with a Esterol/iron powder MP containing either 5 or 6 grams of iron powder per gram of Esterol, to magnetically remove B380. The percentage removal of the BB and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.19** shows the relative % Removal, P%, of the BB contaminant from duck feather clusters by both EST 5gFe/g and EST 6gFe/g and the deionised water/iron powder paste as a control.

Increasing the proportion of iron powder in an iron powder/sterol MP does improve BB removal. At N=1 and 2, removal of BB by EST (6gFe/g) and the DW control is comparable. From N=3 to 8, the DW control removes more BB than EST (6gFe/g). Although the proportion of iron powder in the DW control and the EST 5gFe/g is the same., the DW control, removes significantly more BB. This shows that Esterol has an inhibitory effect on BB removal. When the proportion of iron powder is increased to 6gFe/g, the % removal of BB increases but not enough to remove more of the BB than the DW control.

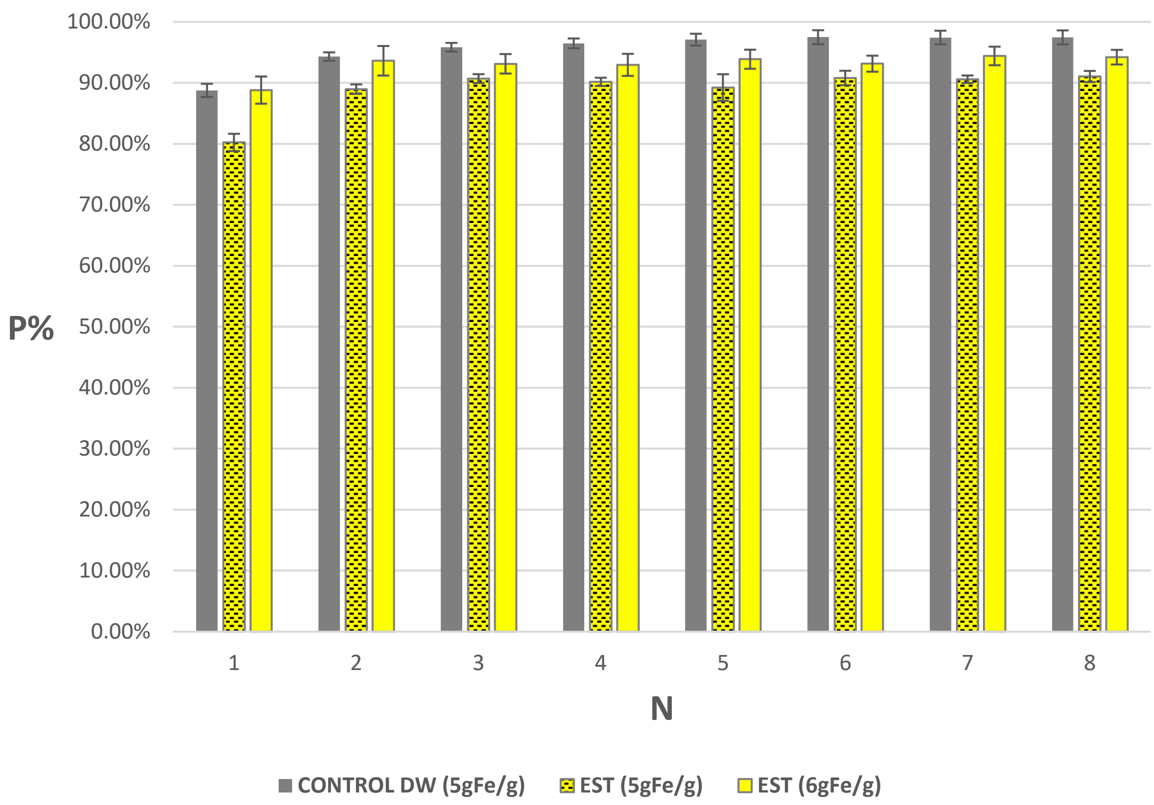


Figure 3.19 The % Removal, P%, of the Bua Ban (BB) crude oil from duck feather clusters using two proportions of iron powder in a Esterol/iron powder magnetic paste, as a function of the Number of Treatments, N. The two proportions are, 5g of iron powder per gram of Esterol (5gFe/g) and 6 grams of iron powder per gram of Esterol (6gFe/g). The control is iron powder/water paste.

The data in **Table 3.12** shows that EST (5gFe/g) and EST (6gFe/g) both remove at least 90% of BB from feather clusters. However, EST (5gFe/g) is less efficient and requires twice as many treatments to remove 90%. Both EST (6gFe/g) and the DW control remove 80% of BB after 0.9 treatments but the DW control has a higher E_{80} rating. This is due to the higher P_0% value of the DW control. Although EST (6gFe/g) has a similar N_{90} and E_{90} value to the DW control, it is still not an efficient MP to remove BB by comparison.

Table 3.12 Relative removal efficacy parameters for **5g** and **6g** of iron powder in an Esterol/iron powder magnetic paste, calculated at x = 80, 90 and 95%.

Magnetic pastes with varying proportions of Fe	P_0%	N_{80}	E_{80}	N_{90}	E_{90}	N_{95}	E_{95}
CONTROL Fe	99.18	0.83	119.51	0.93	106.65	0.98	101.20
CONTROL DW (5gFe/g)	97.49	0.90	108.32	1.22	79.91	2.45	39.79
EST (5gFe/g)	91.04	1.00	91.04	2.60	35.02	N/A	N/A
EST (6gFe/g)	94.41	0.90	104.90	1.26	74.93	N/A	N/A

3.3.3 Mineral Oil/Iron Powder MPs: 5gFe/g and 6gFe/g

Duck Feather clusters contaminated with Bua Ban (BB) were treated 8 times with a Mineral Oil/iron powder MP containing either 5 or 6 grams of iron powder per gram of Mineral Oil, to magnetically remove B380. The percentage removal of the BB and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.20** shows the relative % Removal, P%, of the BB contaminant from duck feather clusters by both MO 5gFe/g and MO 6gFe/g and the deionised water/iron powder paste as a control.

Neither MO (5gFe/g) or MO (6gFe/g) remove as much BB as the DW control from N= 1 to 8. Increasing the proportion of iron powder does improve the removal of BB from N=1 to 5. From N=6 to 8, the difference is not significant. Mineral oil appears to have an inhibitory effect on BB removal. Increasing the proportion of iron powder does improve the removal of BB by an MO paste but the increase does not compensate for the inhibitory effect mineral oil appears to have on BB.

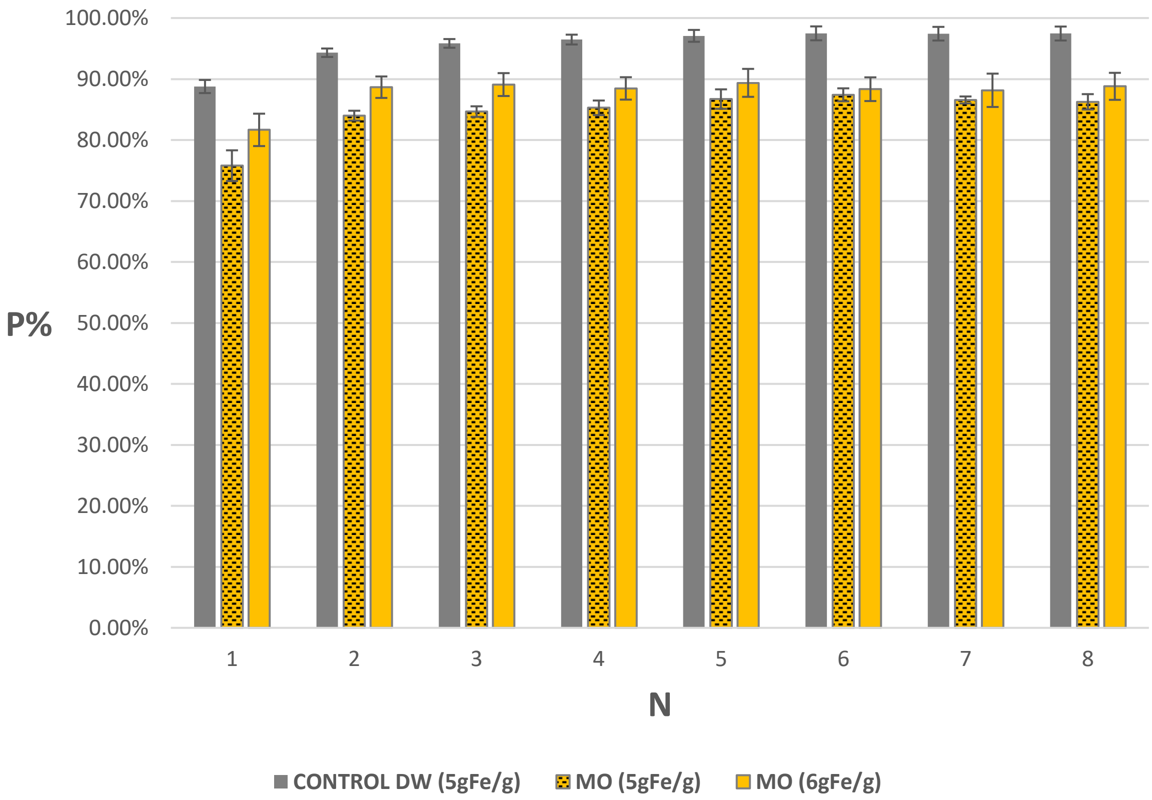


Figure 3.20 The % Removal, P%, of the Bua Ban (BB) crude oil from duck feather clusters using two proportions of iron powder in a Mineral Oil/iron powder magnetic paste, as a function of the Number of Treatments, N. The two proportions are, 5g of iron powder per gram of Mineral Oil (5gFe/g) and 6 grams of iron powder per gram of Mineral Oil (6gFe/g). The control is iron powder/water paste.

The data in **Table 3.13** shows that neither MO (5gFe/g) or MO (5Gfe/g) reaches 90% removal of BB. At N80, MO (6gFe/g) and the DW control have similar N80 values which mean they both require similar number of treatments to achieve 80% removal of BB. However, the efficacy values (E80) in **Figure 3.23** show that the DW control is a significantly more efficient MP than MO (6gFe/g).

Table 3.13 Relative removal efficacy parameters for **5g** and **6g** of iron powder in a Mineral Oil/iron powder magnetic paste, calculated at x = 80, 90 and 95%.

Magnetic pastes with varying proportions of Fe	P_0%	N_{80}	E_{80}	N_{90}	E_{90}	N_{95}	E_{95}
CONTROL Fe	99.18	0.83	119.51	0.93	106.65	0.98	101.20
CONTROL DW (5gFe/g)	97.49	0.90	108.32	1.22	79.91	2.45	39.79
MO (5gFe/g)	87.41	1.51	57.89	N/A	N/A	N/A	N/A
MO (6gFe/g)	89.37	0.98	91.19	N/A	N/A	N/A	N/A

3.3.4 BD1/Iron Powder MPs: 5gFe/g and 6gFe/g

Duck Feather clusters contaminated with Bua Ban (BB) were treated 8 times with a BD1/iron powder MP containing either 5 or 6 grams of iron powder per gram of BD1, to magnetically remove B380. The percentage removal of the BB and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.21** shows the relative % Removal, P%, of the BB contaminant from duck feather clusters by both BD1 5gFe/g and BD1 6gFe/g and the deionised water/iron powder paste as a control.

Neither the BD1 (5gFe/g) or the BD1 (6gFe/g) remove more BB than the DW control. However, the increasing the proportion of iron powder does improve BB removal. BD1 (5gFe/g) appears more unstable as feathers become noticeably heavier at N=3 and 6. This shows that when the proportion of iron powder is too low, there are not enough iron particles to magnetically remove both the contaminant and the BD1. BD1 then becomes a secondary contaminant. The proportion of iron powder in the BD1 (6gFe/g) MP appears to have adequate iron particles to remove both the BB and the BD1.

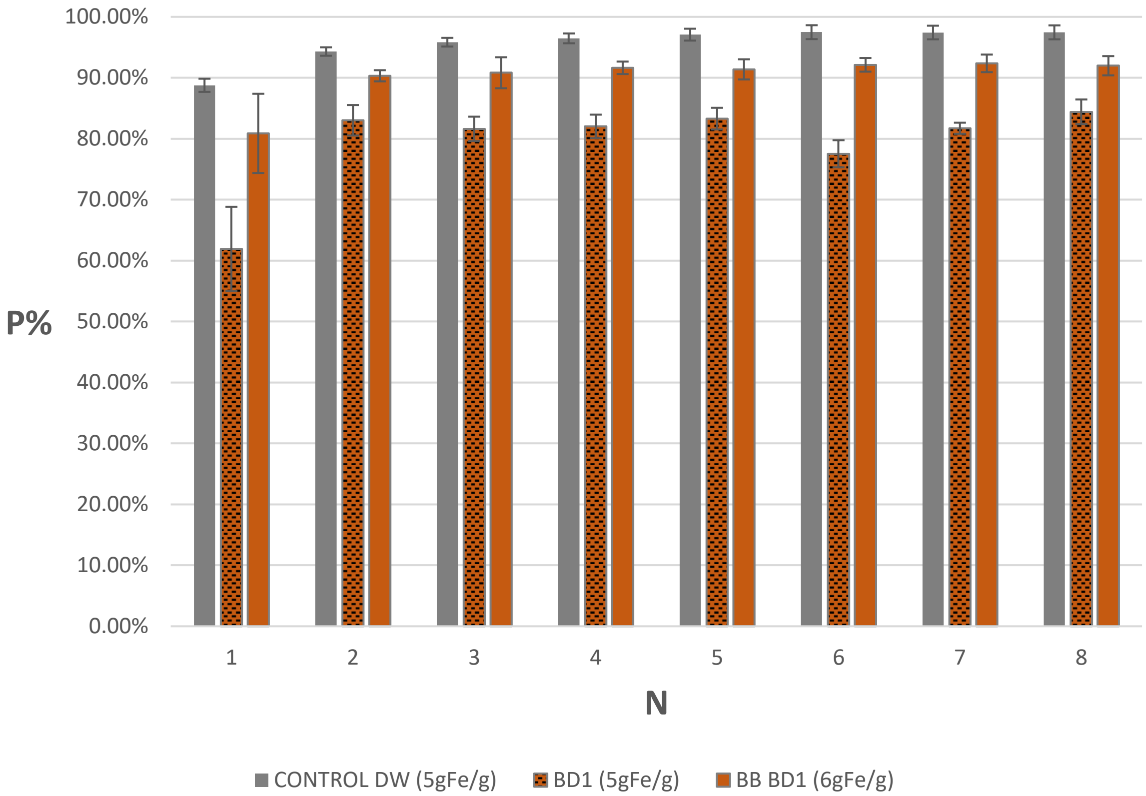


Figure 3.21 The % Removal, P%, of the Bua Ban (BB) crude oil from duck feather clusters using two proportions of iron powder in a BD1/iron powder magnetic paste, as a function of the Number of Treatments, N. The two proportions are, 5g of iron powder per gram of BD1 (5gFe/g) and 6 grams of iron powder per gram of BD1 (6gFe/g). The control is iron powder/water paste.

Table 3.14 Relative removal efficacy parameters for **5g** and **6g** of iron powder in a BD1/iron powder magnetic paste, calculated at x = 80, 90 and 95%.

Magnetic pastes with varying proportions of Fe	P_0%	N_{80}	E_{80}	N_{90}	E_{90}	N_{95}	E_{95}
CONTROL Fe	99.19	0.83	119.51	0.93	106.65	0.98	101.20
CONTROL DW (5gFe/g)	97.49	0.90	108.32	1.22	79.91	2.45	39.79
BD1 (5gFe/g)	84.42	1.85	45.63	N/A	N/A	N/A	N/A
BD1 (6gFe/g)	92.37	0.99	93.30	1.97	46.89	N/A	N/A

The differences between the BD1 (5gFe/g) and BD1 (6gFe/g) are quiet extreme. BD1 (5gFe/g) does not even reach 85% removal of BB whereas BD1 (6gFe/g) removes more than 90%. The DW control is clearly more efficient than either BD1 pastes as it reaches above 95% removal of BB and removes 80% and 90% of BB with fewer treatments. The differences between the efficacies are clearly shown in **Figure 3.22.**

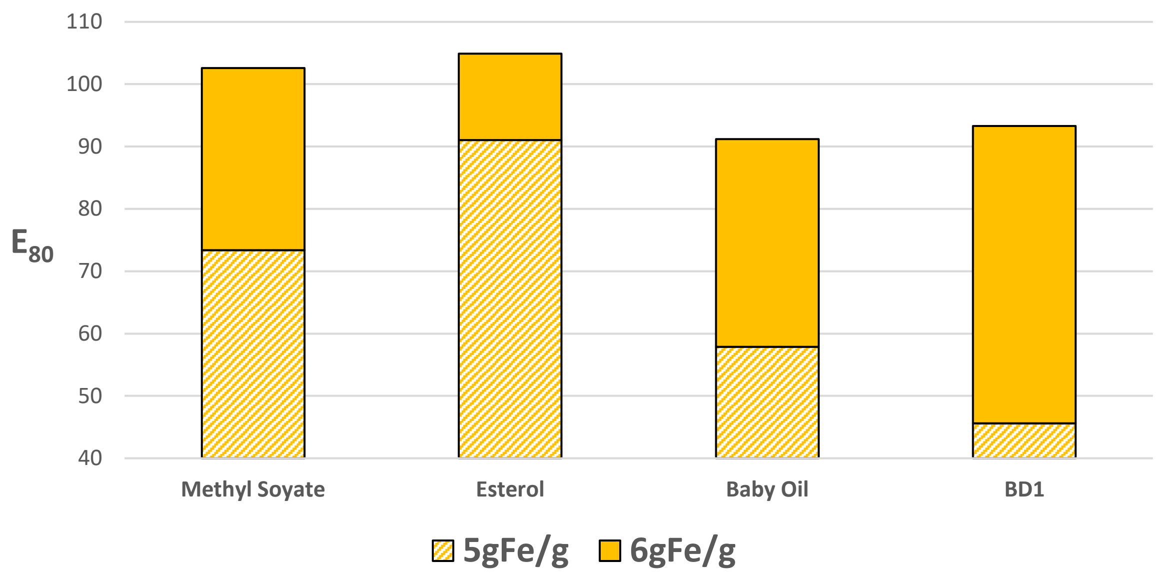


Figure 3.22 The removal efficacy (E_{80}) of BB by the 5gFe/g magnetic pastes are displayed as histograms. The efficiency of 5gFe/g magnetic paste are listed as follows in descending order EST 5gFe/g, MS 5gFe/g, MO 5gFe/g, BD1 5gFe/g. The efficiency of 6gFe/g magnetic paste are listed as follows in descending order EST 6gFe/g, MS 6gFe/g, BD1 6gFe/g, MO 6gFe/g.

Increasing the proportion of iron powder in a MP improves the efficacy of contaminant removal. However, the improvement is not identical for each type of MP with certain MPs showing a heightened improvement in the efficacy of contaminant removal and others showing comparatively minor improvements. BD1 MPs shows the most extreme improvement in removal efficacy of the BB contaminant followed by Mineral Oil, Methyl Soyate and finally Esterol which has a significantly lower improvement in removal efficacy.

Despite the huge improvement in efficacy removal of BB by BD1 when the proportion of iron powder is increased from 5g to 6g per gram of BD1, BD1 6gFe/g does not become the most efficient MP to remove BB. The most efficient 6gFe/g MP is EST (6gFe/g) followed by MS (6gFe/g), BD1 (6gFe/g) with the least efficient MP being MO (6gFe/g). The removal efficacy improvements between the MP types appears to be associated with the efficacy of the 5gFe/g MPs.

3.4 Temperature: The Effects of Heating a MP

Temperature influences the physical properties of liquids, specifically oils. Increasing the temperature of an oil decreases its viscosity. Lower viscosity oils are easier to remove from a substrate. High viscosity is a key characteristic of hard and tarry ("recalcitrant") oil contaminants.

While conducting the contaminant removal experiments, the ambient temperature within the laboratory was 21 ± 1 °C. The pastes themselves were of similar temperature. However, the temperature of the pastes that included acetic acid did show an initial rise in temperature by up to 3 °C which relaxed back to room temperature after approximately 20 minutes[5].

Penguins often inhabit cool climates especially the 5 species living in Antarctica and the 4 species living on sub-Antarctic islands. The remaining penguin species live along cool currents in warmer sub-tropical climates. Little penguins on Phillip Island are exposed to terrestrial temperatures ranging from 23.8 to 14.0℃ in summer and 13.5 to 6.8℃ in winter (Bureau of Meteorology, 2024). The physical properties of the contaminant oil and the MP will therefore vary between the laboratory and in the field, and the removal (P%) of a contaminant will vary accordingly. In this regard, the properties of the MP are expected to vary with temperature.

An experiment was conducted whereby Mineral Oil (MO 6gFe/g), Olive Oil (OO 5gFe/g) and Mayonnaise (MAYO 4gFe/g) were heated to 35°C. The temperature of 35°C was chosen as it is significantly warmer than the ambient temperature used in the lab (~21℃) and is a safe temperature for Little Penguins. Penguins experience distress when exposed to high temperatures and, when a penguin is contaminated by oil, its ability to thermoregulate is compromised (Goldsworthy, Giese, Gales, Brothers, & Hamill, 2000). Due to COVID-19 lockdowns, additional temperature experiments were unable to be completed. This not only included heating other categories of MPs but also conducting incremental temperature experiments to build a temperature scale for each MP for example the P% removal of contaminant at 21, 25, 30, 35, and 40℃.

For heating, the MPs were placed in a glass beaker and on top of a heating plate. The paste was then stirred continuously until its temperature reached 35°C. If the temperature went above 35°C, the paste was removed from the hot plate to cool down and monitored regularly until its

[5] It is suggested that this temperature rise is due to an exotermic reaction between the acetic acid and the zero valent iron particles, which also undergo a change in colour to a brown orange.

temperature dropped to 35°C. It was noted that the MPs took more time to heat up than they did to cool down. This method of maintaining the desired temperature required constant monitoring (reheating and cooling) as the paste could not hold the exact temperature for long enough periods of time to complete the 8 treatments involved in the experiment). The same methods described in **Chapter 3.2** were used to assess the effect heating a MP has on removing a contaminant. The contaminant used in this experiment was Bunker 380 (B380). The comparisons do not include the iron powder alone or the DW control.

3.4.1 Heated Mineral Oil, MO 6gFe/g

Duck Feather clusters contaminated with Bunker (B380) were treated 8 times with a Mineral Oil (MO 6gFe/g) MP that was either heated or unheated, to magnetically remove B380. The percentage removal of the B380 and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.23** shows the relative % Removal, P%, of the B380 contaminant from duck feather clusters by a heated (35°C MO 6gFe/g) and unheated (~21°C MO 6gFe/g) Mineral Oil/iron powder magnetic paste.

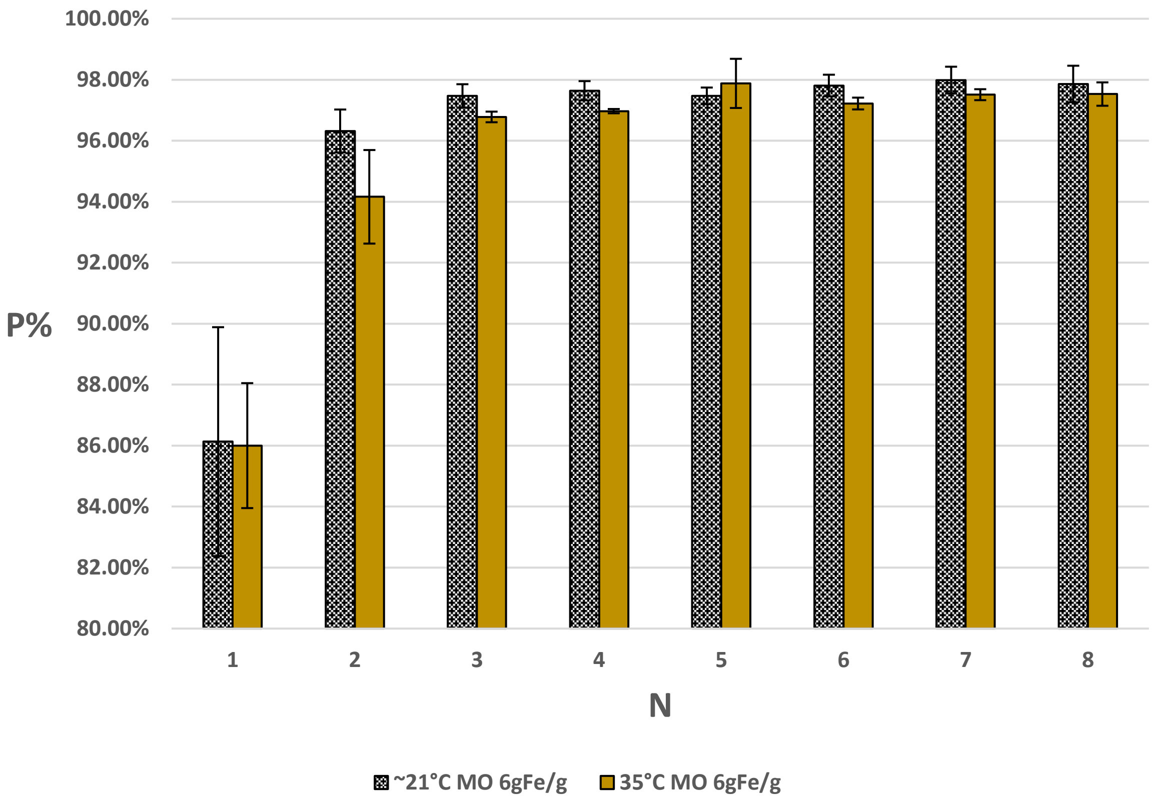


Figure 3.23 The % Removal, P%, of the Bunker 380 (B380) crude oil from duck feather clusters by a Mineral oil/iron powder magnetic paste (MO 6gFe/g) at two different temperatures, unheated (21°C ± 1) and heated (35°C), as a function of the Number of Treatments, N.

At N= 1 there is no difference in B380 removal between the heated and unheated paste. From N= 2 to 4 and 6 to 8 the unheated paste removes more B380 than the heated paste. At N= 5 the heated paste removes more B380 than the unheated paste and this is at the point that the heated paste reaches its maximum removal of B380. Additional treatments, from N= 6 to 8, cause B380 contaminated feather clusters treated with a heated paste to gain weight suggesting that the heated paste becomes a contaminant at this point. The unheated paste reaches its maximum removal of B380 at N= 7 and this removal is more than what the heated paste removed at N= 5. Heating a mineral oil MP impedes the initial removal for B380 most notably between N= 2 and 4. It improves the removal after 5 treatments however subsequent treatments are a detriment to treated feathers as the heated paste becomes a contaminant itself. Meanwhile the unheated mineral oil MP improves initial removal of the paste but has a delayed impact by removing the highest possible B380 with two extra treatments.

The reason why the heated paste becomes a contaminant could be because the heated mineral oil does not adhere to the iron particles and when the iron particles are magnetically removed, the mineral oil remains on the feather clusters.

Table 3.15 Relative removal efficacy parameters for **heated** and **unheated** mineral oil/iron powder magnetic paste, calculated at x = 90 and 95%.

Temperature of Magnetic Pastes	P_0%	N_{90}	E_{90}	N_{95}	E_{95}
~21°C MO (6gFe/g)	97.99	1.38	71.01	1.97	49.74
35°C MO (6gFe/g)	97.88	1.50	65.25	2.33	42.01

The unheated MO MP is more efficient at 90 and 95% removal of B380 than the heated MO MP. The overall removal of B380, P_0% is comparable between the two pastes although the unheated paste removes slightly more.

In summary, heating the MO paste diminishes its ability to remove B380 and this MP is not recommended to be heated to remove crude oil. This paste may be better suited to remove crude oil in cooler temperatures without the need to increase temperatures to improve the mobility of the crude oil. This is not necessarily an undesirable quality of MO, and it may mean using MO MP in cool climates is advantageous over other MP categories.

3.4.2 Heated Extra Virgin Olive Oil, OO 5gFe/g

Duck Feather clusters contaminated with Bunker (B380) were treated 8 times with an Extra Virgin Olive Oil (OO 6gFe/g) MP that was either heated or un-heated, to magnetically remove B380. The percentage removal of the B380 and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.24** shows the relative % Removal, P%, of the B380 contaminant from duck feather clusters by a heated (35°C OO 6gFe/g) and unheated (~21°C OO 6gFe/g) Extra Virgin Olive Oil/iron powder magnetic paste.

At N=1, the unheated Extra Virgin Olive Oil MP removes more B380. The heated paste is more unstable at N=1 and this is evident in the length of the error bars. The instability may be related to a difficulty maintaining a constant temperature of the paste or a disruption between the interaction between the iron particles and the paste additive.

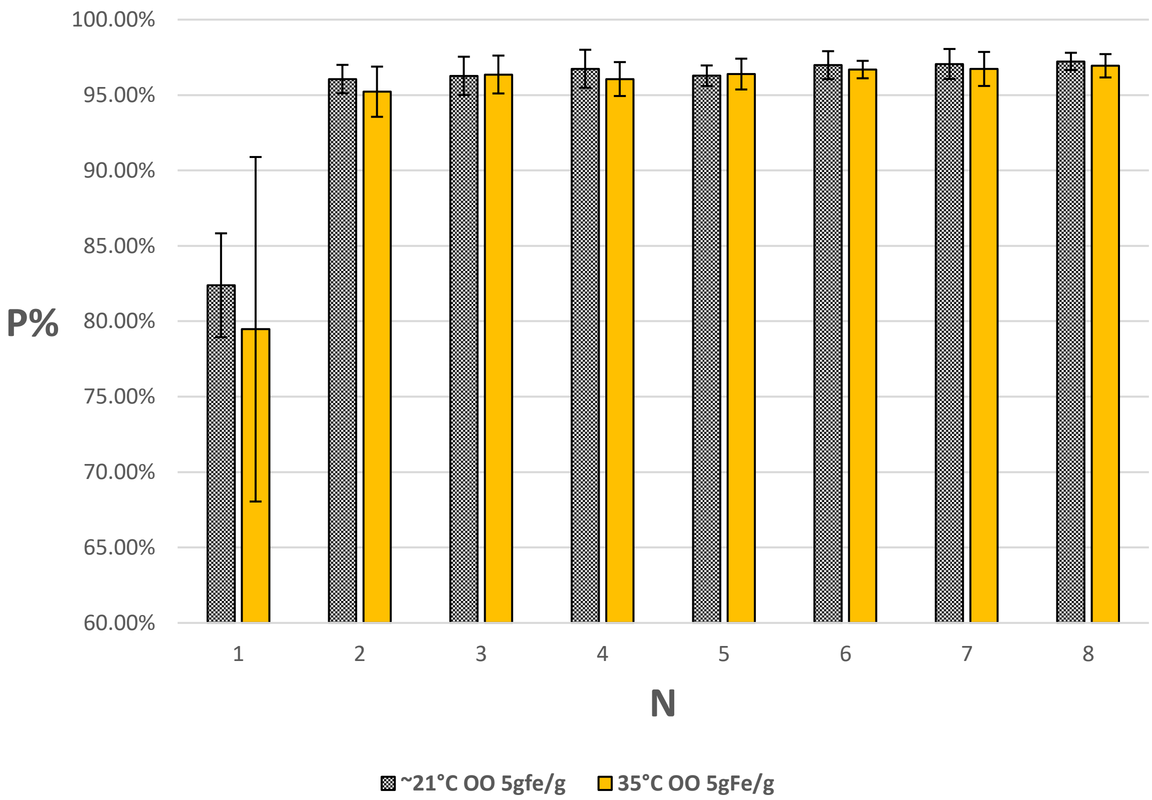


Figure 3.24 The % Removal, P%, of the Bunker 380 (B380) crude oil from duck feather clusters by an extra virgin olive oil/iron powder magnetic paste (OO 5gFe/g) at two different temperatures, unheated (21°C ± 1) and heated (35°C), as a function of the Number of Treatments, N.

The unheated OO (5gFe/g) MP removes more B380 than the heated OO (5gFe/g) MP except at N=3 and 5. The effect paste temperature has on B380 removal is quite subtle, but the differences are shown more clearly in **Table 3.13.**

Table 3.16 Relative removal efficacy parameters for **heated** and **unheated** extra virgin olive oil/iron powder magnetic paste, calculated at x = 90 and 95%.

Magnetic Pastes with an olive oil component	**P_0%**	**N_{90}**	**E_{90}**	**N_{95}**	**E_{95}**
~21°C OO (5gFe/g)	97.23	1.56	62.33	1.92	50.64
35°C OO (5gFe/g)	96.73	1.67	57.92	1.99	48.61

Unheated OO (5gFe/g) has a higher overall removal of BB and greater efficacy values at 90% and 95%. However, the difference between efficacy values at E_{95} are not as large. Thus, the efficacy of OO (5gFe/g) is more sensitive to temperature at initial removal.

3.4.3 Heated Mayonnaise, MAYO 4gFe/g

Duck Feather clusters contaminated with Bunker (B380) were treated 8 times with a Mayonnaise (MAYO 6gFe/g) MP that was either heated or un-heated, to magnetically remove B380. The percentage removal of the B380 and SE were calculated using the same method previously described in **Chapter 3.2.1**. **Figure 3.25** shows the relative % Removal, P%, of the B380 contaminant from duck feather clusters by a heated (35°C MAYO 6gFe/g) and unheated (~21°C MAYO 6gFe/g) Mayonnaise/iron powder magnetic paste.

Heated MAYO 4gFe/g MP greatly improves removal of B380 at N= 1 and 2. Removal of B380 is only slightly higher at N= 3 and 4. From N=5 to 8, the unheated MAYO 4gFe/g MP removes slightly more B380. The increase in MP temperature appears to only be beneficial in initial treatments and detrimental in later treatments. This could be due to degradation of the paste overtime as oxidation the iron particles by the components of mayonnaise is accelerated by the application of heat. The consistency and colour of the mayonnaise paste changed during the application of the 8 treatments. The paste changed from a light, grey-coloured smooth-textured paste to a brown-coloured rough-textured paste.

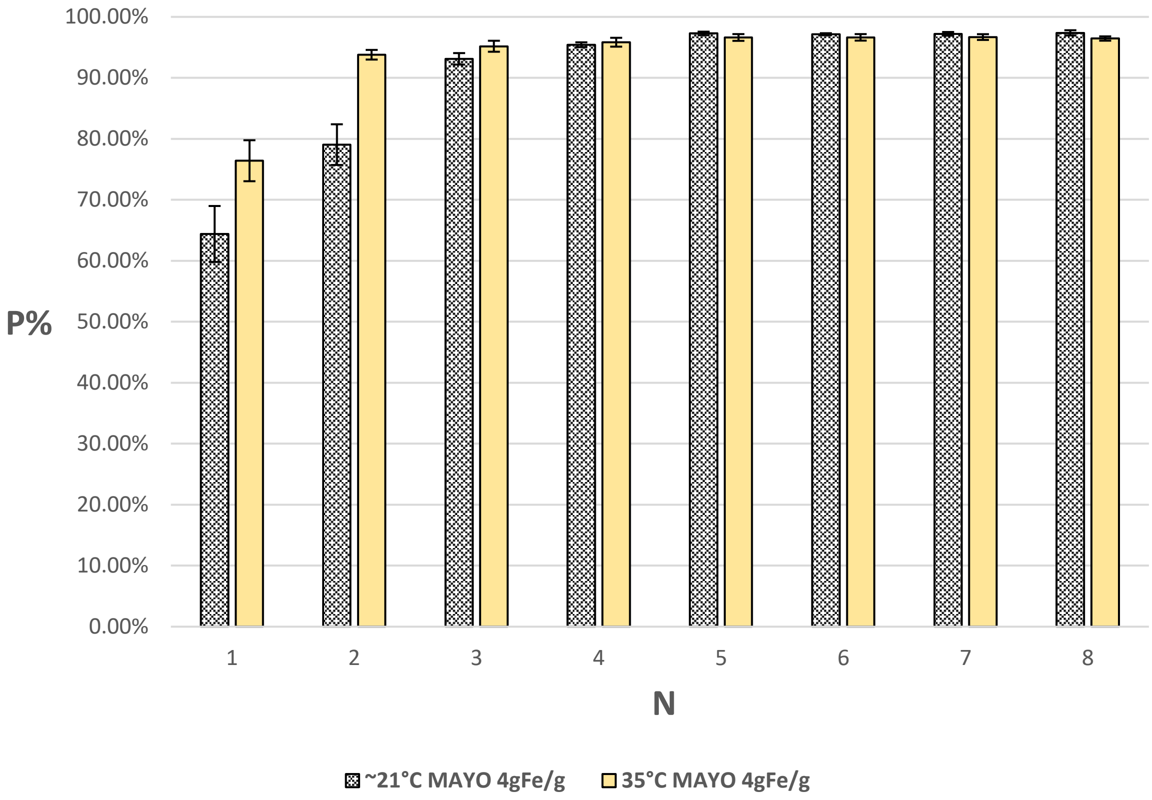


Figure 3.25 The % Removal, P%, of the Bunker 380 (B380) crude oil from duck feather clusters by a mayonnaise/iron powder magnetic paste (MAYO 4gFe/g) at two different temperatures, unheated (21°C ± 1) and heated (35°C), as a function of the Number of Treatments, N.

Table 3.17 Relative removal efficacy parameters for **heated** and **unheated** mayonnaise/iron powder magnetic paste, calculated at x = 90 and 95%.

Magnetic Pastes with an olive oil component	P_0%	N_{90}	E_{90}	N_{95}	E_{95}
~21°C MAYO (4gFe/g)	97.38	2.78	35.03	3.83	25.43
35°C MAYO (4gFe/g)	96.69	1.78	54.32	2.87	33.69

The MP with a mayonnaise component had a higher P_0% when unheated. However, the efficacy of the MP significantly improved at 90 and 95% B380 removal when heated.

Increasing the temperature of an MP reduced the total removal of all 3 MPs tested and reduced the efficacy of 2 of the 3 MPs. The effect of the change in MP temperature is not consistent across the different types of MPs. The efficacy of B380 removal by MO 6gFe/g and OO 5gFe/g decreases when the pastes are heated from room temperature to 35°C. This effect is greatest for MO 6gFe/g than for OO 5gFe/g. The increased temperature of MAYO 4gFe/g improved the initial removal but reduced the overall maximum B380 removal. However, the removal efficacy of MAYO 4gFe/g improved when it was heated from room temperature to 35°C.

Heating a MP may have more of an effect on the viscosity of the paste additive rather than the contaminant. Lowering the viscosity of the paste additive may reduce the adherence of the iron particles to the paste additive. This may be more pronounced in paste additives that are less viscous by nature such as mineral oil. Mayonnaise has a significantly higher viscosity than either MO or OO, and when heated, improved B380 removal efficacy. Heated Mayonnaise MP only removes significantly more B380 after initial treatments most likely due to the degradation of the paste through oxidation of the iron particles as previously noted in **Chapter 3.4.3**.

The paste temperature affects each MP differently and this is shown by the change in E_{95} values in **Figure 3.26** for MO, **Figure 3.27** for OO and **Figure 3.28** for MAYO.

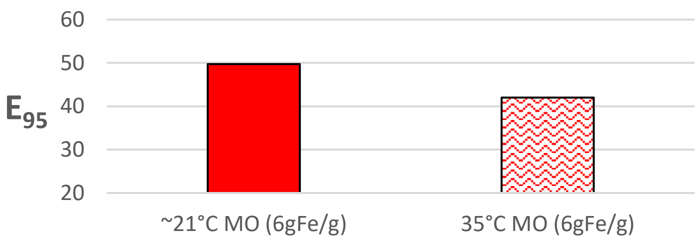


Figure 3.26 E_{95} values of the heated and unheated mineral oil/iron powder MPs

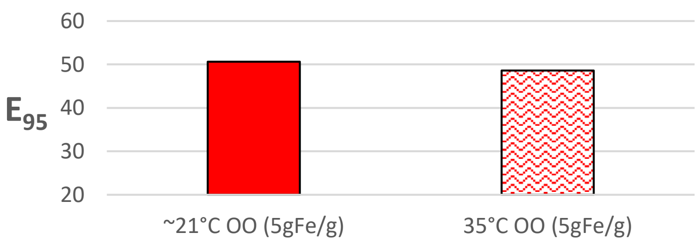


Figure 3.27 E_{95} values of the heated and unheated extra virgin olive oil /iron powder MPs

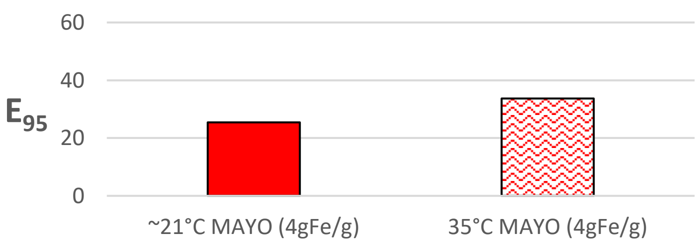


Figure 3.28 E_{95} values of the heated and unheated mayonnaise/iron powder MPs.

Chapter 4: Conclusions and suggestions for future work

4.1 Iron powder and DW as controls

Iron powder by itself is the standard MPT material and is not a paste. However, as iron powder is the active ingredient in removing a contaminant, using it in a paste can initially limit the amount of iron particles that can infiltrate the contaminant. Therefore, it is not surprising that iron powder alone is generally more effective than a MP with respect to the initial removal (N = 1 to 3). However, as the removal proceeds, the paste additives begin to exert their softening/adhesive effect on a recalcitrant contaminant allowing both components to work together. Iron powder/deionised water as a paste (DW) was considered to be the most appropriate control for referencing how a given MP affects the removal of a contaminant from a feather substrate.

4.2 Removal of Heavy Versus Medium Contaminants

Notably, both iron powder and the DW controls work more efficiently on the medium crude oil (BB) than on the heavy crude oil (B380). This is consistent with previous studies that show lighter (less viscous/more volatile) components to be more effectively removed by MPT. Therefore, it might be tacitly assumed that this is invariably true for the pastes themselves. However, although this is true for most of the pastes studied, there are some that actually have a greater efficacy for removing the heavier B380 over the lighter BB. These pastes are identified as follows:

- Fairy 5% v/v (5gFe/g). Category ii: Pastes with a commercial cleansing product
- Nivea (5gFe/g). Category ii: Pastes with a commercial cleansing product
- Mineral Oil (6gFe/g). Category iv: Pastes with a "conventional" PTA
- Methyl Soyate (6gFe/g). Category iv: Pastes with a "conventional" PTA
- Olive Oil (5gFe/g). Category v: Pastes with a "vegetable" oil component

These pastes are spread across several different categories. It is suggested that this is an adhesion/affinity effect, whereby these additives interact in a more intimate way with the components of the B380. This warrants further investigation.

4.3 Comments on the Different Paste Categories

4.3.1 Category i: Pastes with an Acetic Acid Component

AA ~4% v/v (5gFe/g) is the most efficient MP in this category for the removal of both BB and B380. Increasing the acetic acid concentration in a paste impedes contaminant removal, rather than improving it. Thus, it was found that the ideal concentration of acetic acid in a MP, for the removal of either oil, is ~4% (as in store-bought white vinegar). Indeed, the AA ~4% v/v (5gFe/g) MP is the only MP that is more effective than the DW control for the removal of both contaminants. This is consistent with previous studies that demonstrated the effectiveness of vinegar as a PTA for the removal of oil contamination from plumage (Diep, 2017).

4.3.2 Category ii: Pastes with a commercial cleansing product

The most efficient MP from this category for the removal of BB is Perfect Gel® (4gFe/g), but the most efficient for B380 is Fairy® 5% v/v (5gFe/g). This demonstrates that MPs can be contaminant specific. Notably, MPs from this category are very different in their chemical and physical components and this provides the opportunity of examining the effects of component diversity in MPs. Perfect Gel®, for example, has a long list of ingredients, whereas Nivea® eye makeup remover and diluted Fairy® dishwashing liquid (5% v/v) are aqueous solutions with fewer ingredients. However, they all contain a proportion of surfactants.

4.3.3 Category iii: Pastes with a Eucalyptus Oil Component

Eucalyptus oil MP removes contaminants more efficiently when the concentration of eucalyptus oil content increases, i.e., 25%. Eucalyptus oil is a natural solvent but is typically used to remove grease with a 100% concentration. The higher the concentration of eucalyptus oil, the more effective it is but increasing the daily dosage of eucalyptus oil also increases the risk of toxicity which in humans a recommended daily dose of eucalyptol is (1,8-cineole) is 0.1mg/kg (De Vincenzi, Silano, De Vincenzi, Maialetti & Scazzocchio, 2002). The main component of eucalyptus oil is 1,8-cineole (60-85%) which is a cyclic ether and monoterpenoid (NCBI 2021). These pastes are found to work more efficiently on the lighter BB, than the heavier B380. The eucalyptus oil MPs are in fact water emulsion. The efficacy and stability of eucalyptus oil MPs may improve if mixed with an oil rather than water.

4.3.4 Category iv: Pastes with a Conventional “PTA” Component

The efficacy of MPs in this category clearly differs between the two contaminants. For example, 70%ETOH is the most efficient MP within this category for the removal of BB, whereas Mineral Oil is the most efficient for the removal of B380. Thus, the 70% ETOH MP has a similar efficacy profile to the DW control as it is significantly more efficient at removing the lighter BB than the heavier B380. The Methyl Soyate and Esterol MPs work almost as efficiently on either contaminant, with Methyl Soyate being slightly more efficient for B380 removal and Esterol being slightly more efficient for BB removal. MO or other agents with similar chemical and physical properties are ideal candidates to use as additives in a MP to remove hard tarry crude oil from feather substrates. These results clearly demonstrate that MPs may be tailored to remove more recalcitrant heavy oils.

4.3.5 Category v: Pastes with a Vegetable Oil Component

Two different “vegetable” oils, namely Extra Virgin Olive Oil (OO) and Extra Virgin Coconut Oil (CO) have been compared within this category. The OO was found to be the most efficient vegetable oil for the removal of both contaminants BB and B380. However, OO works more efficiently on the heavier crude oil, B380, than the medium crude oil BB. Notably, OO is often used as a PTA in the field.

Vegetable Oils that share similar chemical and physical properties are ideal candidates to use as additives in a MP to remove hard tarry crude oil from feather substrates. Thus, OO and CO were chosen since they are expected to share similar, although not identical, chemical compositions. The fact that they perform differently in MPs, especially with respect to the heavy oil suggests that the identification of specific differences in chemical composition could provide clues to the development of MPs that are more specific for heavier oils. In this regard, the comparative fatty acid contents could be informative, **Table 4.1.**

Extra Virgin Olive Oil and Extra Virgin Coconut vary in their fatty acid composition. For example, both oils contain oleic acid and palmitic acid, but these are far more prevalent in OO than in CO (70.56% to 1.48% and 15.51% to 6.69% respectively). Furthermore, CO contains many fatty acids not found in extra virgin olive oil and these fatty acids represent the highest concentrations in CO (Caprilic 12.98%; Lauric acid 47.28%; Mystritic 15.80%). Thus, OO has a preponderance of longer chain fatty acids. This suggests that the presence of longer chain fatty acids in a paste ingredient favours the removal of heavier contaminants. Experiments of this kind show how further information on the optimization of MPs may be gleaned.

Table 4.1 Comparative list of fatty acid components of OO and CO. Major differences in composition are shown in bold type. Note that OO has a preponderance of longer chain fatty acids. Adapted from Ghanbari Shendi et al. (2019) and Liau et al. (2011).

Fatty acids	**C chain length**	**OO (%)**	**CO (%)**
Caproic	C6	None	2.22
Caprylic	C8	None	12.98
Capric	C10	None	6.81
Undecanoic	C11	None	0.03
Lauric	C12	None	47.28
Tridecanoic	C13	None	0.30
Myristic	C14	0.01	15.80
Pentadecanoic	C15	None	0.01
Palmitic	C16	15.51	6.69
Palmitoleic	C16: 1n7	1.05	None
Heptadecanoic	C16:1	0.02	0.01
Cis-10-heptadecenoic	C16	0.03	None
Stearic	C17	2.60	0.01
Oleic	C18	70.56	1.48
Elaidic	C18: 1n9c	0	5.07
Linoleic	C18: ln9t	9.12	0.23
Linolelaidic	C18: 2n6c	None	1.17
Linolenic	C18: 2n6t	0.50	0.05
Arachidic	C18: 3n3a	0.36	0.01
Cis-11-elcosenoic	C20	0.10	0.04
Behenic	C20: 1n9	0.11	0.04
Cis-13,16-Docisadienoic	C22	None	0.01
Lignoceric	C24	0.03	0.02

4.3.6 The Most Efficient MP from each Category

The most efficient MP from each category for the removal of BB and B380, using the E_{90} measure of efficacy, are shown in **Table 4.2**. It should be noted that, for three of the categories;

namely (i), (iii) and (v); these pastes are the same for both oils. For the other two categories; namely (ii) and (iv); the preferred MPs are clearly different. This further demonstrates that the viscosity of the oil itself can be a deciding factor in paste efficacy.

Table 4.2 The most efficient MPs within each category for the removal of BB and B380

Paste Category	BB	B380
(i)	4% Acetic acid (5gFe/g)	4% Acetic Acid (5gFe/g)
(ii)	Perfect Gel (4gFe/g)	Fairy 5% v/v (5gFe/g)
(iii)	25% Eucalyptus oil (5gFe/g)	25% Eucalyptus oil (5gFe/g)
(iv)	70% ETOH (7gFe/g)	Methyl Soyate (6gFe/g)
(v)	Olive Oil (5gFe/g)	Olive Oil (5gFe/g)

4.4 MPs that are more Efficient than the DW Control

There are many MPs that are more efficient with respect to the overall removal of BB and B380 than the DW control, as indicated by their relative E_{90} or E_{95} values, **Table 4.3**. This data also demonstrates how the efficacy of removal depends on the contaminant.

This data shows that all the acetic acid and the ethanol MPs are more efficient than the DW control for the removal of BB. The types of MPs that are more efficient than the DW control to remove B380 are more varied and include MPs from all categories. At E_{90}, these include all the MPs with a PTA component, the OO MP, the fairy dishwashing liquid MP, 4 and 8% acetic acid MPs and the 5% and 25% eucalyptus oil MPs. When the removal benchmark is increased to E_{95}, there are fewer pastes that are more efficient than the DW control. At E_{95} no MP with a commercial cleansing product is more efficient than the DW control. The ethanol MP is no longer more efficient than the DW control but all the other MPs with a PTA component are.

4% AA 5gFe/g, 8% AA 5gFe/g and 70% ETOH 7gFe/g are more efficient than the DW control at E_{90} on both BB and B380. However, 4% AA 5gFe/g is the only paste that is more efficient than the DW control at E_{95} on both BB and B380. 4% AA 5gFe/g appears to be more effective at removing various contaminants than other MPs.

The MPs that are more efficient than the DW control for either BB or B380 removal are listed in **Table 4.3**. The E_{90} and E_{95} values are used to determine efficacy.

Table 4.3 MPs with higher E_{90} or E_{95} values than the DW control for both BB and B380.

Bua Ban	**E_{90}**
CONTROL DW (5gFe/g)	79.91
AA ~4% (5gFe/g)	102.74
70%ETOH (7gFe/g)	101.06
AA 10% (5gFe/g)	100.85
MAYO (4gFe/g)	*97.43*
AA 20% (5gFe/g)	97.35
AA ~8% (5gFe/g)	86.64

Bua Ban	**E_{95}**
CONTROL DW (5gFe/g)	39.79
AA ~4% (5gFe/g)	72.3
70%ETOH (7gFe/g)	69.04
AA 10% (5gFe/g)	59.28
AA ~8% (5gFe/g)	52.92
AA 20% (5gFe/g)	43.27

Bunker 380	**E_{90}**
CONTROL DW (5gFe/g)	40.28
MS (6gFe/g)	71.31
MO (6gFe/g)	71.01
EST (6gFe/g)	66.56
OO (5gFe/g)	62.33
AA ~4% (5gFe/g)	52.14
EO 25% (5gFe/g)	50.76
Fairy 5% v/v (5gFe/g)	*49.17*
70%ETOH (7gFe/g)	*45.88*
AA ~8% (5gFe/g)	*40.64*
EO 5% (5gFe/g)	*40.22*

Bunker 380	**E_{95}**
CONTROL DW (5gFe/g)	33.43
MS (6gFe/g)	54.37
EST (6gFe/g)	52.61
OO (5gFe/g)	50.64
MO (6gFe/g)	49.74
EO 25% (5gFe/g)	39.95
AA ~4% (5gFe/g)	38.39
EO 20% (5gFe/g)	*33.74*

Iron powder alone is more efficient than any MP to remove BB. However, this is not the case for B380 removal. There are 4 MPs that are more efficient than iron powder alone, see **Table 4.4**. At E_{90} these MPs contain conventional PTA agents – Methyl Soyate (MS) Mineral Oil (MO), Esterol (EST) and Olive Oil (OO). At E_{95}, only MPs containing MS (6gFe/g) and EST (6gFe/g) are more efficient than the iron powder alone. The most efficient magnetic particle technology to remove B380 is MS (6gFe/g).

Table 4.4 MPs with higher E_{90} and E_{95} values than the iron powder control for the B380 contaminant.

Bunker 380	**E_{90}**
Iron powder (alone)	57.45
MS (6gFe/g)	71.31
MO (6gFe/g)	71.01
EST (6gFe/g)	66.56
OO (5gFe/g)	62.33

Bunker 380	**E_{95}**
Iron powder (alone)	51.49
MS (6gFe/g)	54.37
EST (6gFe/g)	52.61

4.5 Proportion of Iron Powder in a MP

Perhaps, not surprisingly, increasing the proportion of iron powder increases the removal capacity and efficiency of a magnetic paste. However, the degree of improvement varies between pastes. Increasing the iron proportion in BD1 shows the greatest improvement in contaminant removal. This is followed by MO, MS and EST. Optimising the amount of iron powder in a paste whilst maintaining a spreadable consistency is highly recommended but involves a trade-off with other parameters. Iron powder alone is more efficient at removing BB than any of the MPs. However, MS, EST, MO and OO are more efficient than the iron powder alone in removing B380 (E_{90}). MS and EST are more efficient than iron powder alone in removing BB (E_{95}).

4.6 Temperature Considerations

For these experiments the temperature effects with respect to three pastes were considered: namely, MO, OO, and mayonnaise. It was found that the effects of increasing the temperature of a MP depends upon the paste itself, and merely heating a particular paste does not necessarily lead to an improved removal efficacy. For example, whereas the mayonnaise paste shows an increased efficacy upon heating, the MO and OO pastes are more effective when unheated, particularly MO. A possible explanation for this is that the adherence of the iron powder in a MP is related to the viscosity of the additive - the additive will have a greater hold on the iron powder if it has a higher viscosity. For example, the viscosity of MO is less than OO which is less than Mayonnaise. When these agents are heated, their viscosities change to different extents, and this may affect how the iron particles and the respective additive adhere to each other. Thus, the iron particles in the heated MO and OO pastes may more easily detach from the additive at a higher temperature which becomes, effectively, an additional contaminant. This could in fact decrease the removal efficacy at a higher temperature. On the other hand, the more viscous mayonnaise could better maintain its formulation at a higher temperature and exercise a higher removal. Thus, changing the temperature of a paste can affect its physical integrity. Furthermore, there could be more complex explanations. For example, mayonnaise is an emulsion of several ingredients: namely, oil, water, and egg yolk. Oil and water viscosity decrease as temperature increases. However, this is not true of egg yolk. When heated, the proteins in egg yolk bind to each other, with a thickening effect. Heating Mayonnaise MP may actually *increase* the paste's viscosity due to the denaturing of the egg yolk, and this may aid in the adhesion between the iron particles to the mayonnaise.

Considering the rationale for why increasing the temperature of some MPs would negatively impact removal efficacies, decreasing the temperature of these MPs to below 21 ℃ may, in fact, *improve* removal efficacies, as the adherence of the iron particles to the paste additive would improve. This has potentially important implications for the application of MPs to the removal of oil contamination at lower ambient temperatures, as some pastes show an inverse relationship between removal efficacy and temperature. This is an exciting area for further investigation.

4.7 Overall conclusions

This research project has shown that MPT can be developed into MPs that have the potential for the removal of medium to heavy contaminants, that might be otherwise recalcitrant. Thus, it has been shown that some MPs are more efficient at removing a heavy contaminant (B380) from duck feathers than iron powder alone. Overall, this project has involved a detailed experimental determination and comparison of the relative contaminant removal efficacies of seventeen MPs across five arbitrary categories, that encompass a wide range of paste additives. These studies have provided valuable insights into the potential usefulness of such magnetic cleansing agents. Of particular note is the effectiveness of the 4% acetic acid (i.e., vinegar) paste for the removal of both medium and heavy contaminants from duck feather clusters. These investigations also demonstrate that MPs are contaminant specific suggesting that such pastes can be tailored to specific contaminants. Notably, the experiments conducted with two different vegetable oils as additives, for which the relative fatty acid compositions are known, demonstrate that it is feasible to rationally design pastes that are more specific for heavy contaminants. A surprising, counterintuitive, effect from removal experiments conducted at a higher temperature (35 C°), is the observation that the effectiveness of some pastes has an inverse relationship to temperature. This suggests a potential application for lower temperature regimes. Finally, these studies help to delineate the effects of various physical properties such as the relative proportion of iron power in the formulation, the effect of additive and contaminant viscosity and iron powder adhesion on oil removal efficacy.

4.8 Some suggestions for future research

- Incremental tests on increasing the proportion of iron powder in MS, EST, MO and OO pastes to further delineate and improve their removal efficacy and capacity.
- Incremental tests on paste temperature from for example 14℃ < 35℃Mix various paste additives together such as vinegar/eucalyptus oil with conventional PTAs or any other combination.
- Test more MPs such as MO, MS, EST and OO across a range of temperatures.
- Test MPs on a wider variety of contaminants.
- Combining MP treatments with iron powder alone for example MPs used for initial removal and iron powder (alone) for final removal of a contaminant.
- Combining MP treatments with conventional (surfactant-based) cleaning technologies, i.e. initial removal with a MP; final removal with conventional cleaning technologies such as detergent baths.
- Test MPs on penguin pelt.

List of Appendices

Appendix A – Experimental data – Bua Ban removal

Appendix B – Experimental data – Bunker 380 removal

Appendix C – Statistical results – Bua Ban removal

Appendix D – Statistical results – Bunker 380 removal

Appendix E – N values – Bua Ban

Appendix F – N values – Bunker 380

Appendix A

N values - Bua Ban

Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
iron powder		**0**	0.0000	0.00%
Replicate	1	**1**	0.0374	95.37%
		2	0.0312	97.95%
	weight of petri dish= 7.5064g	**3**	0.0304	98.29%
f_1	weight of feather cluster = 0.0263g	**4**	0.0291	98.83%
f_2	weight of oiled cluster = 0.2916g	**5**	0.029	98.87%
	residual oil = 0.0258g	**6**	0.0291	98.83%
f_3	oil laden feathers = 0.2916g - 0.0258g = 0.2658g	**7**	0.0287	99.00%
f_4	weight of feather after treatment	**8**	0.0291	98.83%

Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
iron powder		**0**	0.0000	0.00%
Replicate	2	**1**	0.032	97.47%
		2	0.027	99.51%
	weight of petri dish= 7.2517g	**3**	0.0275	99.30%
f_1	weight of feather cluster = 0.0258g	**4**	0.0268	99.59%
f_2	weight of oiled cluster = 0.2882g	**5**	0.0268	99.59%
	residual oil = 0.0178g	**6**	0.0271	99.47%
f_3	oil laden feathers = 0.2882g - 0.0178g = 0.2704g	**7**	0.0273	99.39%
f_4	weight of feather after treatment	**8**	0.027	99.51%

Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
iron powder		**0**	0.0000	0.00%
Replicate	3	**1**	0.0393	97.60%
		2	0.0323	99.97%
	weight of petri dish= 7.6203g	**3**	0.0325	99.90%
f_1	weight of feather cluster = 0.0322g	**4**	0.033	99.73%
f_2	weight of oiled cluster = 0.3596g	**5**	0.0322	100.00%
	residual oil = 0.0319g	**6**	0.0323	99.97%
f_3	oil laden feathers = 0.3596g - 0.0319g = 0.3277g	**7**	0.0323	99.97%
f_4	weight of feather after treatment	**8**	0.0327	99.83%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
iron powder		**0**	0.0000	0.00%
Replicate	4	**1**	0.0513	96.36%
		2	0.0408	98.69%
	weight of petri dish= 7.4882g	**3**	0.039	99.09%
f_1	weight of feather cluster = 0.0349g	**4**	0.0395	98.98%
f_2	weight of oiled cluster = 0.5158g	**5**	0.0382	99.27%
	residual oil = 0.0299g	**6**	0.0382	99.27%
f_3	oil laden feathers = 0.5158g - 0.0299g = 0.4859g	**7**	0.0379	99.33%
f_4	weight of feather after treatment	**8**	0.0378	99.36%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
iron powder		**0**	0.0000	0.00%
Replicate	5	**1**	0.0347	95.95%
		2	0.0318	97.63%
	weight of petri dish= 7.4735g	**3**	0.0313	97.92%
f_1	weight of feather cluster = 0.0277g	**4**	0.0319	97.57%
f_2	weight of oiled cluster = 0.2161g	**5**	0.0318	97.63%
	residual oil = 0.0155g	**6**	0.0315	97.80%
f_3	oil laden feathers = 0.2161g - 0.0155g = 0.2006g	**7**	0.0308	98.21%
f_4	weight of feather after treatment	**8**	0.0315	97.80%

Contaminant	Bua Ban	N	weight (g)	P%
Magnetic Paste	DW (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0499	87.08%
		2	0.0380	94.47%
	weight of petri dish = 7.9862g	**3**	0.0355	96.02%
f_1	weight of feather cluster = 0.0291g	**4**	0.0348	96.46%
f_2	weight of oiled cluster = 0.2028g	**5**	0.0347	96.52%
	residual oil = 0.0127g	**6**	0.0343	96.77%
f_3	oil laden feathers = 0.2028g - 0.0127g = 0.1901g	**7**	0.0345	96.65%
f_4	weight of feather after treatment	**8**	0.0347	96.52%

Contaminant	Bua Ban	N	weight (g)	P%
Magnetic Paste	DW (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0499	85.40%
		2	0.0380	91.86%
	weight of petri dish = 7.9877g	**3**	0.0355	93.22%
f_1	weight of feather cluster = 0.0230g	**4**	0.0348	93.60%
f_2	weight of oiled cluster = 0.2293g	**5**	0.0347	93.65%
	residual oil = 0.0220g	**6**	0.0343	93.87%
f_3	oil laden feathers = 0.2293g - 0.0220g = 0.2073g	**7**	0.0345	93.76%
f_4	weight of feather after treatment	**8**	0.0347	93.65%

Contaminant	Bua Ban	N	weight (g)	P%
Magnetic Paste	DW (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0606	90.05%
		2	0.0518	93.98%
	weight of petri dish = 7.9886g	**3**	0.0458	96.65%
f_1	weight of feather cluster = 0.0383g	**4**	0.0423	98.22%
f_2	weight of oiled cluster = 0.2946g	**5**	0.0398	99.33%
	residual oil = 0.0322g	**6**	0.0367	100.71%
f_3	oil laden feathers = 0.2946g - 0.0322g = 0.2624g	**7**	0.0372	100.49%
f_4	weight of feather after treatment	**8**	0.0372	100.49%

			N	weight (g)	P%
Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	DW (5gFe/g)		**0**	0.0000	0.00%
Replicate	4		**1**	0.0701	90.94%
			2	0.0554	95.75%
	weight of petri dish = 7.9785g		**3**	0.0502	97.45%
f_1	weight of feather cluster = 0.0424g		**4**	0.0493	97.74%
f_2	weight of oiled cluster = 0.3766g		**5**	0.0474	98.37%
	residual oil = 0.0283g		**6**	0.0458	98.89%
f_3	oil laden feathers = 0.3766g - 0.0283g = 0.3483g		**7**	0.0464	98.69%
f_4	weight of feather after treatment		**8**	0.0469	98.53%

Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	DW (5gFe/g)		**0**	0.0000	0.00%
Replicate	5		**1**	0.0531	90.38%
			2	0.0422	95.50%
	weight of petri dish = 7.9785g		**3**	0.0414	95.87%
f_1	weight of feather cluster = 0.0326g		**4**	0.0404	96.34%
f_2	weight of oiled cluster = 0.2861g		**5**	0.0379	97.51%
	residual oil = 0.0404g		**6**	0.0385	97.23%
f_3	oil laden feathers = 0.2861g - 0.0404g = 0.2457g		**7**	0.0378	97.56%
f_4	weight of feather after treatment		**8**	0.0366	98.12%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	4% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0353	94.23%
		2	0.0298	96.44%
	weight of petri dish = 7.6566g	**3**	0.0277	97.28%
f_1	*weight of feather cluster = 0.0209g*	**4**	0.0282	97.08%
f_2	*weight of oiled cluster = 0.2912g*	**5**	0.0265	97.76%
	residual oil = 0.0206g	**6**	0.0261	97.92%
f_3	*oil laden feathers = 0.2912g - 0.0206g = 0.2706g*	**7**	0.0256	98.12%
f_4	*weight of feather after treatment*	**8**	0.0256	98.12%

		N	weight (g)	P%
Contaminant	*Bua Ban*			
Magnetic Paste	*4% v/v acetic acid (5gFe/g)*	**0**	0.0000	0.00%
Replicate	*2*	**1**	0.0439	92.20%
		2	0.0334	96.31%
	weight of petri dish = 7.6566g	**3**	0.0347	95.80%
f_1	*weight of feather cluster = 0.0240g*	**4**	0.0318	96.94%
f_2	*weight of oiled cluster = 0.3294g*	**5**	0.0304	97.49%
	residual oil = 0.0504g	**6**	0.0303	97.53%
f_3	*oil laden feathers = 0.3294g - 0.0504g = 0.2790g*	**7**	0.0294	97.88%
f_4	*weight of feather after treatment*	**8**	0.0293	97.92%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	4% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0452	94.69%
		2	0.0473	93.54%
	weight of petri dish = 7.6639g	**3**	0.0425	96.17%
f_1	weight of feather cluster = 0.0355g	**4**	0.0411	96.93%
f_2	weight of oiled cluster = 0.2431g	**5**	0.0416	96.66%
	residual oil = 0.0250g	**6**	0.0436	95.56%
f_3	oil laden feathers = 0.2431g - 0.0250g = 0.2181g	**7**	0.0445	95.07%
f_4	weight of feather after treatment	**8**	0.0498	92.17%

			N	weight (g)	P%
Contaminant	Bua Ban				
Magnetic Paste	4% v/v acetic acid (5gFe/g)		**0**	0.0000	0.00%
Replicate	4		**1**	0.041	95.08%
			2	0.0354	97.56%
	weight of petri dish = 7.6639g		**3**	0.035	97.74%
f_1	weight of feather cluster = 0.0299g		**4**	0.0344	98.01%
f_2	weight of oiled cluster = 0.2956g		**5**	0.0347	97.87%
	residual oil = 0.0400g		**6**	0.0354	97.56%
f_3	oil laden feathers = 0.2956g - 0.0400g = 0.2556g		**7**	0.0372	96.77%
f_4	weight of feather after treatment		**8**	0.0409	95.13%

		N		weight (g)	% R
Contaminant	Bua Ban				
Magnetic Paste	4% v/v acetic acid (5gFe/g)		**0**	0.0000	0.00%
Replicate	5		**1**	0.0316	95.44%
			2	0.0279	97.63%
	weight of petri dish = 7.6564g		**3**	0.0274	97.93%
f_1	weight of feather cluster = 0.0239g		**4**	0.0255	99.06%
f_2	weight of oiled cluster = 0.2074g		**5**	0.0282	97.45%
	residual oil = 0.0148g		**6**	0.0291	96.92%
f_3	oil laden feathers = 0.2074g - 0.0148g = 0.1926g		**7**	0.0313	95.61%
f_4	weight of feather after treatment		**8**	0.0305	96.09%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	8% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	**1**	**1**	0.0687	91.16%
		2	0.0464	97.17%
	weight of petri dish= 7.4857g	**3**	0.0437	97.90%
f_1	weight of feather cluster = 0.0359g	**4**	0.0442	97.76%
f_2	weight of oiled cluster = 0.4228g	**5**	0.0449	97.57%
	residual oil = 0.0160g	**6**	0.0446	97.65%
f_3	oil laden feathers = 0.4228g - 0.0160g = 0.4068g	**7**	0.0446	97.65%
f_4	weight of feather after treatment	**8**	0.0445	97.68%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	8% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	**2**	**1**	0.048	88.43%
		2	0.0381	93.52%
	weight of petri dish= 7.4856g	**3**	0.0323	96.50%
f_1	weight of feather cluster = 0.0255g	**4**	0.0314	96.97%
f_2	weight of oiled cluster = 0.2581g	**5**	0.0325	96.40%
	residual oil = 0.0381g	**6**	0.0295	97.94%
f_3	oil laden feathers = 0.2581g - 0.0381g = 0.220g	**7**	0.0307	97.33%
f_4	weight of feather after treatment	**8**	0.031	97.17%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	8% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	**3**	**1**	0.0396	91.75%
		2	0.0313	95.75%
	weight of petri dish= 7.2456g	**3**	0.0293	96.39%
f_1	weight of feather cluster = 0.0213g	**4**	0.0288	96.62%
f_2	weight of oiled cluster = 0.2673g	**5**	0.0267	97.57%
	residual oil = 0.0246g	**6**	0.0262	97.79%
f_3	oil laden feathers = 0.2678g - 0.0246g = 0.2432g	**7**	0.0258	97.97%
f_4	weight of feather after treatment	**8**	0.0249	98.38%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	8% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0331	83.28%
		2	0.0213	95.31%
	weight of petri dish= 7.4340g	**3**	0.0198	96.84%
f_1	weight of feather cluster = 0.0167g	**4**	0.0192	97.45%
f_2	weight of oiled cluster = 0.1217g	**5**	0.0178	98.88%
	residual oil = 0.0069g	**6**	0.0186	98.06%
f_3	oil laden feathers = 0.1217g - 0.0069g = 0.1148g	**7**	0.0189	97.76%
f_4	weight of feather after treatment	**8**	0.0206	96.02%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	8% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0446	90.90%
		2	0.0288	98.47%
	weight of petri dish= 7.4213g	**3**	0.0306	97.61%
f_1	weight of feather cluster = 0.0256g	**4**	0.0288	97.61%
f_2	weight of oiled cluster = 0.2492g	**5**	0.0284	98.66%
	residual oil = 0.0148g	**6**	0.0296	98.08%
f_3	oil laden feathers = 0.2492g - 0.0148g = 0.2344g	**7**	0.0311	97.37%
f_4	weight of feather after treatment	**8**	0.0306	97.61%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	10% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.1044	89.21%
		2	0.0714	96.69%
	weight of petri dish = 7.9230g	**3**	0.0703	96.94%
f_1	weight of feather cluster = 0.0568g	**4**	0.0655	98.03%
f_2	weight of oiled cluster = 0.5622g	**5**	0.0651	98.12%
	residual oil = 0.0641g	**6**	0.0672	97.64%
f_3	oil laden feathers = 0.5622g - 0.0641g = 0.4981g	**7**	0.0686	97.33%
f_4	weight of feather after treatment	**8**	0.0654	98.05%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	10% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0381	94.33%
		2	0.0324	97.27%
	weight of petri dish = 7.9230g	**3**	0.0304	98.30%
f_1	weight of feather cluster = 0.0271g	**4**	0.0302	98.40%
f_2	weight of oiled cluster = 0.2329g	**5**	0.0293	98.87%
	residual oil = 0.0119g	**6**	0.0307	98.14%
f_3	oil laden feathers = 0.2329g - 0.0119g = 0.2210g	**7**	0.0318	97.58%
f_4	weight of feather after treatment	**8**	0.0306	98.19%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	10% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0551	**92.93%**
		2	0.0481	**95.58%**
	weight of petri dish = 7.9230g	**3**	0.0434	**97.35%**
f_1	weight of feather cluster = 0.0364g	**4**	0.0415	**98.07%**
f_2	weight of oiled cluster = 0.3231g	**5**	0.0422	**97.81%**
	residual oil = 0.0222g	**6**	0.0421	**97.84%**
f_3	oil laden feathers = 0.3231g - 0.0222g = 0.3009g	**7**	0.0476	**95.77%**
f_4	weight of feather after treatment	**8**	0.0457	**96.48%**

			N	weight (g)	P%
Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	10% v/v acetic acid (5gFe/g)		**0**	0.0000	0.00%
Replicate	4		**1**	0.0474	91.24%
			2	0.0401	95.50%
	weight of petri dish = 8.1375g		**3**	0.0383	96.56%
f_1	weight of feather cluster = 0.0324g		**4**	0.0379	96.79%
f_2	weight of oiled cluster = 0.2288g		**5**	0.0381	96.67%
	residual oil = 0.0251g		**6**	0.0385	96.44%
f_3	oil laden feathers = 0.2288g - 0.0251g = 0.2037g		**7**	0.0406	95.21%
f_4	weight of feather after treatment		**8**	0.0404	95.33%

Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	10% v/v acetic acid (5gFe/g)		**0**	0.0000	0.00%
Replicate	5		**1**	0.0525	94.44%
			2	0.0462	96.79%
	weight of petri dish = 8.1375g		**3**	0.0460	96.87%
f_1	weight of feather cluster = 0.0376g		**4**	0.0449	97.28%
f_2	weight of oiled cluster = 0.3246g		**5**	0.0439	97.65%
	residual oil = 0.0188g		**6**	0.0455	97.05%
f_3	oil laden feathers = 0.3246g - 0.0188g = 0.3058g		**7**	0.0475	96.31%
f_4	weight of feather after treatment		**8**	0.0471	96.46%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	20% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0935	85.35%
		2	0.0618	95.13%
	weight of petri dish = 7.5504g	**3**	0.0592	95.93%
f_1	weight of feather cluster = 0.0460g	**4**	0.0580	96.30%
f_2	weight of oiled cluster = 0.3975g	**5**	0.0565	96.76%
	residual oil = 0.0272g	**6**	0.0560	96.92%
f_3	oil laden feathers = 0.3975g - 0.0272g = 0.3703g	**7**	0.0553	97.13%
f_4	weight of feather after treatment	**8**	0.0542	97.47%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	20% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0461	91.80%
		2	0.0316	97.28%
	weight of petri dish = 7.5411g	**3**	0.0297	98.00%
f_1	weight of feather cluster = 0.0244g	**4**	0.0288	98.34%
f_2	weight of oiled cluster = 0.3044g	**5**	0.0280	98.64%
	residual oil = 0.0155g	**6**	0.0291	98.22%
f_3	oil laden feathers = 0.3044g - 0.0155g = 0.2889g	**7**	0.0307	97.62%
f_4	weight of feather after treatment	**8**	0.0299	97.92%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	20% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0902	94.06%
		2	0.0877	94.78%
	weight of petri dish = 7.5411g	**3**	0.0842	95.79%
f_1	weight of feather cluster = 0.0696g	**4**	0.0833	96.05%
f_2	weight of oiled cluster = 0.4383g	**5**	0.0858	95.33%
	residual oil = 0.0218g	**6**	0.0806	96.83%
f_3	oil laden feathers = 0.4383g - 0.0218g = 0.4165g	**7**	0.0870	94.98%
f_4	weight of feather after treatment	**8**	0.0834	96.02%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	20% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0601	88.07%
		2	0.0419	95.61%
	weight of petri dish = 7.5454g	**3**	0.0378	97.31%
f_1	weight of feather cluster = 0.0313g	**4**	0.0371	97.60%
f_2	weight of oiled cluster = 0.3035g	**5**	0.0367	97.76%
	residual oil = 0.0307g	**6**	0.0368	97.72%
f_3	oil laden feathers = 0.3035g - 0.0307g = 0.2728g	**7**	0.0348	98.55%
f_4	weight of feather after treatment	**8**	0.0352	98.39%

Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	20% v/v acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0530	90.17%
		2	0.0522	90.61%
	weight of petri dish = 7.5499g	**3**	0.0480	92.89%
f_1	weight of feather cluster = 0.0349g	**4**	0.0470	93.43%
f_2	weight of oiled cluster = 0.2335g	**5**	0.0440	95.06%
	residual oil = 0.0144g	**6**	0.0410	96.68%
f_3	oil laden feathers = 0.2335g - 0.0144g = 0.2191g	**7**	0.0423	95.98%
f_4	weight of feather after treatment	**8**	0.0405	96.96%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0581	91.04%
		2	0.0550	91.77%
	weight of petri dish = 7.3022g	**3**	0.0496	93.05%
f_1	weight of feather cluster = 0.0203g	**4**	0.0378	95.85%
f_2	weight of oiled cluster = 0.5312g	**5**	0.0378	95.85%
	residual oil = 0.0892g	**6**	0.0379	95.83%
f_3	oil laden feathers = 0.5312g - 0.0892g = 0.442g	**7**	0.0371	96.02%
f_4	weight of feather after treatment	**8**	0.0387	95.64%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.2403	75.36%
		2	0.0738	94.87%
	weight of petri dish = 7.5091g	**3**	0.0522	97.40%
f_1	weight of feather cluster = 0.0300g	**4**	0.0492	97.75%
f_2	weight of oiled cluster = 0.9751g	**5**	0.0491	97.76%
	residual oil = 0.0915g	**6**	0.0508	97.56%
f_3	oil laden feathers = 0.9751g - 0.0915g = 0.8836g	**7**	0.0483	97.86%
f_4	weight of feather after treatment	**8**	0.0444	98.31%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0716	86.69%
		2	0.0463	93.38%
	weight of petri dish = 7.7580g	**3**	0.0406	94.89%
f_1	weight of feather cluster = 0.0213g	**4**	0.0223	99.74%
f_2	weight of oiled cluster = 0.4603g	**5**	0.034	96.64%
	residual oil = 0.0611g	**6**	0.0343	96.56%
f_3	oil laden feathers = 0.4603g - 0.0611g = 0.3992g	**7**	0.0341	96.61%
f_4	weight of feather after treatment	**8**	0.0299	97.72%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.1687	68.96%
		2	0.1031	83.32%
	weight of petri dish = 7.5091g	**3**	0.0582	93.15%
f_1	weight of feather cluster = 0.0269g	**4**	0.0456	95.91%
f_2	weight of oiled cluster = 0.5183g	**5**	0.0457	95.89%
	residual oil = 0.0345g	**6**	0.0453	95.97%
f_3	oil laden feathers = 0.5183g - 0.0345g = 0.4838g	**7**	0.0417	96.76%
f_4	weight of feather after treatment	**8**	0.0424	96.61%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.2822	33.44%
		2	0.0868	85.80%
	weight of petri dish = 7.5091g	**3**	0.0598	93.03%
f_1	weight of feather cluster = 0.0338g	**4**	0.0554	94.21%
f_2	weight of oiled cluster = 0.4242g	**5**	0.0538	94.64%
	residual oil = 0.0172g	**6**	0.0532	94.80%
f_3	oil laden feathers = 0.4242g - 0.0172g = 0.407g	**7**	0.0552	94.27%
f_4	weight of feather after treatment	**8**	0.0434	97.43%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	Fairy 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0501	86.94%
		2	0.0534	85.03%
	weight of petri dish= 7.5455g	**3**	0.0482	88.04%
f_1	weight of feather cluster = 0.0276g	**4**	0.0502	86.88%
f_2	weight of oiled cluster = 0.2126g	**5**	0.048	88.16%
	residual oil = 0.0127g	**6**	0.0476	88.39%
f_3	oil laden feathers = 0.2126g - 0.0127g = 0.1999g	**7**	0.0444	90.25%
f_4	weight of feather after treatment	**8**	0.047	88.74%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	Fairy 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0504	78.48%
		2	0.0431	84.03%
	weight of petri dish= 7.5880g	**3**	0.0421	84.79%
f_1	weight of feather cluster = 0.0221g	**4**	0.0409	85.70%
f_2	weight of oiled cluster = 0.1595g	**5**	0.039	87.15%
	residual oil = 0.0059g	**6**	0.0429	84.18%
f_3	oil laden feathers = 0.1595g - 0.0059g = 0.1536g	**7**	0.0385	87.53%
f_4	weight of feather after treatment	**8**	0.0391	87.07%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	Fairy 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.072	84.66%
		2	0.0511	92.15%
	weight of petri dish= 7.4658g	**3**	0.0487	93.01%
f_1	weight of feather cluster = 0.0292g	**4**	0.049	92.90%
f_2	weight of oiled cluster = 0.3634g	**5**	0.0487	93.01%
	residual oil = 0.0552g	**6**	0.0508	92.26%
f_3	oil laden feathers = 0.3634g - 0.0552g = 0.3082g	**7**	0.0482	93.19%
f_4	weight of feather after treatment	**8**	0.0507	92.29%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Fairy 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0483	83.86%
		2	0.0424	87.54%
	weight of petri dish= 7.2222g	**3**	0.0401	88.97%
f_1	weight of feather cluster = 0.0224g	**4**	0.0396	89.28%
f_2	weight of oiled cluster = 0.1971g	**5**	0.0381	90.22%
	residual oil = 0.0142g	**6**	0.0382	90.16%
f_3	oil laden feathers = 0.1971g - 0.0142g = 0.1829g	**7**	0.0378	90.40%
f_4	weight of feather after treatment	**8**	0.037	90.90%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Fairy 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0591	82.64%
		2	0.0495	88.00%
	weight of petri dish= 7.4944g	**3**	0.0487	88.44%
f_1	weight of feather cluster = 0.0280g	**4**	0.0494	88.05%
f_2	weight of oiled cluster = 0.2360g	**5**	0.0447	90.68%
	residual oil = 0.0289g	**6**	0.0449	90.56%
f_3	oil laden feathers = 0.2360g - 0.0289g = 0.2071g	**7**	0.0479	88.89%
f_4	weight of feather after treatment	**8**	0.0458	90.06%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Nivea (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0556	79.91%
		2	0.0405	89.76%
	weight of petri dish = 7.6643g	**3**	0.0382	91.26%
f_1	weight of feather cluster = 0.0248g	**4**	0.0358	92.82%
f_2	weight of oiled cluster = 0.1932g	**5**	0.0351	93.28%
	residual oil = 0.0151g	**6**	0.0362	92.56%
f_3	oil laden feathers = 0.1932g - 0.0151g = 0.1781g	**7**	0.0362	92.56%
f_4	weight of feather after treatment	**8**	0.0362	92.56%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Nivea (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0784	76.63%
		2	0.0546	89.45%
	weight of petri dish = 7.5841g	**3**	0.0567	88.31%
f_1	weight of feather cluster = 0.0350g	**4**	0.0551	89.18%
f_2	weight of oiled cluster = 0.2256g	**5**	0.0552	89.12%
	residual oil = 0.0049g	**6**	0.0534	90.09%
f_3	oil laden feathers = 0.2256g - 0.0049g = 0.2207g	**7**	0.0524	90.63%
f_4	weight of feather after treatment	**8**	0.0519	90.90%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Nivea (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.1063	**64.66%**
		2	0.0653	**85.21%**
	weight of petri dish = 7.5464g	**3**	0.0637	**86.02%**
f_1	weight of feather cluster = 0.0358g	**4**	0.0622	**86.77%**
f_2	weight of oiled cluster = 0.2520g	**5**	0.0595	**88.12%**
	residual oil = 0.0167g	**6**	0.0601	**87.82%**
f_3	oil laden feathers = 0.2520g - 0.0167g = 0.2353g	**7**	0.0585	**88.62%**
f_4	weight of feather after treatment	**8**	0.0563	**89.72%**

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Nivea (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0973	69.16%
		2	0.0613	87.13%
	weight of petri dish = 7.5892g	**3**	0.0589	88.32%
f_1	weight of feather cluster = 0.0355g	**4**	0.0582	88.67%
f_2	weight of oiled cluster = 0.2515g	**5**	0.0559	89.82%
	residual oil = 0.0156g	**6**	0.0551	90.22%
f_3	oil laden feathers = 0.2515g - 0.0156g = 0.2359g	**7**	0.0562	89.67%
f_4	weight of feather after treatment	**8**	0.0556	89.97%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Nivea (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0901	83.88%
		2	0.0728	89.52%
	weight of petri dish = 7.5432g	**3**	0.0668	91.48%
f_1	weight of feather cluster = 0.0407g	**4**	0.0660	91.74%
f_2	weight of oiled cluster = 0.3806g	**5**	0.0670	91.42%
	residual oil = 0.0335g	**6**	0.0651	92.04%
f_3	oil laden feathers = 0.3806g - 0.0335g = 0.3471g	**7**	0.0680	91.09%
f_4	weight of feather after treatment	**8**	0.0639	92.43%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Perfect Gel (4gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0427	92.23%
		2	0.0335	95.05%
	weight of petri dish = 7.6643g	**3**	0.033	95.20%
f_1	weight of feather cluster = 0.0173g	**4**	0.0287	96.51%
f_2	weight of oiled cluster = 0.4170g	**5**	0.0267	97.13%
	residual oil = 0.0726g	**6**	0.0259	97.37%
f_3	oil laden feathers = 0.4170g - 0.0726g = 0.3444g	**7**	0.0262	97.28%
f_4	weight of feather after treatment	**8**	0.0271	97.00%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Perfect Gel (4gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.033	86.80%
		2	0.0257	93.58%
	weight of petri dish= 7.5138g	**3**	0.0248	94.42%
f_1	weight of feather cluster = 0.0188g	**4**	0.0257	93.58%
f_2	weight of oiled cluster = 0.1366g	**5**	0.026	93.30%
	residual oil = 0.0103g	**6**	0.0261	93.21%
f_3	oil laden feathers = 0.1366g - 0.0103g = 0.0263g	**7**	0.0265	92.84%
f_4	weight of feather after treatment	**8**	0.0239	95.26%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Perfect Gel (4gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0664	81.61%
		2	0.0521	89.53%
	weight of petri dish= 7.2607g	**3**	0.0474	92.13%
f_1	weight of feather cluster = 0.0332g	**4**	0.0448	93.57%
f_2	weight of oiled cluster = 0.2347g	**5**	0.0478	91.91%
	residual oil = 0.0210g	**6**	0.0516	89.81%
f_3	oil laden feathers = 0.2347g - 0.0210g = 0.2137g	**7**	0.0465	92.63%
f_4	weight of feather after treatment	**8**	0.0478	91.91%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Perfect Gel (4gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.064	79.54%
		2	0.043	90.10%
	weight of petri dish= 7.4231g	**3**	0.0413	90.95%
f_1	weight of feather cluster = 0.0233g	**4**	0.0391	92.06%
f_2	weight of oiled cluster = 0.2388g	**5**	0.0358	93.72%
	residual oil = 0.0166g	**6**	0.0367	93.26%
f_3	oil laden feathers = 0.2388g - 0.0166g = 0.2222g	**7**	0.0352	94.02%
f_4	weight of feather after treatment	**8**	0.0346	94.32%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Perfect Gel (4gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0761	83.59%
		2	0.0626	88.29%
	weight of petri dish= 7.4139g	**3**	0.0489	93.05%
f_1	weight of feather cluster = 0.0289g	**4**	0.0419	95.48%
f_2	weight of oiled cluster = 0.3426g	**5**	0.0423	95.34%
	residual oil = 0.0260g	**6**	0.0424	95.31%
f_3	oil laden feathers = 0.3426g - 0.026g = 0.3166g	**7**	0.0405	95.97%
f_4	weight of feather after treatment	**8**	0.0401	96.11%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 5% v/v (5gFe/g)	**0**	0.0000	**0.00%**
Replicate	1	**1**	0.0502	88.95%
		2	0.0433	92.71%
	weight of petri dish = 7.6090g	**3**	0.0387	95.21%
f_1	weight of feather cluster = 0.0299g	**4**	0.037	96.14%
f_2	weight of oiled cluster = 0.2527g	**5**	0.0345	97.50%
	residual oil = 0.0391g	**6**	0.0352	97.11%
f_3	oil laden feathers = 0.2527g - 0.0391g = 0.2136g	**7**	0.034	97.77%
f_4	weight of feather after treatment	**8**	0.0337	97.93%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.05	91.42%
		2	0.041	96.16%
	weight of petri dish = 7.3277g	**3**	0.041	96.16%
f_1	weight of feather cluster = 0.0337g	**4**	0.0388	97.32%
f_2	weight of oiled cluster = 0.2408g	**5**	0.0388	97.32%
	residual oil = 0.0171g	**6**	0.038	97.74%
f_3	oil laden feathers = 0.2408g - 0.0171g = 0.2237g	**7**	0.0373	98.11%
f_4	weight of feather after treatment	**8**	0.0359	98.84%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.1016	74.25%
		2	0.042	95.02%
	weight of petri dish = 7.4817g	**3**	0.0371	96.72%
f_1	weight of feather cluster = 0.0277g	**4**	0.0352	97.39%
f_2	weight of oiled cluster = 0.3474g	**5**	0.0319	98.54%
	residual oil = 0.0327g	**6**	0.0315	98.68%
f_3	oil laden feathers = 0.3474g - 0.0327g = 0.3147g	**7**	0.0309	98.89%
f_4	weight of feather after treatment	**8**	0.0299	99.23%

		N	weight (g)	P%
Contaminant	Bua ban	**0**	0.0000	**0.00%**
Magnetic Paste	EO 5% v/v (5gFe/g)	**1**	0.0539	82.43%
Replicate	4	**2**	0.0427	89.41%
	weight of petri dish = 7.2626g	**3**	0.0407	90.65%
f_1	weight of feather cluster = 0.0257g	**4**	0.0395	91.40%
f_2	weight of oiled cluster = 0.2004g	**5**	0.0374	92.71%
	residual oil = 0.0142g	**6**	0.0358	93.71%
f_3	oil laden feathers = 0.2004g - 0.0142g = 0.1862g	**7**	0.035	94.21%
f_4	weight of feather after treatment	**8**	0.0349	94.27%

		N	weight (g)	P%
Contaminant	Bua ban	**0**	0.0000	0.00%
Magnetic Paste	EO 5% v/v (5gFe/g)	**1**	0.1118	86.82%
Replicate	5	**2**	0.0885	93.26%
	weight of petri dish = 7.9862g	**3**	0.0783	96.08%
f_1	weight of feather cluster = 0.0641g	**4**	0.0777	96.24%
f_2	weight of oiled cluster = 0.4767g	**5**	0.0731	96.69%
	residual oil = 0.0506	**6**	0.0718	97.87%
f_3	oil laden feathers = 0.4767g - 0.0506g = 0.4261g	**7**	0.0695	98.51%
f_4	weight of feather after treatment	**8**	0.069	98.65%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 20% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0622	91.64%
		2	0.0586	93.15%
	weight of petri dish= 7.2325g	**3**	0.0474	97.86%
f_1	weight of feather cluster = 0.0423g	**4**	0.0467	98.15%
f_2	weight of oiled cluster = 0.2802g	**5**	0.0527	95.63%
	residual oil = 0.0100g	**6**	0.0455	98.65%
f_3	oil laden feathers = 0.2702g - 0.0100g = 0.2802g	**7**	0.0455	98.65%
f_4	weight of feather after treatment	**8**	0.0455	98.65%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 20% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0792	81.11%
		2	0.0547	93.19%
	weight of petri dish= 7.4697g	**3**	0.0464	97.29%
f_1	weight of feather cluster = 0.0408g	**4**	0.0524	94.18%
f_2	weight of oiled cluster = 0.2516g	**5**	0.0477	96.65%
	residual oil = 0.0081g	**6**	0.049	96.00%
f_3	oil laden feathers = 0.2516g - 0.0081g = 0.2435g	**7**	0.049	96.00%
f_4	weight of feather after treatment	**8**	0.049	96.00%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 20% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.1536	85.98%
		2	0.1261	92.31%
	weight of petri dish= 7.4305g	**3**	0.1144	95.01%
f_1	weight of feather cluster = 0.0927g	**4**	0.1084	96.39%
f_2	weight of oiled cluster = 0.5730g	**5**	0.118	94.18%
	residual oil = 0.0458g	**6**	0.1208	93.53%
f_3	oil laden feathers = 0.5730g - 0.0458g = 0.5272g	**7**	0.1208	93.53%
f_4	weight of feather after treatment	**8**	0.1208	93.53%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 20% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.2003	83.15%
		2	0.1851	87.32%
	weight of petri dish= 7.4305g	**3**	0.1546	95.71%
f_1	weight of feather cluster = 0.1390g	**4**	0.155	95.60%
f_2	weight of oiled cluster = 0.5168g	**5**	0.158	94.78%
	residual oil = 0.0141g	**6**	0.158	94.78%
f_3	oil laden feathers = 0.5168g - 0.0141g = 0.5027g	**7**	0.158	94.78%
f_4	weight of feather after treatment	**8**	0.158	94.78%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 20% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0679	83.17%
		2	0.0484	93.72%
	weight of petri dish= 7.4864g	**3**	0.0463	94.86%
f_1	weight of feather cluster = 0.0368g	**4**	0.0452	95.45%
f_2	weight of oiled cluster = 0.2338g	**5**	0.0446	95.78%
	residual oil = 0.0122g	**6**	0.0457	95.18%
f_3	oil laden feathers = 0.2338g - 0.0122g = 0.2216g	**7**	0.0469	94.53%
f_4	weight of feather after treatment	**8**	0.0468	94.59%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 25% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0574	88.70%
		2	0.0441	95.86%
	weight of petri dish= 7.4294g	**3**	0.0476	93.98%
f_1	weight of feather cluster = 0.0364g	**4**	0.0476	93.98%
f_2	weight of oiled cluster = 0.2345g	**5**	0.049	93.22%
	residual oil = 0.0122g	**6**	0.0495	92.95%
f_3	oil laden feathers = 0.2345g - 0.0122g = 0.2223g	**7**	0.0458	94.94%
f_4	weight of feather after treatment	**8**	0.0447	95.54%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 25% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0674	75.82%
		2	0.0532	86.10%
	weight of petri dish= 7.4294g	**3**	0.0433	93.12%
f_1	weight of feather cluster = 0.0336g	**4**	0.0444	92.34%
f_2	weight of oiled cluster = 0.1882g	**5**	0.0432	93.20%
	residual oil = 0.0136g	**6**	0.0409	94.82%
f_3	oil laden feathers = 0.1882g - 0.0136g = 0.1746g	**7**	0.0403	95.25%
f_4	weight of feather after treatment	**8**	0.0421	93.97%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 25% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0885	89.01%
		2	0.0732	94.73%
	weight of petri dish= 7.4701g	**3**	0.0729	94.84%
f_1	weight of feather cluster = 0.0591g	**4**	0.0671	97.01%
f_2	weight of oiled cluster = 0.3394g	**5**	0.0727	94.92%
	residual oil = 0.0127g	**6**	0.0726	94.96%
f_3	oil laden feathers = 0.3394g - 0.0127g = 0.3267g	**7**	0.078	92.94%
f_4	weight of feather after treatment	**8**	0.0734	94.66%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 25% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.1171	83.14%
		2	0.0969	90.56%
	weight of petri dish= 7.4701g	**3**	0.097	90.52%
f_1	weight of feather cluster = 0.0712g	**4**	0.0992	89.71%
f_2	weight of oiled cluster = 0.3775g	**5**	0.1011	89.02%
	residual oil = 0.0341g	**6**	0.0897	93.20%
f_3	oil laden feathers = 0.3775g - 0.0341g = 0.3434g	**7**	0.1013	88.94%
f_4	weight of feather after treatment	**8**	0.1162	83.47%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	MS (6gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0581	85.00%
		2	0.0521	88.95%
	weight of petri dish= 7.4651g	**3**	0.0456	93.32%
f_1	weight of feather cluster = 0.0353g	**4**	0.0511	89.61%
f_2	weight of oiled cluster = 0.1983g	**5**	0.0486	91.25%
	residual oil = 0.0110g	**6**	0.0471	92.24%
f_3	oil laden feathers = 0.1983g - 0.0110g = 0.1873g	**7**	0.0503	90.13%
f_4	weight of feather after treatment	**8**	0.0487	91.18%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	MS (6gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0573	89.95%
		2	0.0446	95.16%
	weight of petri dish= 7.4068g	**3**	0.046	94.58%
f_1	weight of feather cluster = 0.0328g	**4**	0.0431	95.77%
f_2	weight of oiled cluster = 0.2913g	**5**	0.042	96.22%
	residual oil = 0.0148g	**6**	0.0423	96.10%
f_3	oil laden feathers = 0.2913g - 0.0148g = 0.2765g	**7**	0.0446	95.16%
f_4	weight of feather after treatment	**8**	0.044	95.40%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	MS (6gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0907	81.90%
		2	0.0704	90.31%
	weight of petri dish= 7.3144g	**3**	0.0687	91.01%
f_1	weight of feather cluster = 0.0470g	**4**	0.0705	90.27%
f_2	weight of oiled cluster = 0.3226g	**5**	0.0685	91.09%
	residual oil = 0.0342g	**6**	0.0636	93.12%
f_3	oil laden feathers = 0.3226g - 0.0342g = 0.2884g	**7**	0.0638	93.07%
f_4	weight of feather after treatment	**8**	0.0663	92.00%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	MS (6gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0707	**81.93%**
		2	0.0588	**89.10%**
	weight of petri dish= 7.5973g	**3**	0.057	**90.18%**
f_1	weight of feather cluster = 0.0407g	**4**	0.0503	**94.22%**
f_2	weight of oiled cluster = 0.2243g	**5**	0.0534	**92.35%**
	residual oil = 0.0176g	**6**	0.0543	**91.81%**
f_3	oil laden feathers = 0.2243g - 0.0176g = 0.2067g	**7**	0.054	**91.99%**
f_4	weight of feather after treatment	**8**	0.0553	**91.20%**

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	MS (6gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0375	89.16%
		2	0.0316	94.40%
	weight of petri dish= 7.5512g	**3**	0.0331	93.07%
f_1	weight of feather cluster = 0.0253g	**4**	0.0326	93.51%
f_2	weight of oiled cluster = 0.1462g	**5**	0.0332	92.98%
	residual oil = 0.0084g	**6**	0.0324	93.69%
f_3	oil laden feathers = 0.1462g - 0.0084g = 0.1378g	**7**	0.0315	94.49%
f_4	weight of feather after treatment	**8**	0.0315	94.49%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	EST (6gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0548	89.91%
		2	0.0421	95.34%
	weight of petri dish = 8.4679g	**3**	0.0471	93.20%
f_1	weight of feather cluster = 0.0312g	**4**	0.0581	88.50%
f_2	weight of oiled cluster = 0.2722g	**5**	0.0429	94.50%
	residual oil = 0.0071g	**6**	0.0458	93.76%
f_3	oil laden feathers = 0.2722g - 0.0071g = 0.2651g	**7**	0.0377	97.22%
f_4	weight of feather after treatment	**8**	0.0388	96.75%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EST (6gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0426	90.04%
		2	0.0309	97.15%
	weight of petri dish = 7.4125g	**3**	0.0351	94.60%
f_1	weight of feather cluster = 0.0262g	**4**	0.0346	94.98%
f_2	weight of oiled cluster = 0.2140g	**5**	0.0325	96.17%
	residual oil = 0.0231g	**6**	0.0353	94.47%
f_3	oil laden feathers = 0.2140g - 0.0231g = 0.1909g	**7**	0.0374	93.20%
f_4	weight of feather after treatment	**8**	0.0346	94.90%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EST (6gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0390	95.47%
		2	0.0345	97.53%
	weight of petri dish = 7.2568g	**3**	0.0360	96.84%
f_1	weight of feather cluster = 0.0291g	**4**	0.0347	97.44%
f_2	weight of oiled cluster = 0.2575g	**5**	0.0337	97.90%
	residual oil = 0.0098g	**6**	0.0365	96.61%
f_3	oil laden feathers = 0.2575g - 0.0098g = 0.2477g	**7**	0.0328	98.31%
f_4	weight of feather after treatment	**8**	0.0370	96.39%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EST (6gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0953	86.75%
		2	0.0728	93.78%
	weight of petri dish = 7.4258g	**3**	0.0731	93.72%
f_1	weight of feather cluster = 0.0531g	**4**	0.0691	94.98%
f_2	weight of oiled cluster = 0.3988g	**5**	0.0798	91.62%
	residual oil = 0.0272g	**6**	0.0782	92.12%
f_3	oil laden feathers = 0.3988g - 0.0272g = 0.3716g	**7**	0.0739	93.47%
f_4	weight of feather after treatment	**8**	0.0765	92.65%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EST (6gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0842	81.86%
		2	0.0786	84.31%
	weight of petri dish = 7.4220g	**3**	0.0719	87.25%
f_1	weight of feather cluster = 0.0428g	**4**	0.0683	88.83%
f_2	weight of oiled cluster = 0.2929g	**5**	0.0675	89.18%
	residual oil = 0.0219g	**6**	0.0685	88.74%
f_3	oil laden feathers = 0.2929g - 0.0219g = 0.2710g	**7**	0.0660	89.83%
f_4	weight of feather after treatment	**8**	0.0648	90.36%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Mineral Oil (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0447	85.24%
		2	0.0366	90.80%
	weight of petri dish = 7.6480g	**3**	0.0346	92.18%
f_1	weight of feather cluster = 0.0232g	**4**	0.0394	88.89%
f_2	weight of oiled cluster = 0.1766g	**5**	0.0324	93.69%
	residual oil = 0.0077g	**6**	0.0356	91.49%
f_3	oil laden feathers = 0.1766g - 0.0077g = 0.1689g	**7**	0.0335	92.93%
f_4	weight of feather after treatment	**8**	0.0356	91.49%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Mineral Oil (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0938	71.37%
		2	0.0735	82.32%
	weight of petri dish = 7.6480g	**3**	0.0731	82.53%
f_1	weight of feather cluster = 0.0407g	**4**	0.0739	82.10%
f_2	weight of oiled cluster = 0.2378g	**5**	0.0726	82.80%
	residual oil = 0.0116g	**6**	0.0722	83.02%
f_3	oil laden feathers = 0.2378g - 0.0116g = 0.2262g	**7**	0.0796	79.03%
f_4	weight of feather after treatment	**8**	0.0738	82.16%

		N	weight (g)	P%
Contaminant	Bua Ban			
Magnetic Paste	Mineral Oil (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0674	85.05%
		2	0.0554	91.28%
	weight of petri dish = 7.6480g	**3**	0.0565	90.71%
f_1	weight of feather cluster = 0.0386g	**4**	0.0583	89.77%
f_2	weight of oiled cluster = 0.2442g	**5**	0.0539	92.06%
	residual oil = 0.0130g	**6**	0.0601	88.84%
f_3	oil laden feathers = 0.2442g - 0.0130g = 0.2312g	**7**	0.0569	90.50%
f_4	weight of feather after treatment	**8**	0.0539	92.06%

Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	Mineral Oil (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0775	81.73%
		2	0.0556	91.58%
	weight of petri dish = 7.6480g	**3**	0.0533	92.62%
f_1	weight of feather cluster = 0.0369g	**4**	0.0514	93.47%
f_2	weight of oiled cluster = 0.2715g	**5**	0.0516	93.38%
	residual oil = 0.0124g	**6**	0.0516	93.38%
f_3	oil laden feathers = 0.2715g - 0.0124g = 0.2591g	**7**	0.0516	93.38%
f_4	weight of feather after treatment	**8**	0.0516	93.38%

Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	Mineral Oil (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0418	84.92%
		2	0.0392	87.34%
	weight of petri dish = 7.6480g	**3**	0.0391	87.43%
f_1	weight of feather cluster = 0.0256g	**4**	0.0384	88.08%
f_2	weight of oiled cluster = 0.1438g	**5**	0.0418	84.92%
	residual oil = 0.0108g	**6**	0.0418	84.92%
f_3	oil laden feathers = 0.1438g - 0.0108g = 0.1330g	**7**	0.0418	84.92%
f_4	weight of feather after treatment	**8**	0.0418	84.92%

			N	weight (g)	P%
Contaminant	Bua ban		**N**	**weight (g)**	**P%**
Magnetic Paste	70% ETOH (7gFe/g)		**0**	0	0.00%
Replicate	1		**1**	0.0511	93.82%
			2	0.0414	97.37%
	weight of petri dish= 7.4390g		**3**	0.04	97.88%
f_1	weight of feather cluster = 0.0342g		**4**	0.0416	97.29%
f_2	weight of oiled cluster = 0.3425g		**5**	0.0424	97.00%
	residual oil = 0.0350g		**6**	0.0411	97.48%
f_3	oil laden feathers = 0.3425g - 0.0250g = 0.3075g		**7**	0.0425	96.96%
f_4	weight of feather after treatment		**8**	0.0416	97.29%

			N	weight (g)	P%
Contaminant	Bua ban		**N**	**weight (g)**	**P%**
Magnetic Paste	70% ETOH (7gFe/g)		**0**	0	0.00%
Replicate	2		**1**	0.046	96.07%
			2	0.0414	97.71%
	weight of petri dish= 7.5554g		**3**	0.0407	97.96%
f_1	weight of feather cluster = 0.0350g		**4**	0.0403	98.11%
f_2	weight of oiled cluster = 0.3326g		**5**	0.0396	98.36%
	residual oil = 0.0178g		**6**	0.0402	98.14%
f_3	oil laden feathers = 0.3326g - 0.0178g = 0.3148g		**7**	0.0393	98.46%
f_4	weight of feather after treatment		**8**	0.0396	98.36%

			N	weight (g)	P%
Contaminant	Bua ban		**N**	**weight (g)**	**P%**
Magnetic Paste	70% ETOH (7gFe/g)		**0**	0	0.00%
Replicate	3		**1**	0.055	90.66%
			2	0.0376	97.49%
	weight of petri dish= 7.6793g		**3**	0.0363	98.00%
f_1	weight of feather cluster = 0.0312g		**4**	0.0361	98.08%
f_2	weight of oiled cluster = 0.3209g		**5**	0.0359	98.16%
	residual oil = 0.0348g		**6**	0.0367	97.84%
f_3	oil laden feathers = 0.3209g - 0.0348g = 0.2861g		**7**	0.0382	97.25%
f_4	weight of feather after treatment		**8**	0.0388	97.02%

		N	weight (g)	P%
Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	70% ETOH (7gFe/g)	**0**	0	0.00%
Replicate	4	**1**	0.0694	92.45%
		2	0.0413	99.66%
	weight of petri dish= 7.3035g	**3**	0.0445	98.84%
f_1	weight of feather cluster = 0.0400g	**4**	0.0437	99.04%
f_2	weight of oiled cluster = 0.4492g	**5**	0.0439	98.99%
	residual oil = 0.0224g	**6**	0.0438	99.02%
f_3	oil laden feathers = 0.4492g - 0.0224g = 0.4268g	**7**	0.0443	98.89%
f_4	weight of feather after treatment	**8**	0.039	100.26%

Contaminant	Bua ban	**N**	**weight (g)**	**P%**
Magnetic Paste	70% ETOH (7gFe/g)	**0**	0	0.00%
Replicate	5	**1**	0.0418	92.06%
		2	0.0332	96.83%
	weight of petri dish= 7.4174g	**3**	0.0321	97.44%
f_1	weight of feather cluster = 0.0275g	**4**	0.0318	97.61%
f_2	weight of oiled cluster = 0.2302g	**5**	0.0323	97.33%
	residual oil = 0.0227g	**6**	0.032	97.50%
f_3	oil laden feathers = 0.2302g - 0.0227g = 0.2075g	**7**	0.032	97.50%
f_4	weight of feather after treatment	**8**	0.0329	97.00%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	CO (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0402	85.28%
		2	0.0343	90.13%
	weight of petri dish= 7.5513g	**3**	0.0345	90.13%
f_1	weight of feather cluster = 0.0223g	**4**	0.0343	90.13%
f_2	weight of oiled cluster = 0.1516g	**5**	0.0372	87.75%
	residual oil = 0.0077g	**6**	0.0385	86.68%
f_3	oil laden feathers = 0.1516g - 0.0077g = 0.1439g	**7**	0.0397	85.69%
f_4	weight of feather after treatment	**8**	0.0391	86.18%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	CO (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0671	78.87%
		2	0.0455	91.10%
	weight of petri dish= 7.6782g	**3**	0.0445	91.67%
f_1	weight of feather cluster = 0.0298g	**4**	0.0478	89.80%
f_2	weight of oiled cluster = 0.2562g	**5**	0.0456	91.05%
	residual oil = 0.0499g	**6**	0.0469	90.31%
f_3	oil laden feathers = 0.2562g - 0.0499g = 0.2063g	**7**	0.0452	91.27%
f_4	weight of feather after treatment	**8**	0.0462	90.71%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	CO (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0577	82.87%
		2	0.0437	91.17%
	weight of petri dish= 7.5349g	**3**	0.0484	88.38%
f_1	weight of feather cluster = 0.0288g	**4**	0.0448	90.52%
f_2	weight of oiled cluster = 0.2143g	**5**	0.0451	90.34%
	residual oil = 0.0168g	**6**	0.0477	88.80%
f_3	oil laden feathers = 0.2143g - 0.0168g = 0.1975g	**7**	0.0441	90.93%
f_4	weight of feather after treatment	**8**	0.0392	93.84%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	CO (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0524	85.18%
		2	0.0432	90.07%
	weight of petri dish= 7.5433g	**3**	0.044	89.64%
f_1	weight of feather cluster = 0.0245g	**4**	0.0439	89.70%
f_2	weight of oiled cluster = 0.2436g	**5**	0.0427	90.33%
	residual oil = 0.0308g	**6**	0.0436	89.86%
f_3	oil laden feathers = 0.2436g - 0.0308g = 0.2128g	**7**	0.0427	90.33%
f_4	weight of feather after treatment	**8**	0.0404	91.56%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	CO (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0721	86.46%
		2	0.0516	92.10%
	weight of petri dish = 7.6544g	**3**	0.0502	92.49%
f_1	weight of feather cluster = 0.0229g	**4**	0.0465	93.51%
f_2	weight of oiled cluster = 0.5150g	**5**	0.0464	93.53%
	residual oil = 0.1287g	**6**	0.0474	93.26%
f_3	oil laden feathers = 0.5150g - 0.1287g = 0.3863g	**7**	0.0484	92.98%
f_4	weight of feather after treatment	**8**	0.0508	92.32%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	OO (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.5726	68.82%
		2	0.3006	90.90%
	weight of petri dish = 35.5497g	**3**	0.2877	91.95%
f_1	weight of feather cluster = 0.1885g	**4**	0.2857	92.11%
f_2	weight of oiled cluster = 1.8815g	**5**	0.2724	93.19%
	residual oil = 0.4612g	**6**	0.2682	93.53%
f_3	oil laden feathers = 1.4203g	**7**	0.2689	93.47%
f_4	weight of feather after treatment	**8**	0.2717	93.25%

Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	OO (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.302	85.31%
		2	0.2446	89.78%
	weight of petri dish = 35.5497g	**3**	0.2138	92.18%
f_1	weight of feather cluster = 0.1134g	**4**	0.1994	93.30%
f_2	weight of oiled cluster = 2.1409g	**5**	0.1951	93.64%
	residual oil = 0.7438g	**6**	0.1901	94.03%
f_3	oil laden feathers = 1.3971g	**7**	0.1954	94.39%
f_4	weight of feather after treatment	**8**	0.1912	93.94%

Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	OO (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.3529	91.90%
		2	0.2684	95.59%
	weight of petri dish = 35.5497g	**3**	0.2697	95.53%
f_1	weight of feather cluster = 0.1676g	**4**	0.2673	95.64%
f_2	weight of oiled cluster = 3.1126g	**5**	0.2612	95.90%
	residual oil = 0.6603g	**6**	0.2569	96.09%
f_3	oil laden feathers = 2.4523g	**7**	0.263	95.82%
f_4	weight of feather after treatment	**8**	0.2577	96.06%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	OO (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.2093	91.00%
		2	0.1935	93.27%
	weight of petri dish = 35.5497g	**3**	0.194	92.35%
f_1	weight of feather cluster = 0.1071g	**4**	0.1855	93.10%
f_2	weight of oiled cluster = 1.4267g	**5**	0.1843	93.20%
	residual oil = 0.1839g	**6**	0.1908	92.63%
f_3	oil laden feathers = 1.2428g	**7**	0.1843	93.20%
f_4	weight of feather after treatment	**8**	0.1918	92.54%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	OO (5gFe/g)	**0**	0.0000	0.00%
Replicate	**5**	**1**	0.4626	78.42%
		2	0.2967	90.66%
	weight of petri dish = 35.5497g	**3**	0.2841	91.59%
f_1	weight of feather cluster = 0.1702g	**4**	0.2849	91.54%
f_2	weight of oiled cluster = 2.1117g	**5**	0.2932	90.92%
	residual oil = 0.5865g	**6**	0.2837	91.62%
f_3	oil laden feathers = 1.5252g	**7**	0.2851	91.52%
f_4	weight of feather after treatment	**8**	0.2803	91.87%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	MS (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.2049	76.05%
		2	0.1547	84.35%
	weight of petri dish= 7.3969g	**3**	0.1322	89.42%
f_1	weight of feather cluster = 0.0852g	**4**	0.1303	89.85%
f_2	weight of oiled cluster = 0.5900g	**5**	0.1488	85.68%
	residual oil = 0.0606g	**6**	0.1394	87.80%
f_3	oil laden feathers = 0.5900g - 0.0606g = 0.5294g	**7**	0.1377	88.18%
f_4	weight of feather after treatment	**8**	0.144	86.76%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	MS (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0687	83.62%
		2	0.0392	95.12%
	weight of petri dish= 7.4601g	**3**	0.042	94.03%
f_1	weight of feather cluster = 0.0267g	**4**	0.0387	95.32%
f_2	weight of oiled cluster = 0.3044g	**5**	0.0383	95.48%
	residual oil = 0.0213g	**6**	0.0361	96.33%
f_3	oil laden feathers = 0.3044g - 0.0213g = 0.2831g	**7**	0.0372	95.90%
f_4	weight of feather after treatment	**8**	0.0427	93.76%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	MS (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.1191	78.91%
		2	0.0941	87.70%
	weight of petri dish= 7.4032g	**3**	0.0902	89.07%
f_1	weight of feather cluster = 0.0591g	**4**	0.086	90.54%
f_2	weight of oiled cluster = 0.3618g	**5**	0.0904	89.00%
	residual oil = 0.0182g	**6**	0.0909	88.82%
f_3	oil laden feathers = 0.3618g - 0.0182g = 0.3436g	**7**	0.0939	87.77%
f_4	weight of feather after treatment	**8**	0.0947	87.49%

			N	weight (g)	P%
Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	MS (5gFe/g)		**0**	0.0000	0.00%
Replicate	4		**1**	0.0982	79.90%
			2	0.078	88.27%
	weight of petri dish= 7.4594g		**3**	0.0835	85.99%
f_1	weight of feather cluster = 0.0497g		**4**	0.0779	88.31%
f_2	weight of oiled cluster = 0.3136g		**5**	0.0759	89.14%
	residual oil = 0.0226g		**6**	0.0778	88.35%
f_3	oil laden feathers = 0.3136g - 0.0226g = 0.2910g		**7**	0.079	87.86%
f_4	weight of feather after treatment		**8**	0.0772	88.60%

			N	weight (g)	P%
Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	MS (5gFe/g)		**0**	0.0000	0.00%
Replicate	5		**1**	0.0853	69.06%
			2	0.0565	85.09%
	weight of petri dish= 7.3818g		**3**	0.0545	86.20%
f_1	weight of feather cluster = 0.0297g		**4**	0.0527	87.20%
f_2	weight of oiled cluster = 0.2255g		**5**	0.0529	87.09%
	residual oil = 0.0161g		**6**	0.0574	84.59%
f_3	oil laden feathers = 0.2255g - 0.0161g = 0.20947g		**7**	0.0533	86.87%
f_4	weight of feather after treatment		**8**	0.0511	88.09%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EST (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0413	82.39%
		2	0.0318	89.99%
	weight of petri dish= 7.4100g	**3**	0.0303	91.19%
f_1	weight of feather cluster = 0.0193g	**4**	0.0296	91.75%
f_2	weight of oiled cluster = 0.1751g	**5**	0.0278	93.19%
	residual oil = 0.0309g	**6**	0.0291	92.15%
f_3	oil laden feathers = 0.1751g - 0.0309g = 0.1442g	**7**	0.0304	91.11%
f_4	weight of feather after treatment	**8**	0.0272	93.67%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EST (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.061	83.03%
		2	0.0483	89.41%
	weight of petri dish= 7.4164g	**3**	0.0442	91.47%
f_1	weight of feather cluster = 0.0272g	**4**	0.0478	89.66%
f_2	weight of oiled cluster = 0.2564g	**5**	0.04	93.57%
	residual oil = 0.0300g	**6**	0.0385	94.33%
f_3	oil laden feathers = 0.2564g - 0.0300g = 0.2264g	**7**	0.0427	92.22%
f_4	weight of feather after treatment	**8**	0.0423	92.42%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EST (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.1018	80.60%
		2	0.0847	87.02%
	weight of petri dish= 7.3949g	**3**	0.071	92.16%
f_1	weight of feather cluster = 0.0501g	**4**	0.0782	89.46%
f_2	weight of oiled cluster = 0.3408g	**5**	0.0803	88.67%
	residual oil = 0.0242g	**6**	0.0764	90.13%
f_3	oil laden feathers = 0.3408g - 0.0242g = 0.2264g	**7**	0.0774	89.46%
f_4	weight of feather after treatment	**8**	0.0783	89.42%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EST (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0878	74.99%
		2	0.0659	87.35%
	weight of petri dish= 7.4794g	**3**	0.0648	87.97%
f_1	weight of feather cluster = 0.0435g	**4**	0.0643	88.26%
f_2	weight of oiled cluster = 0.2449g	**5**	0.0764	81.42%
	residual oil = 0.0243g	**6**	0.0661	87.24%
f_3	oil laden feathers = 0.2449g - 0.0243g = 0.2206g	**7**	0.0632	88.88%
f_4	weight of feather after treatment	**8**	0.0635	88.71%

		N	weight (g)	P%
Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	EST (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0742	**80.15%**
		2	0.0487	**91.08%**
	weight of petri dish = 7.4794g	**3**	0.0496	**90.70%**
f_1	weight of feather cluster = 0.0279g	**4**	0.0473	**91.68%**
f_2	weight of oiled cluster = 0.2727g	**5**	0.0529	**89.28%**
	residual oil = 0.0115g	**6**	0.0509	**90.14%**
f_3	oil laden feathers = 0.2727g - 0.0115g = 0.2612g	**7**	0.0483	**91.26%**
f_4	weight of feather after treatment	**8**	0.0490	**90.96%**

			N	weight (g)	P%
Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	MO (5gFe/g)		**0**	0.0000	0.00%
Replicate	1		**1**	0.1217	68.37%
			2	0.0890	81.47%
	weight of petri dish= 7.4099g		**3**	0.0875	82.07%
f_1	weight of feather cluster = 0.0427g		**4**	0.0884	81.71%
f_2	weight of oiled cluster = 0.3217g		**5**	0.0872	82.19%
	residual oil = 0.0292g		**6**	0.0816	84.43%
f_3	oil laden feathers = 0.3217g - 0.0292g = 0.2925g		**7**	0.0784	85.71%
f_4	weight of feather after treatment		**8**	0.0798	85.15%

Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	MO (5gFe/g)		**0**	0.0000	0.00%
Replicate	2		**1**	0.0740	77.30%
			2	0.0578	85.71%
	weight of petri dish= 7.4111g		**3**	0.0578	85.71%
f_1	weight of feather cluster = 0.0303g		**4**	0.0570	86.13%
f_2	weight of oiled cluster = 0.2420g		**5**	0.0528	88.31%
	residual oil = 0.0192g		**6**	0.0518	88.81%
f_3	oil laden feathers = 0.2420g - 0.0192g = 0.2228g		**7**	0.0539	87.74%
f_4	weight of feather after treatment		**8**	0.0495	90.03%

Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	MO (5gFe/g)		**0**	0.0000	0.00%
Replicate	3		**1**	0.1138	79.56%
			2	0.0991	84.56%
	weight of petri dish= 7.4232g		**3**	0.0966	85.41%
f_1	weight of feather cluster = 0.0537g		**4**	0.0931	86.60%
f_2	weight of oiled cluster = 0.3807g		**5**	0.0847	89.46%
	residual oil = 0.0329g		**6**	0.0910	87.32%
f_3	oil laden feathers = 0.3807g - 0.0329g = 0.3478g		**7**	0.0964	85.48%
f_4	weight of feather after treatment		**8**	0.0983	84.84%

Contaminant	Bua Ban	**N**	**weight (g)**	**P%**
Magnetic Paste	MO (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0864	77.94%
		2	0.0725	84.21%
	weight of petri dish= 7.4111g	**3**	0.0698	85.43%
f_1	weight of feather cluster = 0.0375g	**4**	0.0670	86.69%
f_2	weight of oiled cluster = 0.2954g	**5**	0.0666	86.87%
	residual oil = 0.0362g	**6**	0.0617	89.08%
f_3	oil laden feathers = 0.2954g - 0.0362g = 0.2592g	**7**	0.0656	87.33%
f_4	weight of feather after treatment	**8**	0.0707	85.02%

- *NO 5^TH REPLICATE DATA AVAILABLE*

			N	weight (g)	P%
Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	BD1 (5gFe/g)		**0**	0.0000	0.00%
Replicate	1		**1**	0.1570	62.88%
			2	0.0856	86.97%
	weight of petri dish= 7.2522g		**3**	0.0868	86.57%
f_1	weight of feather cluster = 0.0470g		**4**	0.0853	87.07%
f_2	weight of oiled cluster = 0.3992g		**5**	0.0841	87.48%
	residual oil = 0.0559g		**6**	0.0939	84.17%
f_3	oil laden feathers = 0.3992g - 0.0559g = 0.3433g		**7**	0.0935	84.31%
f_4	weight of feather after treatment		**8**	0.0870	86.50%

Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	BD1 (5gFe/g)		**0**	0.0000	0.00%
Replicate	2		**1**	0.1160	42.19%
			2	0.0502	86.89%
	weight of petri dish= 7.4840g		**3**	0.0594	80.64%
f_1	weight of feather cluster = 0.0309g		**4**	0.0619	78.94%
f_2	weight of oiled cluster = 0.1900g		**5**	0.0534	84.71%
	residual oil = 0.0119g		**6**	0.0662	76.02%
f_3	oil laden feathers = 0.1900g - 0.0119g = 0.1781g		**7**	0.0579	81.66%
f_4	weight of feather after treatment		**8**	0.0608	79.69%

Contaminant	Bua Ban		**N**	**weight (g)**	**P%**
Magnetic Paste	BD1 (5gFe/g)		**0**	0.0000	0.00%
Replicate	3		**1**	0.1303	72.89%
			2	0.1032	81.80%
	weight of petri dish= 7.2334g		**3**	0.1016	82.33%
f_1	weight of feather cluster = 0.0479g		**4**	0.0996	82.99%
f_2	weight of oiled cluster = 0.3699g		**5**	0.1108	79.30%
	residual oil = 0.0181g		**6**	0.1238	75.02%
f_3	oil laden feathers = 0.3699g - 0.0181g = 0.3518g		**7**	0.1066	80.68%
f_4	weight of feather after treatment		**8**	0.0819	88.81%

				weight	
Contaminant	Bua Ban		**N**	**(g)**	**P%**
Magnetic Paste	BD1 (5gFe/g)		**0**	0.0000	0.00%
Replicate	4		**1**	0.1311	69.76%
			2	0.1140	76.45%
	weight of petri dish= 7.4734g		**3**	0.1123	76.92%
f_1	weight of feather cluster = 0.0517g		**4**	0.1065	79.13%
f_2	weight of oiled cluster = 0.3392g		**5**	0.0997	81.72%
	residual oil = 0.0249g		**6**	0.1175	74.94%
f_3	oil laden feathers = 0.3392g - 0.0249g = 0.3143g		**7**	0.1036	80.24%
f_4	weight of feather after treatment		**8**	0.0972	82.67%

Appendix B

Experimental data - Bunker 380 removal

		N	weight (g)	P%
Contaminant	Bunker 380			
iron powder		**0**	0.0000	0.00%
Replicate	1	**1**	0.023	93.14%
		2	0.0194	95.61%
	weight of petri dish= 7.8136g	**3**	0.0175	96.91%
f_1	weight of feather cluster = 0.0130g	**4**	0.0173	97.05%
f_2	weight of oiled cluster = 0.2294g	**5**	0.0146	98.90%
	residual oil = 0.0707g	**6**	0.017	97.25%
f_3	oil laden feathers = 0.2294g - 0.0707g = 0.1587g	**7**	0.0169	97.32%
f_4	weight of feather after treatment	**8**	0.0161	97.87%

		N	weight (g)	P%
Contaminant	Bunker 380			
iron powder		**0**	0.0000	0.00%
Replicate	2	**1**	0.3699	57.78%
		2	0.0417	97.31%
	weight of petri dish= 7.6869g	**3**	0.0235	99.51%
f_1	weight of feather cluster = 0.0194g	**4**	0.0232	99.54%
f_2	weight of oiled cluster = 1.1201g	**5**	0.0223	99.65%
	residual oil = 0.2706g	**6**	0.0217	99.72%
f_3	oil laden feathers = 1.1201g - 0.2706g = 0.8495g	**7**	0.0225	99.63%
f_4	weight of feather after treatment	**8**	0.0215	99.75%

Contaminant	Bunker 380	N	weight (g)	P%
iron powder		0	0.0000	0.00%
Replicate	3	1	0.1799	51.43%
		2	0.0276	96.73%
	weight of petri dish= 7.4426g	3	0.0203	98.90%
f_1	weight of feather cluster = 0.0166g	4	0.0181	99.55%
f_2	weight of oiled cluster = 0.4371g	5	0.0176	99.70%
	residual oil = 0.0843g	6	0.0175	99.73%
f_3	oil laden feathers = 0.4371g - 0.0843g = 0.3528g	7	0.0173	99.79%
f_4	weight of feather after treatment	8	0.017	99.88%

Contaminant	Bunker 380	N	weight (g)	P%
iron powder		0	0.0000	0.00%
Replicate	4	1	0.0944	81.16%
		2	0.0251	97.77%
	weight of petri dish= 7.7087g	3	0.0198	99.04%
f_1	weight of feather cluster = 0.0158g	4	0.0188	99.28%
f_2	weight of oiled cluster = 0.4791g	5	0.0187	99.30%
	residual oil = 0.0462g	6	0.0178	99.52%
f_3	oil laden feathers = 0.4791g - 0.0462g = 0.4329g	7	0.0182	99.42%
f_4	weight of feather after treatment	8	0.0171	99.69%

Contaminant	Bunker 380	N	weight (g)	P%
iron powder		0	0.0000	0.00%
Replicate	5	1	0.1175	72.23%
		2	0.0238	97.18%
	weight of petri dish= 7.5142g	3	0.0172	98.94%
f_1	weight of feather cluster = 0.0132g	4	0.0157	99.33%
f_2	weight of oiled cluster = 0.4520g	5	0.0156	99.36%
	residual oil = 0.0632g	6	0.0148	99.57%
f_3	oil laden feathers = 0.4520g - 0.0632g = 0.3888g	7	0.0153	99.44%
f_4	weight of feather after treatment	8	0.0146	99.63%

			N	weight (g)	P%
Contaminant	Bunker 380		**N**	**weight (g)**	**P%**
Magnetic Paste	DW (5gFe/g)		**0**	0.0000	0.00%
Replicate		1	**1**	0.3837	45.04%
			2	0.0818	91.49%
	weight of petri dish= 7.7216g		**3**	0.0525	96.00%
f_1	weight of feather cluster = 0.0265g		**4**	0.0422	97.58%
f_2	weight of oiled cluster = 0.7776g		**5**	0.0382	98.20%
	residual oil = 0.1012g		**6**	0.0375	98.31%
f_3	oil laden feathers = 0.7776g - 0.1012g = 0.6764g		**7**	0.0355	98.62%
f_4	weight of feather after treatment		**8**	0.0354	98.63%

			N	weight (g)	P%
Contaminant	Bunker 380		**N**	**weight (g)**	**P%**
Magnetic Paste	DW (5gFe/g)		**0**	0.0000	0.00%
Replicate		2	**1**	0.1521	60.85%
			2	0.0594	89.07%
	weight of petri dish= 7.5215g		**3**	0.0393	95.19%
f_1	weight of feather cluster = 0.0235g		**4**	0.0332	97.05%
f_2	weight of oiled cluster = 0.3852g		**5**	0.0307	97.81%
	residual oil = 0.0332g		**6**	0.0303	97.93%
f_3	oil laden feathers = 0.3852g - 0.0332g = 0.352g		**7**	0.0293	98.23%
f_4	weight of feather after treatment		**8**	0.0283	98.54%

			N	weight (g)	P%
Contaminant	Bunker 380		**N**	**weight (g)**	**P%**
Magnetic Paste	DW (5gFe/g)		**0**	0.0000	0.00%
Replicate		3	**1**	0.4732	17.31%
			2	0.098	87.20%
	weight of petri dish= 7.3202g		**3**	0.0607	94.15%
f_1	weight of feather cluster = 0.0293g		**4**	0.0622	93.87%
f_2	weight of oiled cluster = 0.7455g		**5**	0.0511	95.94%
	residual oil = 0.1794g		**6**	0.045	97.08%
f_3	oil laden feathers = 0.7455g - 0.1794g = 0.5661g		**7**	0.0424	97.56%
f_4	weight of feather after treatment		**8**	0.0426	97.52%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	DW (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.4419	36.83%
		2	0.117	86.43%
	weight of petri dish= 7.6664g	**3**	0.0448	97.45%
f_1	weight of feather cluster = 0.0281g	**4**	0.0406	98.09%
f_2	weight of oiled cluster = 0.7540g	**5**	0.0397	98.23%
	residual oil = 0.0708g	**6**	0.0387	98.38%
f_3	oil laden feathers = 0.7540g - 0.0708g = 0.6832g	**7**	0.0363	98.75%
f_4	weight of feather after treatment	**8**	0.0373	98.60%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	DW (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.6636	22.11%
		2	0.2448	74.09%
	weight of petri dish= 7.2932g	**3**	0.0752	95.14%
f_1	weight of feather cluster = 0.0360g	**4**	0.0587	97.18%
f_2	weight of oiled cluster = 0.9839g	**5**	0.0551	97.63%
	residual oil = 0.1421g	**6**	0.0522	97.99%
f_3	oil laden feathers = 0.9839g - 0.1421g = 0.8418g	**7**	0.0513	98.10%
f_4	weight of feather after treatment	**8**	0.051	98.14%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	4% acetic acid v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.1418	66.47%
		2	0.0295	96.28%
	weight of petri dish= 7.2754g	**3**	0.0228	98.06%
f_1	weight of feather cluster = 0.0155g	**4**	0.0224	98.17%
f_2	weight of oiled cluster = 0.4725g	**5**	0.0229	98.04%
	residual oil = 0.0803g	**6**	0.0215	98.41%
f_3	oil laden feathers = 0.4725g - 0.0803g = 0.3922g	**7**	0.0225	98.14%
f_4	weight of feather after treatment	**8**	0.0227	98.09%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	4% acetic acid v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.135	74.91%
		2	0.042	95.18%
	weight of petri dish= 7.6837g	**3**	0.0393	95.77%
f_1	weight of feather cluster = 0.0199g	**4**	0.028	98.23%
f_2	weight of oiled cluster = 0.5603g	**5**	0.0262	98.63%
	residual oil = 0.0817g	**6**	0.027	98.45%
f_3	oil laden feathers = 0.5603g - 0.0817g = 0.4786g	**7**	0.0265	98.56%
f_4	weight of feather after treatment	**8**	0.0262	98.63%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	4% acetic acid v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.1548	54.54%
		2	0.038	97.64%
	weight of petri dish= 7.2661g	**3**	0.0464	94.54%
f_1	weight of feather cluster = 0.0316g	**4**	0.0441	95.39%
f_2	weight of oiled cluster = 0.3272g	**5**	0.0429	95.83%
	residual oil = 0.0246g	**6**	0.0408	96.61%
f_3	oil laden feathers = 0.3272g - 0.0246g = 0.3026g	**7**	0.041	96.53%
f_4	weight of feather after treatment	**8**	0.0412	96.46%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	4% acetic acid v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.247	53.82%
		2	0.0695	92.54%
	weight of petri dish= 7.6383g	**3**	0.06	94.61%
f_1	weight of feather cluster = 0.0353g	**4**	0.0521	96.34%
f_2	weight of oiled cluster = 0.5490g	**5**	0.0491	96.99%
	residual oil = 0.0553g	**6**	0.0476	97.32%
f_3	oil laden feathers = 0.5490g - 0.0553g = 0.4937g	**7**	0.0433	98.25%
f_4	weight of feather after treatment	**8**	0.0445	97.99%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	4% acetic acid v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.168	60.95%
		2	0.0632	90.29%
	weight of petri dish= 7.6690g	**3**	0.0461	95.07%
f_1	weight of feather cluster = 0.0285g	**4**	0.0414	96.39%
f_2	weight of oiled cluster = 0.4132g	**5**	0.0401	96.75%
	residual oil = 0.0275g	**6**	0.042	96.22%
f_3	oil laden feathers = 0.4132g - 0.0275g = 0.3857g	**7**	0.0425	96.08%
f_4	weight of feather after treatment	**8**	0.0415	96.36%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	8% acetic acid v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.5056	28.67%
		2	0.1371	86.64%
	weight of petri dish= 7.1746g	**3**	0.0649	96.19%
f_1	weight of feather cluster = 0.0361g	**4**	0.0467	98.60%
f_2	weight of oiled cluster = 0.8664g	**5**	0.0482	98.40%
	residual oil = 0.0741g	**6**	0.0467	98.60%
f_3	oil laden feathers = 0.8664g - 0.0741g = 0.7923g	**7**	0.0441	98.94%
f_4	weight of feather after treatment	**8**	0.0473	98.52%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	8% acetic acid v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.2531	45.06%
		2	0.0806	87.60%
	weight of petri dish= 7.8217g	**3**	0.0542	94.11%
f_1	weight of feather cluster = 0.0303g	**4**	0.0488	95.44%
f_2	weight of oiled cluster = 0.5108g	**5**	0.0492	95.34%
	residual oil = 0.0750g	**6**	0.0481	95.61%
f_3	oil laden feathers = 0.5108g - 0.0750g = 0.4358g	**7**	0.0447	96.45%
f_4	weight of feather after treatment	**8**	0.0435	96.74%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	8% acetic acid v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.1392	72.94%
		2	0.0688	89.49%
	weight of petri dish= 7.8108g	**3**	0.0461	94.83%
f_1	weight of feather cluster = 0.0241g	**4**	0.037	96.97%
f_2	weight of oiled cluster = 0.4944g	**5**	0.0348	97.48%
	residual oil = 0.0450g	**6**	0.0321	98.12%
f_3	oil laden feathers = 0.4944g - 0.0450g = 0.4494g	**7**	0.0318	98.19%
f_4	weight of feather after treatment	**8**	0.0301	98.59%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	8% acetic acid v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.182	49.98%
		2	0.0696	86.30%
	weight of petri dish= 7.1594g	**3**	0.0516	92.12%
f_1	weight of feather cluster = 0.0272	**4**	0.0464	93.80%
f_2	weight of oiled cluster = 0.3563g	**5**	0.0379	96.54%
	residual oil = 0.0196g	**6**	0.0419	95.25%
f_3	oil laden feathers = 0.3563g - 0.0196g = 0.3367g	**7**	0.0414	95.41%
f_4	weight of feather after treatment	**8**	0.0407	95.64%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	8% acetic acid v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.1585	62.89%
		2	0.0676	88.21%
	weight of petri dish= 7.8365g	**3**	0.0543	91.92%
f_1	weight of feather cluster = 0.0253g	**4**	0.0434	94.96%
f_2	weight of oiled cluster = 0.4267g	**5**	0.0432	95.01%
	residual oil = 0.0425g	**6**	0.0395	96.04%
f_3	oil laden feathers = 0.4267g - 0.0425g = 0.3842g	**7**	0.0404	95.79%
f_4	weight of feather after treatment	**8**	0.0392	96.13%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	10% acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.1945	67.54%
		2	0.1052	84.32%
	weight of petri dish= 7.7477g	**3**	0.0939	86.45%
f_1	weight of feather cluster = 0.0218g	**4**	0.0386	96.84%
f_2	weight of oiled cluster = 0.6406g	**5**	0.0313	98.21%
	residual oil = 0.0868g	**6**	0.0302	98.42%
f_3	oil laden feathers = 0.6406g - 0.0868g = 0.5538g	**7**	0.0278	98.87%
f_4	weight of feather after treatment	**8**	0.0286	98.72%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	10% acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.2258	67.32%
		2	0.1552	78.79%
	weight of petri dish= 7.4891g	**3**	0.102	87.43%
f_1	weight of feather cluster = 0.0246g	**4**	0.0624	93.86%
f_2	weight of oiled cluster = 0.7370g	**5**	0.0409	97.35%
	residual oil = 0.0967g	**6**	0.038	97.82%
f_3	oil laden feathers = 0.7370g - 0.0967g = 0.6403g	**7**	0.0342	98.44%
f_4	weight of feather after treatment	**8**	0.0307	99.01%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	10% acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.241	62.44%
		2	0.0655	92.61%
	weight of petri dish= 6.5798g	**3**	0.0469	95.81%
f_1	weight of feather cluster = 0.0225g	**4**	0.0379	97.35%
f_2	weight of oiled cluster = 0.7280g	**5**	0.017	100.95%
	residual oil = 0.1238g	**6**	0.0334	98.13%
f_3	oil laden feathers = 0.7280g - 0.1238g = 0.6042g	**7**	0.0323	98.32%
f_4	weight of feather after treatment	**8**	0.0323	98.32%

			weight	
Contaminant	Bunker 380	**N**	**(g)**	**P%**
Magnetic Paste	10% acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.1541	62.13%
		2	0.0917	80.42%
	weight of petri dish= 7.6512g	**3**	0.0368	96.51%
f_1	weight of feather cluster = 0.0249g	**4**	0.0373	96.37%
f_2	weight of oiled cluster = 0.4433g	**5**	0.035	97.04%
	residual oil = 0.0772g	**6**	0.0337	97.42%
f_3	oil laden feathers = 0.4433g - 0.0772g = 0.3661g	**7**	0.0321	97.89%
f_4	weight of feather after treatment	**8**	0.0318	97.98%

			weight	
Contaminant	Bunker 380	**N**	**(g)**	**P%**
Magnetic Paste	10% acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.3257	50.44%
		2	0.1349	82.56%
	weight of petri dish= 6.6081g	**3**	0.1011	88.25%
f_1	weight of feather cluster = 0.0313g	**4**	0.057	95.67%
f_2	weight of oiled cluster = 0.7328g	**5**	0.0592	95.30%
	residual oil = 0.1075g	**6**	0.0452	97.66%
f_3	oil laden feathers = 0.7328g - 0.1075g = 0.6253g	**7**	0.0433	97.98%
f_4	weight of feather after treatment	**8**	0.0402	98.50%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	20% acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.4435	43.18%
		2	0.2521	68.97%
	weight of petri dish= 6.5252g	**3**	0.0816	91.94%
f_1	weight of feather cluster = 0.0218g	**4**	0.0422	97.25%
f_2	weight of oiled cluster = 0.9080g	**5**	0.0346	98.28%
	residual oil = 0.1440g	**6**	0.0314	98.71%
f_3	oil laden feathers = 0.9080g - 0.1440g = 0.764g	**7**	0.0313	98.72%
f_4	weight of feather after treatment	**8**	0.032	98.63%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	20% acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate		**1**	0.2513	68.05%
		2	0.1355	84.23%
	weight of petri dish= 6.5187g	**3**	0.0612	94.62%
f_1	weight of feather cluster = 0.0227g	**4**	0.038	97.86%
f_2	weight of oiled cluster = 0.9249g	**5**	0.0361	98.13%
	residual oil = 0.1868g	**6**	0.0348	98.31%
f_3	oil laden feathers = 0.9249g - 0.1868g = 0.7381g	**7**	0.0328	98.59%
f_4	weight of feather after treatment	**8**	0.033	98.56%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	20% acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.2074	63.22%
		2	0.108	82.62%
	weight of petri dish= 6.5267g	**3**	0.045	94.92%
f_1	weight of feather cluster = 0.0190g	**4**	0.0297	97.91%
f_2	weight of oiled cluster = 0.6189g	**5**	0.026	98.63%
	residual oil = 0.0877g	**6**	0.0268	98.48%
f_3	oil laden feathers = 0.6189g - 0.0877g = 0.5312g	**7**	0.0252	98.79%
f_4	weight of feather after treatment	**8**	0.0254	98.75%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	20% acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.1961	63.37%
		2	0.0873	85.82%
	weight of petri dish= 6.5266g	**3**	0.0498	93.56%
f_1	weight of feather cluster = 0.0262g	**4**	0.0381	95.98%
f_2	weight of oiled cluster = 0.6474g	**5**	0.0345	96.72%
	residual oil = 0.0112g	**6**	0.0309	97.46%
f_3	oil laden feathers = 0.6474g - 0.0112g = 0.5362g	**7**	0.0278	98.10%
f_4	weight of feather after treatment	**8**	0.0268	98.31%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	20% acetic acid (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.1621	55.89%
		2	0.0871	79.12%
	weight of petri dish= 6.5345g	**3**	0.0526	89.81%
f_1	weight of feather cluster = 0.0197g	**4**	0.0516	90.12%
f_2	weight of oiled cluster = 0.4624g	**5**	0.0341	95.54%
	residual oil = 0.1199g	**6**	0.0306	96.62%
f_3	oil laden feathers = 0.4624g - 0.1199g = 0.3425g	**7**	0.0298	96.87%
f_4	weight of feather after treatment	**8**	0.0293	97.03%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.3182	64.15%
		2	0.1838	80.49%
	weight of petri dish= 7.6664g	**3**	0.0582	95.76%
f_1	weight of feather cluster = 0.0233g	**4**	0.0512	96.61%
f_2	weight of oiled cluster = 0.9462g	**5**	0.05	96.75%
	residual oil = 0.1004g	**6**	0.0456	97.29%
f_3	oil laden feathers = 0.9462g - 0.1004g = 0.8458g	**7**	0.0421	97.71%
f_4	weight of feather after treatment	**8**	0.0444	97.43%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.2287	60.22%
		2	0.1711	71.29%
	weight of petri dish= 7.4261g	**3**	0.0575	93.14%
f_1	weight of feather cluster = 0.0218g	**4**	0.0466	95.23%
f_2	weight of oiled cluster = 0.5995g	**5**	0.0325	97.94%
	residual oil = 0.0576g	**6**	0.0399	96.52%
f_3	oil laden feathers = 0.5995g - 0.0576g = 0.5419g	**7**	0.0416	96.19%
f_4	weight of feather after treatment	**8**	0.0393	96.64%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.4143	52.36%
		2	0.2405	73.66%
	weight of petri dish= 7.4503g	**3**	0.0886	92.27%
f_1	weight of feather cluster = 0.0255g	**4**	0.0658	95.06%
f_2	weight of oiled cluster = 0.8529g	**5**	0.053	96.63%
	residual oil = 0.01124g	**6**	0.0461	97.48%
f_3	oil laden feathers = 0.8529g - 0.0112g = 0.8417g	**7**	0.043	97.86%
f_4	weight of feather after treatment	**8**	0.0458	97.51%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.2337	64.81%
		2	0.0821	90.51%
	weight of petri dish= 7.6688g	**3**	0.0599	94.27%
f_1	weight of feather cluster = 0.0261g	**4**	0.05	95.95%
f_2	weight of oiled cluster = 0.6781g	**5**	0.0433	97.08%
	residual oil = 0.0621g	**6**	0.0433	97.08%
f_3	oil laden feathers = 0.6781g - 0.0621g = 0.616g	**7**	0.0441	96.95%
f_4	weight of feather after treatment	**8**	0.0395	97.73%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.113	80.45%
		2	0.1187	79.30%
	weight of petri dish= 7.4011g	**3**	0.0648	90.18%
f_1	weight of feather cluster = 0.0161g	**4**	0.0444	94.29%
f_2	weight of oiled cluster = 0.5899g	**5**	0.026	98.00%
	residual oil = 0.0781g	**6**	0.0292	97.36%
f_3	oil laden feathers = 0.5899g - 0.0781g = 0.5118g	**7**	0.0291	97.38%
f_4	weight of feather after treatment	**8**	0.0281	97.58%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	Fairy 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.2042	60.81%
		2	0.0422	95.37%
	weight of petri dish= 7.4172g	**3**	0.0409	95.65%
f_1	weight of feather cluster = 0.0205g	**4**	0.0409	95.65%
f_2	weight of oiled cluster = 0.5478g	**5**	0.0414	95.54%
	residual oil = 0.0585g	**6**	0.0377	96.33%
f_3	oil laden feathers = 0.5478g - 0.0585g = 0.4893g	**7**	0.0394	95.97%
f_4	weight of feather after treatment	**8**	0.0417	95.48%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	Fairy 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.08	89.34%
		2	0.0372	96.97%
	weight of petri dish= 7.2643g	**3**	0.0382	96.79%
f_1	weight of feather cluster = 0.0202g	**4**	0.0352	97.33%
f_2	weight of oiled cluster = 0.6439g	**5**	0.035	97.36%
	residual oil = 0.0629g	**6**	0.0357	97.24%
f_3	oil laden feathers = 0.6439g - 0.0629g = 0.5810g	**7**	0.0365	97.09%
f_4	weight of feather after treatment	**8**	0.0353	97.31%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	Fairy 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.3011	53.38%
		2	0.0871	90.01%
	weight of petri dish= 7.4183g	**3**	0.0557	95.38%
f_1	weight of feather cluster = 0.0287g	**4**	0.0534	95.77%
f_2	weight of oiled cluster = 0.6906g	**5**	0.0528	95.88%
	residual oil = 0.0776g	**6**	0.0511	96.17%
f_3	oil laden feathers = 0.6906g - 0.0776g = 0.613g	**7**	0.0492	96.49%
f_4	weight of feather after treatment	**8**	0.0481	96.68%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	Fairy 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.2996	54.28%
		2	0.0805	91.92%
	weight of petri dish= 7.4201g	**3**	0.0618	95.14%
f_1	weight of feather cluster = 0.0335g	**4**	0.0592	95.58%
f_2	weight of oiled cluster = 0.6686g	**5**	0.0598	95.48%
	residual oil = 0.0531g	**6**	0.0557	96.19%
f_3	oil laden feathers = 0.6686g - 0.0531g = 0.6155g	**7**	0.0564	96.07%
f_4	weight of feather after treatment	**8**	0.0556	96.20%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	Fairy 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.2133	62.93%
		2	0.1176	82.20%
	weight of petri dish= 7.4591g	**3**	0.0845	88.86%
f_1	weight of feather cluster = 0.0292g	**4**	0.0713	91.52%
f_2	weight of oiled cluster = 0.5846g	**5**	0.0646	92.87%
	residual oil = 0.0588g	**6**	0.064	92.99%
f_3	oil laden feathers = 0.5846g - 0.0588g = 0.5258g	**7**	0.0586	94.08%
f_4	weight of feather after treatment	**8**	0.0481	96.19%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	Nivea (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.3341	44.50%
		2	0.1596	76.02%
	weight of petri dish= 7.6781g	**3**	0.0948	87.72%
f_1	weight of feather cluster = 0.0268g	**4**	0.0682	92.52%
f_2	weight of oiled cluster = 0.6725g	**5**	0.0588	94.22%
	residual oil = 0.0920g	**6**	0.0565	94.64%
f_3	oil laden feathers = 0.6725g - 0.0920g = 0.5805g	**7**	0.053	95.27%
f_4	weight of feather after treatment	**8**	0.0503	95.76%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	Nivea (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.6304	9.74%
		2	0.3575	51.29%
	weight of petri dish= 7.6700g	**3**	0.1782	78.58%
f_1	weight of feather cluster = 0.0375g	**4**	0.1365	84.93%
f_2	weight of oiled cluster = 0.7539g	**5**	0.0966	91.00%
	residual oil = 0.0595g	**6**	0.0863	92.57%
f_3	oil laden feathers = 0.7539g - 0.0595g = 0.6944g	**7**	0.0759	94.15%
f_4	weight of feather after treatment	**8**	0.073	94.60%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	Nivea (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.3187	52.51%
		2	0.1628	78.00%
	weight of petri dish= 7.4359g	**3**	0.092	89.57%
f_1	weight of feather cluster = 0.0282g	**4**	0.0697	93.22%
f_2	weight of oiled cluster = 0.5912g	**5**	0.0592	94.93%
	residual oil = 0.0487g	**6**	0.0551	95.60%
f_3	oil laden feathers = 0.5912g - 0.0487g = 0.6399g	**7**	0.053	95.95%
f_4	weight of feather after treatment	**8**	0.0503	96.39%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	Nivea (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.2808	49.32%
		2	0.1596	73.14%
	weight of petri dish= 7.4418g	**3**	0.0862	87.56%
f_1	weight of feather cluster = 0.0229g	**4**	0.0674	91.26%
f_2	weight of oiled cluster = 0.5939g	**5**	0.0594	92.83%
	residual oil = 0.0621g	**6**	0.058	93.10%
f_3	oil laden feathers = 0.5939g - 0.0621g = 0.5318g	**7**	0.0453	95.60%
f_4	weight of feather after treatment	**8**	0.0407	96.50%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	Nivea (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.2378	31.80%
		2	0.1058	72.87%
	weight of petri dish= 7.6739g	**3**	0.0786	81.33%
f_1	weight of feather cluster = 0.0186g	**4**	0.0538	89.05%
f_2	weight of oiled cluster = 0.3651g	**5**	0.039	93.65%
	residual oil = 0.0251g	**6**	0.0401	93.31%
f_3	oil laden feathers = 0.3651g - 0.0251g = 0.340g	**7**	0.0366	94.40%
f_4	weight of feather after treatment	**8**	0.0367	94.37%

			N	weight (g)	P%
Contaminant	Bunker 380				
Magnetic Paste	Perfect Gel (4gFe/g)		**0**	0.0000	0.00%
Replicate	1		**1**	0.384	44.83%
			2	0.1739	77.00%
	weight of petri dish= 7.6712g		**3**	0.1095	86.86%
f_1	weight of feather cluster = 0.0237g		**4**	0.0668	93.40%
f_2	weight of oiled cluster = 0.7403g		**5**	0.0516	95.73%
	residual oil = 0.0635g		**6**	0.0374	97.90%
f_3	oil laden feathers = 0.7403g - 0.0635g = 0.6768g		**7**	0.0337	98.47%
f_4	weight of feather after treatment		**8**	0.037	97.96%

			N	weight (g)	P%
Contaminant	Bunker 380				
Magnetic Paste	Perfect Gel (4gFe/g)		**0**	0.0000	0.00%
Replicate	2		**1**	0.3153	48.15%
			2	0.1425	78.76%
	weight of petri dish= 7.6624g		**3**	0.0892	88.20%
f_1	weight of feather cluster = 0.0226g		**4**	0.0608	93.23%
f_2	weight of oiled cluster = 0.6474g		**5**	0.0477	95.55%
	residual oil = 0.0603g		**6**	0.0398	96.95%
f_3	oil laden feathers = 0.6474g - 0.0603g = 0.5871g		**7**	0.039	97.09%
f_4	weight of feather after treatment		**8**	0.0347	97.86%

			N	weight (g)	P%
Contaminant	Bunker 380				
Magnetic Paste	Perfect Gel (4gFe/g)		**0**	0.0000	0.00%
Replicate	3		**1**	0.3793	35.69%
			2	0.1636	74.56%
	weight of petri dish= 7.6816g		**3**	0.1092	84.36%
f_1	weight of feather cluster = 0.0224g		**4**	0.0661	92.13%
f_2	weight of oiled cluster = 0.6410g		**5**	0.0503	94.97%
	residual oil = 0.0627g		**6**	0.0451	95.91%
f_3	oil laden feathers = 0.6410g - 0.0627g = 0.5774g		**7**	0.0398	96.86%
f_4	weight of feather after treatment		**8**	0.0424	96.40%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	Perfect Gel (4gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.1767	78.72%
		2	0.1004	89.80%
	weight of petri dish= 7.4359g	**3**	0.0731	93.77%
f_1	weight of feather cluster = 0.0302g	**4**	0.0453	97.81%
f_2	weight of oiled cluster = 0.8233g	**5**	0.0381	98.85%
	residual oil = 0.1046g	**6**	0.0394	98.66%
f_3	oil laden feathers = 0.8233g - 0.1046g = 0.7187g	**7**	0.0371	99.00%
f_4	weight of feather after treatment	**8**	0.0386	98.78%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	Perfect Gel (4gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.419	40.81%
		2	0.2185	71.38%
	weight of petri dish= 7.6621g	**3**	0.1578	80.64%
f_1	weight of feather cluster = 0.0308g	**4**	0.0926	90.58%
f_2	weight of oiled cluster = 0.7652g	**5**	0.0756	93.17%
	residual oil = 0.0785g	**6**	0.0628	95.12%
f_3	oil laden feathers = 0.7652g - 0.0785g = 0.6867g	**7**	0.0565	96.08%
f_4	weight of feather after treatment	**8**	0.0584	95.79%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.305	26.47%
		2	0.0828	84.59%
	weight of petri dish= 7.6352g	**3**	0.0501	93.15%
f_1	weight of feather cluster = 0.0239g	**4**	0.0416	95.37%
f_2	weight of oiled cluster = 0.4470g	**5**	0.0266	99.29%
	residual oil = 0.0408g	**6**	0.0325	97.75%
f_3	oil laden feathers = 0.4470g - 0.0408g = 0.4062g	**7**	0.031	98.14%
f_4	weight of feather after treatment	**8**	0.0303	98.33%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.2138	50.57%
		2	0.1061	78.34%
	weight of petri dish= 7.4175g	**3**	0.0557	91.34%
f_1	weight of feather cluster = 0.0221g	**4**	0.0323	97.37%
f_2	weight of oiled cluster = 0.4531g	**5**	0.0293	98.14%
	residual oil = 0.0432g	**6**	0.0249	99.28%
f_3	oil laden feathers = 0.4531g - 0.0432g = 0.4099g	**7**	0.0246	99.36%
f_4	weight of feather after treatment	**8**	0.0232	99.72%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0704	71.27%
		2	0.0346	91.56%
	weight of petri dish= 7.4485g	**3**	0.0296	94.39%
f_1	weight of feather cluster = 0.0197g	**4**	0.0271	95.81%
f_2	weight of oiled cluster = 0.2177g	**5**	0.0258	96.54%
	residual oil = 0.0215g	**6**	0.024	97.56%
f_3	oil laden feathers = 0.2177g - 0.0215g = 0.1962g	**7**	0.0243	97.39%
f_4	weight of feather after treatment	**8**	0.0245	97.28%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.1542	73.50%
		2	0.0527	94.48%
	weight of petri dish= 7.6587g	**3**	0.0355	98.04%
f_1	weight of feather cluster = 0.0260g	**4**	0.0319	98.78%
f_2	weight of oiled cluster = 0.5472g	**5**	0.0308	99.01%
	residual oil = 0.0374g	**6**	0.0299	99.19%
f_3	oil laden feathers = 0.5472g - 0.0374g = 0.5098g	**7**	0.0289	99.40%
f_4	weight of feather after treatment	**8**	0.0298	99.21%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 5% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.1183	66.55%
		2	0.0682	83.12%
	weight of petri dish= 7.6405g	**3**	0.0339	94.47%
f_1	weight of feather cluster = 0.0172g	**4**	0.0241	97.72%
f_2	weight of oiled cluster = 0.3437g	**5**	0.0194	99.27%
	residual oil = 0.0243g	**6**	0.0158	100.46%
f_3	oil laden feathers = 0.3437g - 0.0243g = 0.3194g	**7**	0.0257	97.19%
f_4	weight of feather after treatment	**8**	0.0166	100.20%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	EO 20% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	**1**	**1**	0.2924	38.93%
		2	0.0647	89.64%
	weight of petri dish= 7.5357g	**3**	0.031	97.15%
f_1	weight of feather cluster = 0.0182g	**4**	0.0277	97.88%
f_2	weight of oiled cluster = 0.5394g	**5**	0.0268	98.08%
	residual oil = 0.0722g	**6**	0.0279	97.84%
f_3	oil laden feathers = 0.5394g - 0.0722g = 0.4672g	**7**	0.0234	98.84%
f_4	weight of feather after treatment	**8**	0.0215	99.27%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	EO 20% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.4948	27.01%
		2	0.1253	84.92%
	weight of petri dish= 7.7024g	**3**	0.0515	96.49%
f_1	weight of feather cluster = 0.0291g	**4**	0.0398	98.32%
f_2	weight of oiled cluster = 0.7376g	**5**	0.0379	98.62%
	residual oil = 0.0705g	**6**	0.0412	98.10%
f_3	oil laden feathers = 0.7376g - 0.0705g = 0.6671g	**7**	0.0358	98.95%
f_4	weight of feather after treatment	**8**	0.0343	99.18%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	EO 20% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.7826	6.76%
		2	0.2208	77.62%
	weight of petri dish= 7.7217g	**3**	0.0733	96.23%
f_1	weight of feather cluster = 0.0434g	**4**	0.0534	98.74%
f_2	weight of oiled cluster = 0.9811g	**5**	0.0516	98.97%
	residual oil = 0.1449g	**6**	0.052	98.92%
f_3	oil laden feathers = 0.9811g - 0.1449g = 0.8362g	**7**	0.0514	98.99%
f_4	weight of feather after treatment	**8**	0.0522	98.89%

				weight	
Contaminant	Bunker 380		**N**	**(g)**	**P%**
Magnetic Paste	EO 20% v/v (5gFe/g)		**0**	0.0000	0.00%
Replicate	4		**1**	0.5807	23.27%
			2	0.1878	80.75%
	weight of petri dish= 7.4403g		**3**	0.1088	92.31%
f_1	weight of feather cluster = 0.0562g		**4**	0.0756	97.16%
f_2	weight of oiled cluster = 0.8067g		**5**	0.0806	96.43%
	residual oil = 0.0669g		**6**	0.0735	97.47%
f_3	oil laden feathers = 0.8067g - 0.0669g = 0.7398g		**7**	0.0626	99.06%
f_4	weight of feather after treatment		**8**	0.0711	97.82%

				weight	
Contaminant	Bunker 380		**N**	**(g)**	**P%**
Magnetic Paste	EO 20% v/v (5gFe/g)		**0**	0.0000	0.00%
Replicate	5		**1**	0.0587	85.68%
			2	0.0323	95.76%
	weight of petri dish= 7.4142g		**3**	0.0274	97.63%
f_1	weight of feather cluster = 0.0212g		**4**	0.0271	97.75%
f_2	weight of oiled cluster = 0.3084g		**5**	0.0271	97.75%
	residual oil = 0.0254g		**6**	0.0292	96.94%
f_3	oil laden feathers = 0.3084g - 0.0254g = 0.283g		**7**	0.0301	96.60%
f_4	weight of feather after treatment		**8**	0.0289	97.06%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 25% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.1839	72.23%
		2	0.0413	96.96%
	weight of petri dish= 7.6414g	**3**	0.027	99.44%
f_1	weight of feather cluster = 0.0238g	**4**	0.0255	99.71%
f_2	weight of oiled cluster = 0.6569g	**5**	0.029	99.10%
	residual oil = 0.0566g	**6**	0.0257	99.67%
f_3	oil laden feathers = 0.6569g - 0.0566g = 0.6003g	**7**	0.0243	99.91%
f_4	weight of feather after treatment	**8**	0.0241	99.95%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 25% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.1985	68.94%
		2	0.0356	97.14%
	weight of petri dish= 7.3084g	**3**	0.0242	99.12%
f_1	weight of feather cluster = 0.0191g	**4**	0.023	99.32%
f_2	weight of oiled cluster = 0.6642g	**5**	0.0237	99.20%
	residual oil = 0.0676g	**6**	0.0224	99.43%
f_3	oil laden feathers = 0.6642g - 0.0676g = 0.5966g	**7**	0.023	99.32%
f_4	weight of feather after treatment	**8**	0.0237	99.20%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	EO 25% v/v (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.3494	49.64%
		2	0.0569	95.85%
	weight of petri dish= 7.5544g	**3**	0.0377	98.88%
f_1	weight of feather cluster = 0.0306g	**4**	0.0363	99.10%
f_2	weight of oiled cluster = 0.7580g	**5**	0.0335	99.54%
	residual oil = 0.0944g	**6**	0.0334	99.56%
f_3	oil laden feathers = 0.7580g - 0.0944g = 0.6636g	**7**	0.0338	99.49%
f_4	weight of feather after treatment	**8**	0.0309	99.95%

Contaminant Bunker 380
Magnetic Paste EO 25% v/v (5gFe/g)
Replicate 4

weight of petri dish= 7.4992g

f_1 weight of feather cluster = 0.0217g

f_2 weight of oiled cluster = 0.7137g
residual oil = 0.1014g

f_3 oil laden feathers = 0.7137g - 0.1014g = 0.6123g

f_4 weight of feather after treatment

N	**weight (g)**	**P%**
0	0.0000	0.00%
1	0.3681	41.35%
2	0.171	74.72%
3	0.0332	98.05%
4	0.0305	98.51%
5	0.0286	98.83%
6	0.0274	99.03%
7	0.0276	99.00%
8	0.0249	99.46%

Contaminant Bunker 380
Magnetic Paste EO 25% v/v (5gFe/g)
Replicate 5

weight of petri dish= 7.5870g

f_1 weight of feather cluster = 0.0199g

f_2 weight of oiled cluster = 0.5306g
residual oil = 0.1391g

f_3 oil laden feathers = 0.5306g - 0.1391g = 0.3915g

f_4 weight of feather after treatment

N	**weight (g)**	**P%**
0	0.0000	0.00%
1	0.1739	58.56%
2	0.0468	92.76%
3	0.0267	98.17%
4	0.0242	98.84%
5	0.025	98.63%
6	0.0251	98.60%
7	0.0223	99.35%
8	0.0243	98.82%

Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	MS (6gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.1494	80.45%
		2	0.0497	96.83%
	weight of petri dish= 7.1385g	**3**	0.0429	97.95%
f_1	weight of feather cluster = 0.0304g	**4**	0.0435	97.85%
f_2	weight of oiled cluster = 0.6840g	**5**	0.0403	98.37%
	residual oil = 0.0449g	**6**	0.0414	98.19%
f_3	oil laden feathers = 0.6840g - 0.0449g = 0.6391g	**7**	0.0398	98.46%
f_4	weight of feather after treatment	**8**	0.0401	98.41%

Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	MS (6gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0544	92.60%
		2	0.0352	97.73%
	weight of petri dish= 7.8144g	**3**	0.0341	98.02%
f_1	weight of feather cluster = 0.0267g	**4**	0.0339	98.08%
f_2	weight of oiled cluster = 0.4382g	**5**	0.0322	98.53%
	residual oil = 0.0373g	**6**	0.0328	98.37%
f_3	oil laden feathers = 0.4382g - 0.0373g = 0.4009g	**7**	0.0345	97.92%
f_4	weight of feather after treatment	**8**	0.0346	97.89%

Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	MS (6gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.1272	83.74%
		2	0.0386	97.74%
	weight of petri dish= 7.1456g	**3**	0.0322	98.75%
f_1	weight of feather cluster = 0.0243g	**4**	0.0345	98.38%
f_2	weight of oiled cluster = 0.8082g	**5**	0.0315	98.86%
	residual oil = 0.1512g	**6**	0.0355	98.23%
f_3	oil laden feathers = 0.8082g - 0.1512g = 0.657g	**7**	0.0337	98.51%
f_4	weight of feather after treatment	**8**	0.0318	98.81%

			weight	
Contaminant	Bunker 380	**N**	**(g)**	**P%**
Magnetic Paste	MS (6gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0722	85.09%
		2	0.0337	96.92%
	weight of petri dish= 7.821g	**3**	0.0309	97.79%
f_1	weight of feather cluster = 0.0237g	**4**	0.0325	97.29%
f_2	weight of oiled cluster = 0.3860g	**5**	0.0306	97.88%
	residual oil = 0.0371g	**6**	0.0338	96.89%
f_3	oil laden feathers = 0.3860g - 0.0371g = 0.3489g	**7**	0.0322	97.39%
f_4	weight of feather after treatment	**8**	0.0322	97.39%

- No 5th replicate data available

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	EST (6gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.1072	89.24%
		2	0.0418	98.02%
	weight of petri dish= 7.4011g	**3**	0.0389	98.41%
f_1	weight of feather cluster = 0.0271g	**4**	0.0399	98.28%
f_2	weight of oiled cluster = 0.8381g	**5**	0.0384	98.48%
	residual oil = 0.0668g	**6**	0.035	98.94%
f_3	oil laden feathers = 0.8381g - 0.0668g = 0.7713g	**7**	0.0378	98.56%
f_4	weight of feather after treatment	**8**	0.0345	99.01%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	EST (6gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.1576	64.21%
		2	0.0433	94.72%
	weight of petri dish= 7.2270g	**3**	0.0352	96.88%
f_1	weight of feather cluster = 0.0235g	**4**	0.0333	97.38%
f_2	weight of oiled cluster = 0.4635g	**5**	0.036	96.66%
	residual oil = 0.0653g	**6**	0.0337	97.28%
f_3	oil laden feathers = 0.4635g - 0.0653g = 0.3982g	**7**	0.0336	97.30%
f_4	weight of feather after treatment	**8**	0.0358	96.72%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	EST (6gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.058	89.72%
		2	0.0378	95.58%
	weight of petri dish= 7.4242g	**3**	0.0349	96.43%
f_1	weight of feather cluster = 0.0226g	**4**	0.0376	95.64%
f_2	weight of oiled cluster = 0.4294g	**5**	0.0366	95.93%
	residual oil = 0.0626g	**6**	0.0367	95.90%
f_3	oil laden feathers = 0.4294g - 0.0626g = 0.3668g	**7**	0.0378	95.58%
f_4	weight of feather after treatment	**8**	0.0392	95.18%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	EST (6gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0266	95.50%
		2	0.0216	97.58%
	weight of petri dish= 7.2272g	**3**	0.0218	97.50%
f_1	weight of feather cluster = 0.0158g	**4**	0.0215	97.63%
f_2	weight of oiled cluster = 0.3201g	**5**	0.022	97.42%
	residual oil = 0.0643g	**6**	0.0213	97.71%
f_3	oil laden feathers = 0.3201g - 0.0643g = 0.2558g	**7**	0.0221	97.38%
f_4	weight of feather after treatment	**8**	0.0222	97.33%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	EST (6gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.228	81.78%
		2	0.0535	97.92%
	weight of petri dish= 7.4067g	**3**	0.034	99.72%
f_1	weight of feather cluster = 0.0310g	**4**	0.0386	99.30%
f_2	weight of oiled cluster = 1.2067g	**5**	0.037	99.45%
	residual oil = 0.0944g	**6**	0.0372	99.43%
f_3	oil laden feathers = 1.2067g - 0.0944g = 1.1123g	**7**	0.0374	99.41%
f_4	weight of feather after treatment	**8**	0.0413	99.05%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	MO (6gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0295	91.44%
		2	0.0192	96.48%
	weight of petri dish= 7.5427g	**3**	0.0186	96.77%
f_1	weight of feather cluster = 0.0120g	**4**	0.017	97.55%
f_2	weight of oiled cluster = 0.2310g	**5**	0.0176	97.26%
	residual oil = 0.0146g	**6**	0.0162	97.95%
f_3	oil laden feathers = 0.2310g - 0.0146g = 0.2164g	**7**	0.0176	97.26%
f_4	weight of feather after treatment	**8**	0.0177	97.21%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	MO (6gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0523	90.09%
		2	0.023	97.67%
	weight of petri dish= 7.7923g	**3**	0.0218	97.98%
f_1	weight of feather cluster = 0.0140g	**4**	0.0214	98.08%
f_2	weight of oiled cluster = 0.5032g	**5**	0.0219	97.95%
	residual oil = 0.1029g	**6**	0.0205	98.32%
f_3	oil laden feathers = 0.5032g - 0.1029g = 0.4003g	**7**	0.0205	98.32%
f_4	weight of feather after treatment	**8**	0.019	98.71%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	MO (6gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0526	93.28%
		2	0.0294	97.75%
	weight of petri dish= 7.4626g	**3**	0.0254	98.52%
f_1	weight of feather cluster = 0.0177g	**4**	0.0265	98.31%
f_2	weight of oiled cluster = 0.6323g	**5**	0.0278	98.06%
	residual oil = 0.0862g	**6**	0.0248	98.63%
f_3	oil laden feathers = 0.6323g - 0.0862g = 0.537g	**7**	0.0203	99.50%
f_4	weight of feather after treatment	**8**	0.02	99.56%

Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	MO (6gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.1675	72.82%
		2	0.0532	93.94%
	weight of petri dish= 7.4794g	**3**	0.0332	97.63%
f_1	weight of feather cluster = 0.0204g	**4**	0.0326	97.75%
f_2	weight of oiled cluster = 0.7066g	**5**	0.0339	97.51%
	residual oil = 0.1450g	**6**	0.0337	97.54%
f_3	oil laden feathers = 0.7066g - 0.1450g = 0.5616g	**7**	0.0321	97.84%
f_4	weight of feather after treatment	**8**	0.0327	97.73%

Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	MO (6gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0481	83.02%
		2	0.0227	95.74%
	weight of petri dish= 7.6742g	**3**	0.0213	96.44%
f_1	weight of feather cluster = 0.0142g	**4**	0.0212	96.49%
f_2	weight of oiled cluster = 0.2520g	**5**	0.0211	96.54%
	residual oil = 0.0381g	**6**	0.021	96.59%
f_3	oil laden feathers = 0.2520g - 0.0381g = 0.2139g	**7**	0.0201	97.05%
f_4	weight of feather after treatment	**8**	0.022	96.09%

			N	weight (g)	P%
Contaminant	Bunker 380		**N**	**weight (g)**	**P%**
Magnetic Paste	ETOH 70% (7gFe/g)		**0**	0.0000	0.00%
Replicate	1		**1**	0.1599	54.02%
			2	0.0714	84.59%
	weight of petri dish= 7.2075g		**3**	0.0504	91.85%
f_1	weight of feather cluster = 0.0268g		**4**	0.046	93.37%
f_2	weight of oiled cluster = 0.3822g		**5**	0.0444	93.92%
	residual oil = 0.0659g		**6**	0.0425	94.58%
f_3	oil laden feathers = 0.3822g - 0.0659g = 0.3163g		**7**	0.0427	94.51%
f_4	weight of feather after treatment		**8**	0.0429	94.44%

			N	weight (g)	P%
Contaminant	Bunker 380		**N**	**weight (g)**	**P%**
Magnetic Paste	ETOH 70% (7gFe/g)		**0**	0.0000	0.00%
Replicate	2		**1**	0.1699	60.07%
			2	0.0378	94.84%
	weight of petri dish= 7.1926g		**3**	0.0323	96.29%
f_1	weight of feather cluster = 0.0182g		**4**	0.0318	96.42%
f_2	weight of oiled cluster = 0.4069g		**5**	0.0285	97.29%
	residual oil = 0.0088g		**6**	0.0264	97.84%
f_3	oil laden feathers = 0.4069g - 0.0088g = 0.3981g		**7**	0.0263	97.87%
f_4	weight of feather after treatment		**8**	0.0257	98.03%

			N	weight (g)	P%
Contaminant	Bunker 380		**N**	**weight (g)**	**P%**
Magnetic Paste	ETOH 70% (7gFe/g)		**0**	0.0000	0.00%
Replicate	3		**1**	0.156	55.17%
			2	0.0599	87.04%
	weight of petri dish= 7.8281g		**3**	0.0385	94.13%
f_1	weight of feather cluster = 0.0208g		**4**	0.0364	94.83%
f_2	weight of oiled cluster = 0.3975g		**5**	0.0316	96.42%
	residual oil = 0.0751g		**6**	0.0316	96.42%
f_3	oil laden feathers = 0.3975g - 0.0751g = 0.3224g		**7**	0.0303	96.85%
f_4	weight of feather after treatment		**8**	0.0305	96.78%

			weight	
Contaminant	Bunker 380	**N**	**(g)**	**P%**
Magnetic Paste	ETOH 70% (7gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.1937	69.66%
		2	0.0759	91.02%
	weight of petri dish= 7.8193g	**3**	0.0456	96.52%
f_1	weight of feather cluster = 0.0264g	**4**	0.0444	96.74%
f_2	weight of oiled cluster = 0.6880g	**5**	0.0416	97.24%
	residual oil = 0.1101g	**6**	0.0421	97.15%
f_3	oil laden feathers = 0.6880g - 0.1101g = 0.5779g	**7**	0.0383	97.84%
f_4	weight of feather after treatment	**8**	0.041	97.35%

			weight	
Contaminant	Bunker 380	**N**	**(g)**	**P%**
Magnetic Paste	ETOH 70% (7gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0844	71.53%
		2	0.0424	90.16%
	weight of petri dish= 7.2061g	**3**	0.0369	92.59%
f_1	weight of feather cluster = 0.0202g	**4**	0.0361	92.95%
f_2	weight of oiled cluster = 0.2709g	**5**	0.0332	94.24%
	residual oil = 0.0252g	**6**	0.0324	94.59%
f_3	oil laden feathers = 0.2709g - 0.0252g = 0.2457g	**7**	0.0326	94.50%
f_4	weight of feather after treatment	**8**	0.0311	95.17%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	CO (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0816	83.38%
		2	0.0407	95.12%
	weight of petri dish= 7.6502g	**3**	0.0416	94.86%
f_1	weight of feather cluster = 0.0237g	**4**	0.0393	95.52%
f_2	weight of oiled cluster = 0.4304g	**5**	0.0406	95.15%
	residual oil = 0.0584g	**6**	0.0376	96.01%
f_3	oil laden feathers = 0.4304g - 0.0584g = 0.3720g	**7**	0.0394	95.49%
f_4	weight of feather after treatment	**8**	0.0372	96.12%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	CO (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.6925	-8.60%
		2	0.3019	55.25%
	weight of petri dish= 7.4183g	**3**	0.3146	53.17%
f_1	weight of feather cluster = 0.0281g	**4**	0.1896	73.60%
f_2	weight of oiled cluster = 0.6917g	**5**	0.1641	77.77%
	residual oil = 0.0518g	**6**	0.1444	80.99%
f_3	oil laden feathers = 0.6917g - 0.0518g = 0.6399g	**7**	0.1616	78.18%
f_4	weight of feather after treatment	**8**	0.1474	80.50%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	CO (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.101	85.64%
		2	0.0415	96.39%
	weight of petri dish= 7.6577g	**3**	0.0356	97.45%
f_1	weight of feather cluster = 0.0215g	**4**	0.0308	98.32%
f_2	weight of oiled cluster = 0.6173g	**5**	0.0348	97.60%
	residual oil = 0.0422g	**6**	0.0291	98.63%
f_3	oil laden feathers = 0.6173g - 0.0422g = 0.5751g	**7**	0.0302	98.43%
f_4	weight of feather after treatment	**8**	0.0309	98.30%

			weight	
Contaminant	Bunker 380	**N**	**(g)**	**P%**
Magnetic Paste	CO (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.3704	48.87%
		2	0.0601	95.11%
	weight of petri dish= 7.4380g	**3**	0.0436	97.57%
f_1	weight of feather cluster = 0.0273g	**4**	0.0392	98.23%
f_2	weight of oiled cluster = 0.7627g	**5**	0.0414	97.90%
	residual oil = 0.0643g	**6**	0.0438	97.54%
f_3	oil laden feathers = 0.7627g - 0.0643g = 0.6984g	**7**	0.0396	98.17%
f_4	weight of feather after treatment	**8**	0.0404	98.05%

			weight	
Contaminant	Bunker 380	**N**	**(g)**	**P%**
Magnetic Paste	CO (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.2271	71.22%
		2	0.0817	92.75%
	weight of petri dish= 7.4490g	**3**	0.0528	97.02%
f_1	weight of feather cluster = 0.0327g	**4**	0.0553	96.65%
f_2	weight of oiled cluster = 0.7895g	**5**	0.0328	99.99%
	residual oil = 0.0814g	**6**	0.0494	97.53%
f_3	oil laden feathers = 0.7895g - 0.0814g = 0.7081g	**7**	0.0478	97.76%
f_4	weight of feather after treatment	**8**	0.052	97.14%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	OO (5gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.1718	79.62%
		2	0.0423	97.52%
	weight of petri dish= 7.2213g	**3**	0.0397	97.88%
f_1	weight of feather cluster = 0.0244g	**4**	0.0389	98.00%
f_2	weight of oiled cluster = 0.8029g	**5**	0.0398	97.87%
	residual oil = 0.0553g	**6**	0.0398	97.87%
f_3	oil laden feathers = 0.8029g - 0.0553g = 0.7476g	**7**	0.0398	97.87%
f_4	weight of feather after treatment	**8**	0.0398	97.87%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	OO (5gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.1202	78.33%
		2	0.0504	94.77%
	weight of petri dish= 7.4212g	**3**	0.0526	94.25%
f_1	weight of feather cluster = 0.0282g	**4**	0.0517	94.46%
f_2	weight of oiled cluster = 0.5108g	**5**	0.045	96.04%
	residual oil = 0.0581g	**6**	0.0473	95.50%
f_3	oil laden feathers = 0.5108g - 0.0581g = 0.4527g	**7**	0.0483	95.27%
f_4	weight of feather after treatment	**8**	0.0438	96.33%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	OO (5gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.1116	86.38%
		2	0.0528	95.77%
	weight of petri dish= 7.2367g	**3**	0.0455	96.93%
f_1	weight of feather cluster = 0.0263g	**4**	0.0436	97.24%
f_2	weight of oiled cluster = 0.6045g	**5**	0.045	97.01%
	residual oil = 0.0421g	**6**	0.0418	97.52%
f_3	oil laden feathers = 0.6045g - 0.0421g = 0.6524g	**7**	0.0406	97.72%
f_4	weight of feather after treatment	**8**	0.0411	97.64%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	OO (5gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0813	85.81%
		2	0.0372	96.20%
	weight of petri dish= 7.2463g	**3**	0.037	96.25%
f_1	weight of feather cluster = 0.0211g	**4**	0.0364	96.39%
f_2	weight of oiled cluster = 0.4988g	**5**	0.0343	96.89%
	residual oil = 0.0536g	**6**	0.036	96.49%
f_3	oil laden feathers = 0.4988g - 0.0536g = 0.4452g	**7**	0.033	97.19%
f_4	weight of feather after treatment	**8**	0.0326	97.29%

		N	weight (g)	P%
Contaminant	Bunker 380	**N**	**weight (g)**	**P%**
Magnetic Paste	OO (5gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.1291	81.79%
		2	0.0487	96.02%
	weight of petri dish= 7.4145g	**3**	0.0473	96.27%
f_1	weight of feather cluster = 0.0262g	**4**	0.0446	96.74%
f_2	weight of oiled cluster = 0.6750g	**5**	0.0472	96.28%
	residual oil = 0.0837g	**6**	0.0403	97.50%
f_3	oil laden feathers = 0.6750g - 0.0837g = 0.5913g	**7**	0.0417	97.26%
f_4	weight of feather after treatment	**8**	0.0431	97.01%

Contaminant Bunker 380
Magnetic Paste 35℃ MO (6gFe/g)
Replicate 1

weight of petri dish= 6.5091g

f_1 weight of feather cluster = 0.0384g

f_2 weight of oiled cluster = 0.9877g
residual oil = 0.1239g

f_3 oil laden feathers = 0.9877g - 0.1239g = 0.8638g

f_4 weight of feather after treatment

N	**weight (g)**	**P%**
0	0.0000	0.00%
1	0.1252	89.48%
2	0.0676	96.46%
3	0.0611	97.25%
4	0.0633	96.98%
5	0.0622	97.12%
6	0.0624	97.09%
7	0.0592	97.48%
8	0.0608	97.29%

Contaminant Bunker 380
Magnetic Paste 35℃ MO (6gFe/g)
Replicate 2

weight of petri dish= 6.5025g

f_1 weight of feather cluster = 0.0299g

f_2 weight of oiled cluster = 0.5987g
residual oil = 0.0397g

f_3 oil laden feathers = 0.5987g - 0.0397g = 0.559g

f_4 weight of feather after treatment

N	**weight (g)**	**P%**
0	0.0000	0.00%
1	0.1378	79.61%
2	0.0579	94.71%
3	0.0462	96.92%
4	0.0449	97.16%
5	0.0467	96.82%
6	0.0453	97.09%
7	0.045	97.15%
8	0.0444	97.26%

Contaminant Bunker 380
Magnetic Paste 35℃ MO (6gFe/g)
Replicate 3

weight of petri dish= 6.5860g

f_1 weight of feather cluster = 0.0190g

f_2 weight of oiled cluster = 0.3499g
residual oil = 0.0410g

f_3 oil laden feathers = 0.3499g - 0.0410g = 0.3089g

f_4 weight of feather after treatment

N	**weight (g)**	**P%**
0	0.0000	0.00%
1	0.0623	85.06%
2	0.0531	88.24%
3	0.0295	96.38%
4	0.0284	96.76%
5	0.0283	96.79%
6	0.028	96.90%
7	0.0271	97.21%
8	0.027	97.24%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	35℃ MO (6gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.0713	84.57%
		2	0.0346	94.76%
	weight of petri dish= 6.6028g	**3**	0.0288	96.37%
f_1	weight of feather cluster = 0.0157g	**4**	0.0269	96.89%
f_2	weight of oiled cluster = 0.4205g	**5**	0.0119	101.05%
	residual oil = 0.0444g	**6**	0.0264	97.03%
f_3	oil laden feathers = 0.4205g - 0.0444g = 0.3761g	**7**	0.0245	97.56%
f_4	weight of feather after treatment	**8**	0.0271	96.84%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	35℃ MO (6gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.0419	91.30%
		2	0.0266	96.63%
	weight of petri dish= 6.6157g	**3**	0.0256	96.97%
f_1	weight of feather cluster = 0.0169g	**4**	0.0253	97.08%
f_2	weight of oiled cluster = 0.3488g	**5**	0.0237	97.63%
	residual oil = 0.0444g	**6**	0.0227	97.98%
f_3	oil laden feathers = 0.3488g - 0.0444g = 0.3044g	**7**	0.0222	98.16%
f_4	weight of feather after treatment	**8**	0.0197	99.03%

Contaminant	Bunker 380	N	weight (g)	P%
Magnetic Paste	35℃ OO (5gFe/g)	0	0.0000	0.00%
Replicate	1	1	0.1459	59.12%
		2	0.0412	92.51%
	weight of petri dish= 7.6768g	3	0.0339	94.83%
f_1	weight of feather cluster = 0.0180g	4	0.0334	94.99%
f_2	weight of oiled cluster = 0.3752g	5	0.0317	95.54%
	residual oil = 0.0436g	6	0.0309	95.79%
f_3	oil laden feathers = 0.3752g - 0.0436g = 0.3316g	7	0.0294	96.27%
f_4	weight of feather after treatment	8	0.0278	96.78%

Contaminant	Bunker 380	N	weight (g)	P%
Magnetic Paste	35℃ OO (5gFe/g)	0	0.0000	0.00%
Replicate	2	1	0.1105	78.11%
		2	0.0374	95.30%
	weight of petri dish= 7.6768g	3	0.0292	97.23%
f_1	weight of feather cluster = 0.0174g	4	0.0298	97.08%
f_2	weight of oiled cluster = 0.5198g	5	0.0301	97.01%
	residual oil = 0.0771g	6	0.0301	97.01%
f_3	oil laden feathers = 0.5198g - 0.0771g = 0.4427g	7	0.023	98.68%
f_4	weight of feather after treatment	8	0.0279	97.53%

Contaminant	Bunker 380	N	weight (g)	P%
Magnetic Paste	35℃ OO (5gFe/g)	0	0.0000	0.00%
Replicate	3	1	0.0653	86.14%
		2	0.0361	96.04%
	weight of petri dish= 7.4647g	3	0.0365	95.90%
f_1	weight of feather cluster = 0.0244g	4	0.0404	94.58%
f_2	weight of oiled cluster = 0.3514g	5	0.0392	94.98%
	residual oil = 0.0319g	6	0.0351	96.37%
f_3	oil laden feathers = 0.3514g - 0.0319g = 0.3195g	7	0.036	96.07%
f_4	weight of feather after treatment	8	0.0374	95.59%

			N	weight (g)	P%
Contaminant	Bunker 380		**N**	**weight (g)**	**P%**
Magnetic Paste	35℃ OO (5gFe/g)		**0**	0.0000	0.00%
Replicate	4		**1**	0.1228	87.24%
			2	0.0481	97.25%
	weight of petri dish= 7.6896g		**3**	0.0414	98.15%
f_1	weight of feather cluster = 0.0276g		**4**	0.0501	96.98%
f_2	weight of oiled cluster = 1.0758g		**5**	0.0463	97.49%
	residual oil = 0.3021g		**6**	0.05	97.00%
f_3	oil laden feathers = 1.0758g - 0.3021g = 0.7737g		**7**	0.0504	96.94%
f_4	weight of feather after treatment		**8**	0.0469	97.41%

			N	weight (g)	P%
Contaminant	Bunker 380		**N**	**weight (g)**	**P%**
Magnetic Paste	35℃ OO (5gFe/g)		**0**	0.0000	0.00%
Replicate	5		**1**	0.046	86.76%
			2	0.0241	95.00%
	weight of petri dish= 7.6687g		**3**	0.0222	95.71%
f_1	weight of feather cluster = 0.0108g		**4**	0.0197	96.65%
f_2	weight of oiled cluster = 0.3614g		**5**	0.019	96.92%
	residual oil = 0.0847g		**6**	0.018	97.29%
f_3	oil laden feathers = 0.3614g - 0.0847g = 0.2767g		**7**	0.0223	95.68%
f_4	weight of feather after treatment		**8**	0.0177	97.41%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	35℃ MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	1	**1**	0.0775	86.34%
		2	0.0324	96.26%
	weight of petri dish= 6.5982g	**3**	0.0286	97.10%
f_1	weight of feather cluster = 0.0154g	**4**	0.0268	97.49%
f_2	weight of oiled cluster = 0.5479g	**5**	0.0269	97.47%
	residual oil = 0.0779g	**6**	0.0252	97.84%
f_3	oil laden feathers = 0.5479g - 0.0779g = 0.47g	**7**	0.0259	97.69%
f_4	weight of feather after treatment	**8**	0.0273	97.38%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	35℃ MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	2	**1**	0.0669	80.73%
		2	0.0322	94.29%
	weight of petri dish= 6.5302g	**3**	0.0247	97.22%
f_1	weight of feather cluster = 0.0176g	**4**	0.0239	97.54%
f_2	weight of oiled cluster = 0.3075g	**5**	0.0219	98.32%
	residual oil = 0.0341g	**6**	0.0228	97.97%
f_3	oil laden feathers = 0.3075g - 0.0341g = 0.2734g	**7**	0.0233	97.77%
f_4	weight of feather after treatment	**8**	0.0256	96.87%

		N	weight (g)	P%
Contaminant	Bunker 380			
Magnetic Paste	35℃ MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	3	**1**	0.0792	76.79%
		2	0.0326	94.21%
	weight of petri dish= 6.5190g	**3**	0.0314	94.66%
f_1	weight of feather cluster = 0.0171g	**4**	0.0321	94.39%
f_2	weight of oiled cluster = 0.3162g	**5**	0.0272	96.23%
	residual oil = 0.0315g	**6**	0.0276	96.08%
f_3	oil laden feathers = 0.3162g - 0.0315g = 0.2847g	**7**	0.0262	96.60%
f_4	weight of feather after treatment	**8**	0.0262	96.60%

			weight	
Contaminant	Bunker 380	**N**	**(g)**	**P%**
Magnetic Paste	35℃ MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	4	**1**	0.1211	68.15%
		2	0.0479	91.70%
	weight of petri dish= 6.5293g	**3**	0.0457	92.41%
f_1	weight of feather cluster = 0.0221g	**4**	0.0402	94.18%
f_2	weight of oiled cluster = 0.3704g	**5**	0.0364	95.40%
	residual oil = 0.0375g	**6**	0.0367	95.30%
f_3	oil laden feathers = 0.3704g - 0.0375g = 0.3329g	**7**	0.0367	95.30%
f_4	weight of feather after treatment	**8**	0.0367	95.30%

			weight	
Contaminant	Bunker 380	**N**	**(g)**	**P%**
Magnetic Paste	35℃ MAYO (4gFe/g)	**0**	0.0000	0.00%
Replicate	5	**1**	0.1042	70.05%
		2	0.0403	92.51%
	weight of petri dish= 6.5236g	**3**	0.0346	94.52%
f_1	weight of feather cluster = 0.0190g	**4**	0.0315	95.61%
f_2	weight of oiled cluster = 0.3217g	**5**	0.0313	95.68%
	residual oil = 0.0182g	**6**	0.0303	96.03%
f_3	oil laden feathers = 0.3217g - 0.0182g = 0.3035g	**7**	0.0301	96.10%
f_4	weight of feather after treatment	**8**	0.0301	96.10%

Appendix C

Statistical results – Bua Ban removal

CONTROLS

IRON POWDER (MH300)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	95.37%	97.47%	97.60%	96.36%	95.95%	96.55%	0.009666	0.004323	0.009216
2	97.95%	99.51%	99.97%	98.69%	97.63%	98.75%	0.009955	0.004452	0.009492
3	98.29%	99.30%	99.90%	99.09%	97.92%	98.90%	0.007951	0.003556	0.007581
4	98.83%	99.59%	99.73%	98.98%	97.57%	98.94%	0.008569	0.003832	0.008170
5	98.87%	99.59%	100.00%	99.27%	97.63%	99.07%	0.009068	0.004055	0.008646
6	98.83%	99.47%	99.97%	99.27%	97.80%	99.07%	0.008186	0.003661	0.007805
7	99.00%	99.39%	99.97%	99.33%	98.21%	99.18%	0.006450	0.002884	0.006150
8	98.83%	99.51%	99.83%	99.36%	97.80%	99.07%	0.007946	0.003554	0.007576

Magnetic paste: DW (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	87.08%	85.40%	90.05%	90.94%	90.38%	88.77%	0.024058	0.010759	0.022939
2	94.47%	91.86%	93.98%	95.75%	95.50%	94.31%	0.015513	0.006938	0.014791
3	96.02%	93.22%	96.65%	97.45%	95.87%	95.84%	0.015926	0.007122	0.015185
4	96.46%	93.60%	98.22%	97.74%	96.34%	96.47%	0.017979	0.008040	0.017142
5	96.52%	93.65%	99.33%	98.37%	97.51%	97.08%	0.021789	0.009744	0.020775
6	96.77%	93.87%	100.71%	98.89%	97.23%	97.49%	0.025504	0.011406	0.024317
7	96.65%	93.76%	100.49%	98.69%	97.56%	97.43%	0.025023	0.011190	0.023858
8	96.52%	93.65%	100.49%	98.53%	98.12%	97.46%	0.025574	0.011437	0.024384

i. Pastes with an acetic acid (AA) component

Magnetic paste: AA ~4% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	94.23%	92.20%	94.69%	95.08%	95.44%	94.33%	0.012719	0.005688	0.015790
2	96.44%	96.31%	93.54%	97.56%	97.63%	96.30%	0.016578	0.007414	0.020581
3	97.28%	95.80%	96.17%	97.74%	97.93%	96.98%	0.009511	0.004254	0.011808
4	97.08%	96.94%	96.93%	98.01%	99.06%	97.60%	0.009293	0.004156	0.011537
5	97.76%	97.49%	96.66%	97.87%	97.45%	97.45%	0.004738	0.002119	0.005883
6	97.92%	97.53%	95.56%	97.56%	96.92%	97.10%	0.009318	0.004167	0.011568
7	98.12%	97.88%	95.07%	96.77%	95.61%	96.69%	0.013471	0.006024	0.016723
8	98.12%	97.92%	92.17%	95.13%	96.09%	95.89%	0.024264	0.010851	0.030123

Magnetic paste: AA ~8% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	91.16%	88.43%	91.75%	83.28%	90.90%	89.10%	0.034938	0.015625	0.043375
2	97.17%	93.52%	95.75%	95.31%	98.47%	96.04%	0.018808	0.008411	0.023349
3	97.90%	96.50%	96.39%	96.84%	97.61%	97.05%	0.006742	0.003015	0.008370
4	97.76%	96.97%	96.62%	97.45%	97.61%	97.28%	0.004743	0.002121	0.005888
5	97.57%	96.40%	97.57%	98.88%	98.66%	97.82%	0.009963	0.004456	0.012369
6	97.65%	97.94%	97.79%	98.06%	98.08%	97.90%	0.001831	0.000819	0.002273
7	97.65%	97.33%	97.97%	97.76%	97.37%	97.62%	0.002690	0.001203	0.003340
8	97.68%	97.17%	98.38%	96.02%	97.61%	97.37%	0.008712	0.003896	0.010816

Magnetic paste: AA 10% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	89.21%	94.33%	92.93%	91.24%	94.44%	92.43%	0.022184	0.009921	0.021151
2	96.69%	97.27%	95.58%	95.50%	96.79%	96.37%	0.007858	0.003514	0.007492
3	96.94%	98.30%	97.35%	96.56%	96.87%	97.20%	0.006743	0.003015	0.006429
4	98.03%	98.40%	98.07%	96.79%	97.28%	97.71%	0.006594	0.002949	0.006287
5	98.12%	98.87%	97.81%	96.67%	97.65%	97.82%	0.007975	0.003566	0.007604
6	97.64%	98.14%	97.84%	96.44%	97.05%	97.42%	0.006783	0.003034	0.006468
7	97.33%	97.58%	95.77%	95.21%	96.31%	96.44%	0.010088	0.004511	0.009618
8	98.05%	98.19%	96.48%	95.33%	96.46%	96.90%	0.012064	0.005395	0.011502

Magnetic paste: AA 20% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	85.35%	91.80%	94.06%	88.07%	90.17%	89.89%	0.033556	0.015007	0.031994
2	95.13%	97.28%	94.78%	95.61%	90.61%	94.68%	0.024699	0.011046	0.023550
3	95.93%	98.00%	95.79%	97.31%	92.89%	95.98%	0.019644	0.008785	0.018730
4	96.30%	98.34%	96.05%	97.60%	93.43%	96.34%	0.018802	0.008409	0.017927
5	96.76%	98.64%	95.33%	97.76%	95.06%	96.71%	0.015376	0.006876	0.014660
6	96.92%	98.22%	96.83%	97.72%	96.68%	97.27%	0.006650	0.002974	0.006341
7	97.13%	97.62%	94.98%	98.55%	95.98%	96.85%	0.013978	0.006251	0.013327
8	97.47%	97.92%	96.02%	98.39%	96.96%	97.35%	0.009140	0.004088	0.008715

Magnetic paste: MAYO v/v (4gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	75.36%	75.36%	86.69%	68.96%	33.44%	67.96%	0.203283	0.090911	0.193822
2	94.87%	94.87%	93.38%	83.32%	85.80%	90.45%	0.054799	0.024507	0.052249
3	97.40%	97.40%	94.89%	93.15%	93.03%	95.17%	0.021613	0.009665	0.020607
4	97.75%	97.75%	99.74%	95.91%	94.21%	97.07%	0.020964	0.009375	0.019988
5	97.76%	97.76%	96.64%	95.89%	94.64%	96.54%	0.013247	0.005924	0.012630
6	97.56%	97.56%	96.56%	95.97%	94.80%	96.49%	0.011642	0.005206	0.011100
7	97.86%	97.86%	96.61%	96.76%	94.27%	96.67%	0.014666	0.006559	0.013984
8	98.31%	98.31%	97.72%	96.61%	97.43%	97.68%	0.007076	0.003164	0.006747

ii. Pastes with a commercial cleansing product

Magnetic paste: Fairy 5% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	86.94%	78.48%	84.66%	83.86%	82.64%	83.32%	0.031257	0.013978	0.038804
2	85.03%	84.03%	92.15%	87.54%	88.00%	87.35%	0.031585	0.014125	0.039211
3	88.04%	84.79%	93.01%	88.97%	88.44%	88.65%	0.029338	0.013120	0.036422
4	86.88%	85.70%	92.90%	89.28%	88.05%	88.56%	0.027666	0.012373	0.034346
5	88.16%	87.15%	93.01%	90.22%	90.68%	89.84%	0.022890	0.010237	0.028417
6	88.39%	84.18%	92.26%	90.16%	90.56%	89.11%	0.030802	0.013775	0.038240
7	90.25%	87.53%	93.19%	90.40%	88.89%	90.05%	0.021046	0.009412	0.026128
8	88.74%	87.07%	92.29%	90.90%	90.06%	89.81%	0.020033	0.008959	0.024871

Magnetic paste: Nivea (5gFe/g)

No. of Treatments	Oil Removed (%)					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	79.91%	76.63%	64.66%	69.16%	83.88%	74.85%	0.078506	0.035109	0.074852
2	89.76%	89.45%	85.21%	87.13%	89.52%	88.21%	0.019889	0.008895	0.018963
3	91.26%	88.31%	86.02%	88.32%	91.48%	89.08%	0.022938	0.010258	0.021871
4	92.82%	89.18%	86.77%	88.67%	91.74%	89.84%	0.024351	0.010890	0.023218
5	93.28%	89.12%	88.12%	89.82%	91.42%	90.35%	0.020308	0.009082	0.019363
6	92.56%	90.09%	87.82%	90.22%	92.04%	90.55%	0.018731	0.008377	0.017859
7	92.56%	90.63%	88.62%	89.67%	91.09%	90.51%	0.014858	0.006645	0.014167
8	92.56%	90.90%	89.72%	89.97%	92.43%	91.12%	0.013342	0.005967	0.012721

Magnetic paste: Perfect Gel (4gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	92.23%	86.80%	81.61%	79.54%	83.59%	84.75%	0.049624	0.022193	0.061607
2	95.05%	93.58%	89.53%	90.10%	88.29%	91.31%	0.028676	0.012824	0.035601
3	95.20%	94.42%	92.13%	90.95%	93.05%	93.15%	0.017107	0.007650	0.021238
4	96.51%	93.58%	93.57%	92.06%	95.48%	94.24%	0.017555	0.007851	0.021794
5	97.13%	93.30%	91.91%	93.72%	95.34%	94.28%	0.020085	0.008982	0.024935
6	97.37%	93.21%	89.81%	93.26%	95.31%	93.79%	0.028100	0.012567	0.034885
7	97.28%	92.84%	92.63%	94.02%	95.97%	94.55%	0.020224	0.009045	0.025108
8	97.00%	95.26%	91.91%	94.32%	96.11%	94.92%	0.019544	0.008740	0.024263

iii. Pastes with a eucalyptus oil component

Magnetic paste: EO 5% (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	88.95%	91.42%	74.25%	82.43%	86.82%	84.77%	0.067462	0.030170	0.064322
2	92.71%	96.16%	95.02%	89.41%	93.26%	93.31%	0.025797	0.011537	0.024596
3	95.21%	96.16%	96.72%	90.65%	96.08%	94.96%	0.024714	0.011052	0.023563
4	96.14%	97.32%	97.39%	91.40%	96.24%	95.70%	0.024726	0.011058	0.023576
5	97.50%	97.32%	98.54%	92.71%	96.69%	96.55%	0.022484	0.010055	0.021437
6	97.11%	97.74%	98.68%	93.71%	97.87%	97.02%	0.019340	0.008649	0.018439
7	97.77%	98.11%	98.89%	94.21%	98.51%	97.50%	0.018856	0.008432	0.017978
8	97.93%	98.84%	99.23%	94.27%	98.65%	97.78%	0.020202	0.009035	0.019262

Magnetic Paste: EO 20% (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	91.64%	81.11%	85.98%	83.15%	83.17%	85.01%	0.040912	0.018297	0.039008
2	93.15%	93.19%	92.31%	87.32%	93.72%	91.94%	0.026304	0.011764	0.02508
3	97.86%	97.29%	95.01%	95.71%	94.86%	96.15%	0.013584	0.006075	0.012952
4	98.15%	94.18%	96.39%	95.60%	95.45%	95.95%	0.014611	0.006534	0.013931
5	95.63%	96.65%	94.18%	94.78%	95.78%	95.40%	0.00953	0.004262	0.009086
6	98.65%	96.00%	93.53%	94.78%	95.18%	95.63%	0.0191	0.008542	0.018211
7	98.65%	96.00%	93.53%	94.78%	94.53%	95.50%	0.019693	0.008807	0.018777
8	98.65%	96.00%	93.53%	94.78%	94.59%	95.51%	0.019621	0.008775	0.018708

Magnetic paste: EO 25% (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	75.82%	88.70%	89.01%	83.14%	93.60%	86.05%	0.068174	0.030488	0.084636
2	86.10%	95.86%	94.73%	90.56%	99.16%	93.28%	0.050568	0.022615	0.062778
3	93.12%	93.98%	94.84%	90.52%	98.09%	94.11%	0.027504	0.012300	0.034145
4	92.34%	93.98%	97.01%	89.71%	97.89%	94.19%	0.033608	0.015030	0.041723
5	93.20%	93.22%	94.92%	89.02%	98.89%	93.85%	0.035600	0.015921	0.044196
6	94.82%	92.95%	94.96%	93.20%	97.08%	94.60%	0.016591	0.007420	0.020598
7	95.25%	94.94%	92.94%	88.94%	96.28%	93.67%	0.029081	0.013005	0.036103
8	93.97%	95.54%	94.66%	83.47%	98.63%	93.25%	0.057520	0.025724	0.071409

iv. Pastes with a conventional "pre-treatment" agent

Magnetic paste: MS (6gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	85.00%	89.95%	81.90%	81.93%	89.16%	85.59%	0.038443	0.017192	0.047726
2	88.95%	95.16%	90.31%	89.10%	94.40%	91.58%	0.029769	0.013313	0.036958
3	93.32%	94.58%	91.01%	90.18%	93.07%	92.43%	0.017960	0.008032	0.022297
4	89.61%	95.77%	90.27%	94.22%	93.51%	92.68%	0.026383	0.011799	0.032753
5	91.25%	96.22%	91.09%	92.35%	92.98%	92.78%	0.020770	0.009289	0.025785
6	92.24%	96.10%	93.12%	91.81%	93.69%	93.39%	0.016827	0.007525	0.020890
7	90.13%	95.16%	93.07%	91.99%	94.49%	92.97%	0.020089	0.008984	0.024940
8	91.18%	95.40%	92.00%	91.20%	94.49%	92.85%	0.019638	0.008782	0.024380

Magnetic paste: EST (6gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	89.91%	90.04%	95.47%	86.75%	81.86%	88.81%	0.049906	0.022319	0.047583
2	95.34%	97.15%	97.53%	93.78%	84.31%	93.62%	0.054178	0.024229	0.051656
3	93.20%	94.60%	96.84%	93.72%	87.25%	93.12%	0.035655	0.015946	0.033996
4	88.50%	94.98%	97.44%	94.98%	88.83%	92.95%	0.040367	0.018053	0.038488
5	94.50%	96.17%	97.90%	91.62%	89.18%	93.87%	0.034995	0.015650	0.033366
6	93.76%	94.47%	96.61%	92.12%	88.74%	93.14%	0.029409	0.013152	0.028040
7	97.22%	93.20%	98.31%	93.47%	89.83%	94.41%	0.034070	0.015236	0.032484
8	96.75%	94.90%	96.39%	92.65%	90.36%	94.21%	0.026896	0.012028	0.025644

Magnetic paste: MO (6gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	85.24%	71.37%	85.05%	81.73%	84.92%	81.66%	0.059335	0.026535	0.056573
2	90.80%	82.32%	91.28%	91.58%	87.34%	88.66%	0.039341	0.017594	0.037510
3	92.18%	82.53%	90.71%	92.62%	87.43%	89.09%	0.041959	0.018765	0.040006
4	88.89%	82.10%	89.77%	93.47%	88.08%	88.46%	0.041108	0.018384	0.039195
5	93.69%	82.80%	92.06%	93.38%	84.92%	89.37%	0.051222	0.022907	0.048838
6	91.49%	83.02%	88.84%	93.38%	84.92%	88.33%	0.043466	0.019439	0.041443
7	92.93%	79.03%	90.50%	93.38%	84.92%	88.15%	0.061101	0.027325	0.058257
8	91.49%	82.16%	92.06%	93.38%	84.92%	88.80%	0.049493	0.022134	0.047190

Magnetic paste: ETOH (7gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	93.82%	96.07%	90.66%	92.45%	92.06%	93.01%	0.020468	0.009154	0.019516
2	97.37%	97.71%	97.49%	99.66%	96.83%	97.81%	0.010827	0.004842	0.010323
3	97.88%	97.96%	98.00%	98.84%	97.44%	98.02%	0.005080	0.002272	0.004844
4	97.29%	98.11%	98.08%	99.04%	97.61%	98.03%	0.006620	0.002961	0.006312
5	97.00%	98.36%	98.16%	98.99%	97.33%	97.97%	0.008030	0.003591	0.007656
6	97.48%	98.14%	97.84%	99.02%	97.50%	98.00%	0.006336	0.002834	0.006041
7	96.96%	98.46%	97.25%	98.89%	97.50%	97.81%	0.008248	0.003689	0.007864
8	97.29%	98.36%	97.02%	100.26%	97.00%	97.99%	0.013875	0.006205	0.013229

v. Pastes with a vegetable oil component

Magnetic paste: CO (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	85.28%	78.87%	82.87%	85.18%	86.46%	83.73%	0.030132	0.013475	0.037408
2	90.13%	91.10%	91.17%	90.07%	92.10%	90.91%	0.008417	0.003764	0.010449
3	90.13%	91.67%	88.38%	89.64%	92.49%	90.46%	0.016350	0.007312	0.020298
4	90.13%	89.80%	90.52%	89.70%	93.51%	90.73%	0.015857	0.007092	0.019686
5	87.75%	91.05%	90.34%	90.33%	93.53%	90.60%	0.020646	0.009233	0.025631
6	86.68%	90.31%	88.80%	89.86%	93.26%	89.78%	0.023963	0.010716	0.029749
7	85.69%	91.27%	90.93%	90.33%	92.98%	90.24%	0.027274	0.012198	0.033860
8	86.18%	90.71%	93.84%	91.56%	92.32%	90.92%	0.028900	0.012924	0.035878

Magnetic paste: OO (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	68.82%	85.31%	91.90%	91.00%	78.42%	83.09%	0.096249	0.043044	0.091769
2	90.90%	89.78%	95.59%	93.27%	90.66%	92.04%	0.023679	0.010589	0.022577
3	91.95%	92.18%	95.53%	92.35%	91.59%	92.72%	0.015964	0.007139	0.015221
4	92.11%	93.30%	95.64%	93.10%	91.54%	93.14%	0.015731	0.007035	0.014998
5	93.19%	93.64%	95.90%	93.20%	90.92%	93.37%	0.017704	0.007918	0.016880
6	93.53%	94.03%	96.09%	92.63%	91.62%	93.58%	0.016770	0.007500	0.015989
7	93.47%	94.39%	95.82%	93.20%	91.52%	93.68%	0.015830	0.007079	0.015093
8	93.25%	93.94%	96.06%	92.54%	91.87%	93.53%	0.016111	0.007205	0.015362

Magnetic paste: MS (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	76.05%	83.62%	78.91%	79.90%	69.06%	77.51%	0.054438	0.024345	0.051904
2	84.35%	95.12%	87.70%	88.27%	85.09%	88.11%	0.042600	0.019051	0.040618
3	89.42%	94.03%	89.07%	85.99%	86.20%	88.94%	0.032544	0.014554	0.031030
4	89.85%	95.32%	90.54%	88.31%	87.20%	90.24%	0.031231	0.013967	0.029777
5	85.68%	95.48%	89.00%	89.14%	87.09%	89.28%	0.037515	0.016777	0.035769
6	87.80%	96.33%	88.82%	88.35%	84.59%	89.18%	0.043276	0.019354	0.041262
7	88.18%	95.90%	87.77%	87.86%	86.87%	89.32%	0.037126	0.016603	0.035398
8	86.76%	93.76%	87.49%	88.60%	88.09%	88.94%	0.027805	0.012435	0.026511

Magnetic paste: EST (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	82.39%	83.03%	80.60%	74.99%	80.15%	80.23%	0.03166	0.014161	0.030191
2	89.99%	89.41%	87.02%	87.35%	91.08%	88.97%	0.01740	0.007782	0.016592
3	91.19%	91.47%	92.16%	87.97%	90.70%	90.70%	0.01614	0.007217	0.015387
4	91.75%	89.66%	89.46%	88.26%	91.68%	90.16%	0.01516	0.006778	0.014451
5	93.19%	93.57%	88.67%	81.42%	89.28%	89.23%	0.04895	0.021889	0.046668
6	92.15%	94.33%	90.13%	87.24%	90.14%	90.80%	0.02638	0.011799	0.025155
7	91.11%	92.22%	89.46%	88.88%	91.26%	90.59%	0.01376	0.006155	0.013123
8	93.67%	92.42%	89.42%	88.71%	90.96%	91.04%	0.02054	0.009187	0.019587

Magnetic paste: MO (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	68.37%	77.30%	79.56%	77.94%		75.79%	0.050389	0.025195	0.059283
2	81.47%	85.71%	84.56%	84.21%		83.99%	0.017965	0.008982	0.021136
3	82.07%	85.71%	85.41%	85.43%		84.66%	0.017288	0.008644	0.020339
4	81.71%	86.13%	86.60%	86.69%		85.28%	0.023943	0.011971	0.028169
5	82.19%	88.31%	89.46%	86.87%		86.71%	0.031926	0.015963	0.037561
6	84.43%	88.81%	87.32%	89.08%		87.41%	0.021321	0.01066	0.025084
7	85.71%	87.74%	85.48%	87.33%		86.57%	0.011364	0.005682	0.01337
8	85.15%	90.03%	84.84%	85.02%		86.26%	0.025165	0.012583	0.029607

- **Note: 5th replicate data unavailable – experiment not completed**

Magnetic paste: BD1 (5gFe/g)

No. of Treatments	Oil Removed (%) BB					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	62.88%	42.19%	72.89%	69.76%		61.93%	0.138082	0.069041	0.162454
2	86.97%	86.89%	81.80%	76.45%		83.03%	0.050077	0.025039	0.058916
3	86.57%	80.64%	82.33%	76.92%		81.62%	0.040024	0.020012	0.047088
4	87.07%	78.94%	82.99%	79.13%		82.03%	0.038419	0.019210	0.045200
5	87.48%	84.71%	79.30%	81.72%		83.30%	0.035570	0.017785	0.041848
6	84.17%	76.02%	75.02%	74.94%		77.54%	0.044489	0.022244	0.052341
7	84.31%	81.66%	80.68%	80.24%		81.72%	0.018243	0.009121	0.021462
8	86.50%	79.69%	88.81%	82.67%		84.42%	0.040428	0.020214	0.047564

- **Note: 5th replicate data unavailable – experiment not completed**

Appendix D

Statistical results – Bunker 380 removal

CONTROLS

IRON POWDER (MH300)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	93.14%	57.78%	51.43%	81.16%	72.23%	71.15%	0.169747	0.075913	0.161847
2	95.61%	97.31%	96.73%	97.77%	97.18%	96.92%	0.008207	0.00367	0.007825
3	96.91%	99.51%	98.90%	99.04%	98.94%	98.66%	0.010081	0.004509	0.009612
4	97.05%	99.54%	99.55%	99.28%	99.33%	98.95%	0.01069	0.004781	0.010193
5	98.90%	99.65%	99.70%	99.30%	99.36%	99.38%	0.003211	0.001436	0.003062
6	97.25%	99.72%	99.73%	99.52%	99.57%	99.16%	0.010705	0.004788	0.010207
7	97.32%	99.63%	99.79%	99.42%	99.44%	99.12%	0.010175	0.00455	0.009702
8	97.87%	99.75%	99.88%	99.69%	99.63%	99.36%	0.008403	0.003758	0.008012

Magnetic Paste: DW (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	45.04%	60.85%	17.31%	36.83%	22.11%	36.43%	0.176158	0.07878	0.167959
2	91.49%	89.07%	87.20%	86.43%	74.09%	85.66%	0.067536	0.030203	0.064393
3	96.00%	95.19%	94.15%	97.45%	95.14%	95.59%	0.012312	0.005506	0.011739
4	97.58%	97.05%	93.87%	98.09%	97.18%	96.75%	0.016624	0.007434	0.01585
5	98.20%	97.81%	95.94%	98.23%	97.63%	97.56%	0.009421	0.004213	0.008983
6	98.31%	97.93%	97.08%	98.38%	97.99%	97.94%	0.005179	0.002316	0.004938
7	98.62%	98.23%	97.56%	98.75%	98.10%	98.25%	0.004706	0.002105	0.004487
8	98.63%	98.54%	97.52%	98.60%	98.14%	98.29%	0.004716	0.002109	0.004496

i. Pastes with an acetic acid component

Magnetic paste: AA ~4% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	74.91%	54.54%	53.82%	60.95%	66.47%	62.14%	0.088065	0.039384	0.083967
2	95.18%	97.64%	92.54%	90.29%	96.28%	94.39%	0.029577	0.013227	0.028200
3	95.77%	94.54%	94.61%	95.07%	98.06%	95.61%	0.014547	0.006506	0.013870
4	98.23%	95.39%	96.34%	96.39%	98.17%	96.90%	0.012486	0.005584	0.011904
5	98.63%	95.83%	96.99%	96.75%	98.04%	97.25%	0.011026	0.004931	0.010512
6	98.45%	96.61%	97.32%	96.22%	98.41%	97.40%	0.010180	0.004553	0.009706
7	98.56%	96.53%	98.25%	96.08%	98.14%	97.51%	0.011239	0.005026	0.010716
8	98.63%	96.46%	97.99%	96.36%	98.09%	97.51%	0.010303	0.004608	0.009824

Magnetic paste: AA ~8% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	45.06%	72.94%	49.98%	62.89%	28.67%	51.91%	0.169821	0.075946	0.161917
2	87.60%	89.49%	86.30%	88.21%	86.64%	87.65%	0.012791	0.005720	0.012196
3	94.11%	94.83%	92.12%	91.92%	96.19%	93.83%	0.018180	0.008130	0.017334
4	95.44%	96.97%	93.80%	94.96%	98.60%	95.95%	0.018658	0.008344	0.017790
5	95.34%	97.48%	96.54%	95.01%	98.40%	96.55%	0.014251	0.006373	0.013587
6	95.61%	98.12%	95.25%	96.04%	98.60%	96.72%	0.015289	0.006837	0.014577
7	96.45%	98.19%	95.41%	95.79%	98.94%	96.96%	0.015382	0.006879	0.014666
8	96.74%	98.59%	95.64%	96.13%	98.52%	97.12%	0.013634	0.006097	0.013000

Magnetic paste: AA 10% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	67.54%	67.32%	62.44%	62.13%	50.44%	61.97%	0.069432	0.031051	0.066201
2	84.32%	78.79%	92.61%	80.42%	82.56%	83.74%	0.053836	0.024076	0.051330
3	86.45%	87.43%	95.81%	96.51%	88.25%	90.89%	0.048592	0.021731	0.046330
4	96.84%	93.86%	97.35%	96.37%	95.67%	96.02%	0.013557	0.006063	0.012926
5	98.21%	97.35%	100.95%	97.04%	95.30%	97.77%	0.020686	0.009251	0.019723
6	98.42%	97.82%	98.13%	97.42%	97.66%	97.89%	0.003928	0.001757	0.003745
7	98.87%	98.44%	98.32%	97.89%	97.98%	98.30%	0.003922	0.001754	0.003740
8	98.72%	99.01%	98.32%	97.98%	98.50%	98.51%	0.003909	0.001748	0.003727

Magnetic paste: AA 20% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	43.18%	68.05%	63.22%	63.37%	55.89%	58.74%	0.097265	0.043498	0.092738
2	68.97%	84.23%	82.62%	85.82%	79.12%	80.15%	0.067259	0.030079	0.064128
3	91.94%	94.62%	94.92%	93.56%	89.81%	92.97%	0.021166	0.009466	0.020181
4	97.25%	97.86%	97.91%	95.98%	90.12%	95.82%	0.032822	0.014678	0.031294
5	98.28%	98.13%	98.63%	96.72%	95.54%	97.46%	0.012966	0.005798	0.012362
6	98.71%	98.31%	98.48%	97.46%	96.62%	97.92%	0.008648	0.003867	0.008245
7	98.72%	98.59%	98.79%	98.10%	96.87%	98.21%	0.007982	0.00357	0.007611
8	98.63%	98.56%	98.75%	98.31%	97.03%	98.26%	0.00704	0.003148	0.006712

Magnetic paste: MAYO (4gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	64.15%	60.22%	52.36%	64.81%	80.45%	64.40%	0.102502	0.04584	0.097732
2	80.49%	71.29%	73.66%	90.51%	79.30%	79.05%	0.074622	0.033372	0.071149
3	95.76%	93.14%	92.27%	94.27%	90.18%	93.12%	0.021011	0.009396	0.020033
4	96.61%	95.23%	95.06%	95.95%	94.29%	95.43%	0.008859	0.003962	0.008447
5	96.75%	97.94%	96.63%	97.08%	98.00%	97.28%	0.006514	0.002913	0.006211
6	97.29%	96.52%	97.48%	97.08%	97.36%	97.15%	0.003789	0.001695	0.003613
7	97.71%	96.19%	97.86%	96.95%	97.38%	97.22%	0.006725	0.003008	0.006412
8	97.43%	96.64%	97.51%	97.73%	97.58%	97.38%	0.00427	0.00191	0.004072

ii. Pastes with a commercial cleansing product

Magnetic paste: Fairy 5% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	60.81%	89.34%	53.38%	54.28%	62.93%	64.15%	0.146679	0.065597	0.139853
2	95.37%	96.97%	90.01%	91.92%	82.20%	91.29%	0.057787	0.025843	0.055097
3	95.65%	96.79%	95.38%	95.14%	88.86%	94.36%	0.031412	0.014048	0.029950
4	95.65%	97.33%	95.77%	95.58%	91.52%	95.17%	0.021649	0.009682	0.020641
5	95.54%	97.36%	95.88%	95.48%	92.87%	95.43%	0.016198	0.007244	0.015445
6	96.33%	97.24%	96.17%	96.19%	92.99%	95.78%	0.016231	0.007259	0.015476
7	95.97%	97.09%	96.49%	96.07%	94.08%	95.94%	0.011294	0.005051	0.010769
8	95.48%	97.31%	96.68%	96.20%	96.19%	96.37%	0.00677	0.003027	0.006455

Magnetic paste: Nivea (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	44.50%	97.40%	52.51%	49.32%	31.80%	55.11%	0.249232	0.11146	0.237632
2	76.02%	51.29%	78.00%	73.14%	72.87%	70.26%	0.108173	0.048376	0.103138
3	87.72%	78.58%	89.57%	87.56%	81.33%	84.95%	0.047305	0.021155	0.045103
4	92.52%	84.93%	93.22%	91.26%	89.05%	90.20%	0.033437	0.014954	0.031881
5	94.22%	91.00%	94.93%	92.83%	93.65%	93.33%	0.015111	0.006758	0.014407
6	94.64%	92.57%	95.60%	93.10%	93.31%	93.84%	0.012429	0.005558	0.011850
7	95.27%	94.15%	95.95%	95.60%	94.40%	95.07%	0.007731	0.003457	0.007371
8	95.76%	94.60%	96.39%	96.50%	94.37%	95.52%	0.009929	0.004441	0.009467

Magnetic paste: Perfect Gel (4gFe/g)

No. of Treatments	Oil Removed (%)					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	44.83%	48.15%	35.69%	78.22%	40.81%	49.54%	0.166935	0.074656	0.159166
2	77.00%	78.76%	74.56%	89.80%	71.38%	78.30%	0.070005	0.031307	0.066747
3	86.86%	88.20%	84.36%	93.77%	80.64%	86.77%	0.048590	0.021730	0.046328
4	93.40%	93.23%	92.13%	97.81%	90.58%	93.43%	0.026943	0.012049	0.025689
5	95.73%	95.55%	94.97%	98.85%	93.17%	95.65%	0.020536	0.009184	0.019580
6	97.90%	96.95%	95.91%	98.66%	95.12%	96.91%	0.014360	0.006422	0.013692
7	98.47%	97.09%	96.86%	99.00%	96.08%	97.50%	0.012026	0.005378	0.011466
8	97.96%	97.86%	96.40%	98.78%	95.79%	97.36%	0.012261	0.005483	0.011690

iii. Pastes with a eucalyptus oil component

Magnetic paste: EO 5% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	26.47%	50.57%	71.27%	73.50%	66.55%	57.67%	0.196103	0.0877	0.186976
2	84.59%	78.34%	91.56%	94.48%	83.12%	86.42%	0.065366	0.029233	0.062324
3	93.15%	91.34%	94.39%	98.04%	94.47%	94.28%	0.024549	0.010979	0.023407
4	95.37%	97.37%	95.81%	98.78%	97.72%	97.01%	0.014050	0.006283	0.013396
5	99.29%	98.14%	96.54%	99.01%	99.27%	98.45%	0.011657	0.005213	0.011115
6	97.75%	99.28%	97.56%	99.19%	100.46%	98.85%	0.012007	0.005370	0.011448
7	98.14%	99.36%	97.39%	99.40%	97.19%	98.30%	0.010511	0.004701	0.010022
8	98.33%	99.72%	97.28%	99.21%	100.20%	98.95%	0.011615	0.005194	0.011074

Magnetic paste: EO 20% v/v (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	38.93%	27.01%	6.76%	23.27%	85.68%	36.33%	0.298914	0.133679	0.285003
2	89.64%	84.92%	77.62%	80.75%	85.76%	83.74%	0.046550	0.020818	0.044384
3	97.15%	96.49%	96.23%	92.31%	97.63%	95.96%	0.021143	0.009455	0.020159
4	97.88%	98.32%	98.74%	97.16%	97.75%	97.97%	0.005975	0.002672	0.005697
5	98.08%	98.62%	98.97%	96.43%	97.75%	97.97%	0.009817	0.004390	0.009360
6	97.84%	98.10%	98.92%	97.47%	96.94%	97.85%	0.007382	0.003301	0.007039
7	98.94%	98.95%	98.99%	99.06%	96.60%	98.51%	0.010676	0.004775	0.010180
8	99.27%	99.18%	98.89%	97.82%	97.06%	98.44%	0.009654	0.004317	0.009204

Magnetic paste: EO 25% (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	72.23%	68.94%	49.64%	41.35%	58.56%	58.14%	0.129373	0.057858	0.123352
2	96.96%	97.14%	95.85%	74.72%	92.76%	91.49%	0.095354	0.042644	0.090917
3	99.44%	99.12%	98.88%	98.05%	98.17%	98.73%	0.006031	0.002697	0.005750
4	99.10%	99.32%	99.10%	98.51%	98.84%	98.97%	0.003101	0.001387	0.002957
5	99.10%	99.20%	99.54%	98.83%	98.63%	99.06%	0.003498	0.001564	0.003335
6	99.67%	99.43%	99.56%	99.03%	98.60%	99.26%	0.004403	0.001969	0.004198
7	99.91%	99.32%	99.49%	99.00%	99.35%	99.41%	0.003302	0.001477	0.003148
8	99.95%	99.20%	99.95%	99.46%	98.82%	99.48%	0.004889	0.002186	0.004662

iv. Pastes with a "conventional" pre-treatment agent

Magnetic paste: MS (6gFe/g)

No. of Treatments	Oil Removed (%)				Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates							
N	1	2	3	4	AVERAGE	STD	SE	95%CI
1	80.45%	92.60%	83.74%	85.09%	85.47%	0.05137	0.02569	0.06044
2	96.83%	97.73%	97.74%	96.92%	97.31%	0.00498	0.00249	0.00586
3	97.95%	98.02%	98.75%	97.79%	98.13%	0.00426	0.00213	0.00501
4	97.85%	98.08%	98.38%	97.29%	97.90%	0.00461	0.00230	0.00542
5	98.37%	98.53%	98.86%	97.88%	98.41%	0.00408	0.00204	0.00480
6	98.19%	98.37%	98.23%	96.89%	97.92%	0.00691	0.00345	0.00813
7	98.46%	97.92%	98.51%	97.39%	98.07%	0.00526	0.00263	0.00619
8	98.41%	97.89%	98.81%	97.39%	98.13%	0.00618	0.00309	0.00727

- **Note: 5th replicate data unavailable – experiment not completed**

Magnetic paste: EST (6gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	89.24%	64.21%	89.72%	95.50%	81.78%	84.09%	0.121342	0.054266	0.115695
2	98.02%	94.72%	95.58%	97.58%	97.92%	96.76%	0.015132	0.006767	0.014428
3	98.41%	96.88%	96.43%	97.50%	99.72%	97.79%	0.013106	0.005861	0.012496
4	98.28%	97.38%	95.64%	97.63%	99.30%	97.65%	0.013447	0.006014	0.012821
5	98.48%	96.66%	95.93%	97.42%	99.45%	97.59%	0.014054	0.006285	0.013400
6	98.94%	97.28%	95.90%	97.71%	99.43%	97.85%	0.013992	0.006258	0.013341
7	98.56%	97.30%	95.58%	97.38%	99.41%	97.65%	0.014496	0.006483	0.013822
8	99.01%	96.72%	95.18%	97.33%	99.05%	97.46%	0.016350	0.007312	0.015589

Magnetic paste: MO (6gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	91.44%	90.09%	93.28%	72.82%	83.02%	86.13%	0.083939	0.037539	0.080032
2	96.48%	97.67%	97.75%	93.94%	95.74%	96.32%	0.015727	0.007033	0.014995
3	96.77%	97.98%	98.52%	97.63%	96.44%	97.47%	0.008572	0.003833	0.008173
4	97.55%	98.08%	98.31%	97.75%	96.49%	97.64%	0.007045	0.003150	0.006717
5	97.26%	97.96%	98.06%	97.51%	96.54%	97.47%	0.006121	0.002737	0.005836
6	97.95%	98.32%	98.63%	97.54%	96.59%	97.81%	0.007927	0.003545	0.007558
7	97.26%	98.32%	99.50%	97.84%	97.05%	97.99%	0.009783	0.004375	0.009327
8	97.21%	98.71%	99.56%	97.73%	96.09%	97.86%	0.013402	0.005994	0.012778

Magnetic paste: ETOH (7gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	54.02%	60.07%	55.17%	69.66%	71.53%	62.09%	0.081165	0.036298	0.077388
2	84.59%	94.84%	87.04%	91.02%	90.16%	89.53%	0.039184	0.017524	0.037361
3	91.85%	96.29%	94.13%	96.52%	92.59%	94.28%	0.021119	0.009445	0.020136
4	93.37%	96.42%	94.83%	96.74%	92.95%	94.86%	0.017203	0.007693	0.016402
5	93.92%	97.29%	96.42%	97.24%	94.24%	95.82%	0.016312	0.007295	0.015553
6	94.58%	97.84%	96.42%	97.15%	94.59%	96.12%	0.014851	0.006641	0.014160
7	94.51%	97.87%	96.85%	97.84%	94.50%	96.31%	0.017016	0.007610	0.016224
8	94.44%	98.03%	96.78%	97.35%	95.17%	96.35%	0.015040	0.006726	0.014340

v. Paste with a vegetable oil component

Magnetic paste: CO (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	84.38%	-8.60%	85.64%	48.87%	71.22%	56.30%	0.391763	0.175202	0.373531
2	95.12%	55.25%	96.39%	95.11%	92.75%	86.92%	0.177551	0.079403	0.169288
3	94.86%	53.17%	97.45%	97.57%	97.02%	88.01%	0.195092	0.087248	0.186012
4	95.52%	73.60%	98.32%	98.23%	96.65%	92.46%	0.106096	0.047447	0.101158
5	95.15%	77.77%	97.60%	97.90%	99.99%	93.68%	0.090592	0.040514	0.086376
6	96.01%	80.99%	98.63%	97.54%	97.53%	94.14%	0.074100	0.033138	0.070651
7	95.49%	78.18%	98.43%	98.17%	97.76%	93.61%	0.087015	0.038915	0.082966
8	96.12%	80.50%	98.30%	98.05%	97.14%	94.02%	0.076075	0.034022	0.072534

Magnetic paste: OO (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	79.62%	78.33%	86.38%	85.81%	81.79%	82.39%	0.036102	0.016145	0.034421
2	97.52%	94.77%	95.77%	96.20%	96.02%	96.06%	0.009875	0.004416	0.009416
3	97.88%	94.25%	96.93%	96.25%	96.27%	96.32%	0.013321	0.005957	0.012701
4	98.00%	94.46%	97.24%	96.39%	96.74%	96.57%	0.013235	0.005919	0.012619
5	97.87%	96.04%	97.01%	96.89%	96.28%	96.82%	0.007148	0.003196	0.006815
6	97.87%	95.50%	97.52%	96.49%	97.50%	96.98%	0.009727	0.00435	0.009274
7	97.87%	95.27%	97.72%	97.19%	97.26%	97.06%	0.010432	0.004665	0.009946
8	97.87%	96.33%	97.64%	97.29%	97.01%	97.23%	0.005999	0.002683	0.00572

Magnetic paste: 35℃ MO (6gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	89.48%	79.61%	85.06%	84.57%	91.30%	86.00%	0.045815	0.020489	0.043683
2	96.46%	94.71%	88.24%	94.76%	96.63%	94.16%	0.034315	0.015346	0.032718
3	97.25%	96.92%	96.38%	96.37%	96.97%	96.78%	0.003888	0.001739	0.003707
4	96.98%	97.16%	96.76%	96.89%	97.08%	96.97%	0.001571	0.000703	0.001498
5	97.12%	96.82%	96.79%	101.05%	97.63%	97.88%	0.018028	0.008062	0.017189
6	97.09%	97.09%	96.90%	97.03%	97.98%	97.22%	0.004330	0.001936	0.004128
7	97.48%	97.15%	97.21%	97.56%	98.16%	97.51%	0.004017	0.001796	0.003830
8	97.29%	97.26%	97.24%	96.84%	99.03%	97.53%	0.008574	0.003835	0.008175

Magnetic paste: OO (5gFe/g)

No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	59.12%	78.11%	86.14%	87.24%	86.76%	79.47%	0.119789	0.053571	0.114214
2	92.51%	95.30%	96.04%	97.25%	95.00%	95.22%	0.017459	0.007808	0.016646
3	94.83%	97.23%	95.90%	98.15%	95.71%	96.36%	0.013168	0.005889	0.012555
4	94.99%	97.08%	94.58%	96.98%	96.65%	96.06%	0.011801	0.005277	0.011251
5	95.54%	97.01%	94.98%	97.49%	96.92%	96.39%	0.010707	0.004788	0.010209
6	95.79%	97.01%	96.37%	97.00%	97.29%	96.69%	0.006064	0.002712	0.005782
7	96.27%	98.68%	96.07%	96.94%	95.68%	96.73%	0.011828	0.00529	0.011278
8	96.78%	97.53%	95.59%	97.41%	97.41%	96.94%	0.008121	0.003632	0.007743

Magnetic paste: MAYO (4gFe/g)

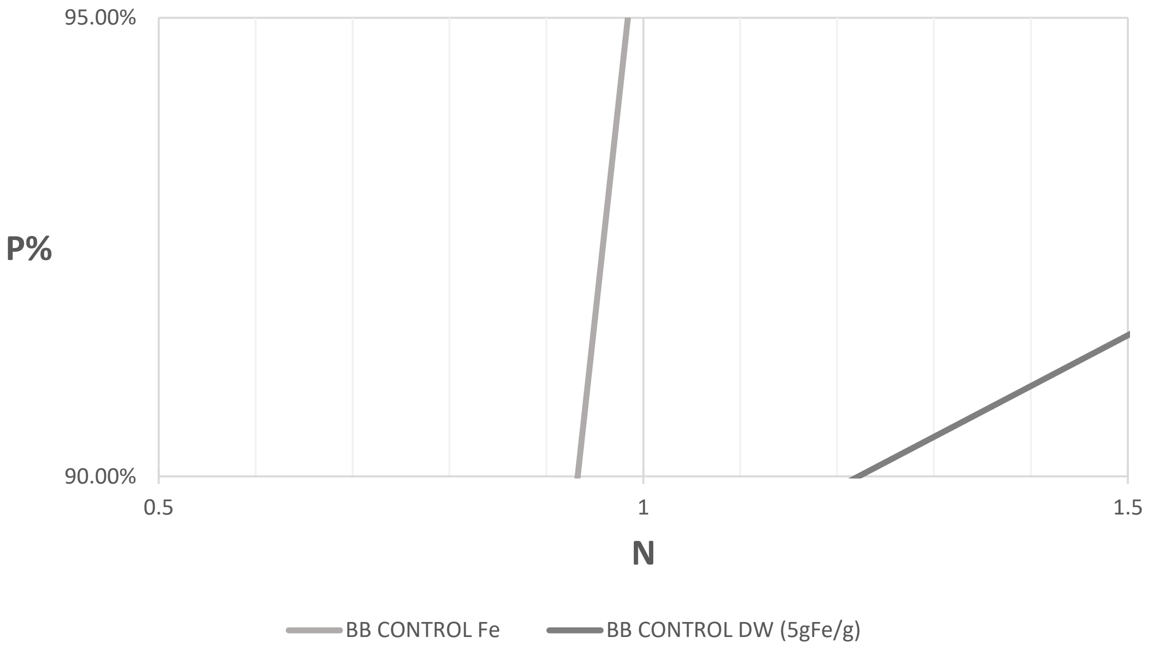
No. of Treatments	Oil Removed (%) B380					Average oil removed (%)	Standard Deviation	Standard Error	95% Confidence Interval
	No. of Replicates								
N	1	2	3	4	5	AVERAGE	STD	SE	95%CI
1	86.34%	80.73%	76.79%	68.15%	70.05%	76.41%	0.075181	0.033622	0.071682
2	96.26%	94.29%	94.21%	91.70%	92.51%	93.79%	0.017701	0.007916	0.016878
3	97.10%	97.22%	94.66%	92.41%	94.52%	95.18%	0.020141	0.009007	0.019204
4	97.49%	97.54%	94.39%	94.18%	95.61%	95.84%	0.016220	0.007254	0.015465
5	97.47%	98.32%	96.23%	95.40%	95.68%	96.62%	0.012386	0.005539	0.011810
6	97.84%	97.97%	96.08%	95.30%	96.03%	96.64%	0.011927	0.005334	0.011372
7	97.69%	97.77%	96.60%	95.30%	96.10%	96.69%	0.010553	0.004719	0.010062
8	97.38%	96.87%	96.60%	95.30%	96.10%	96.45%	0.007920	0.003542	0.007551

Appendix E

N values – Bua Ban

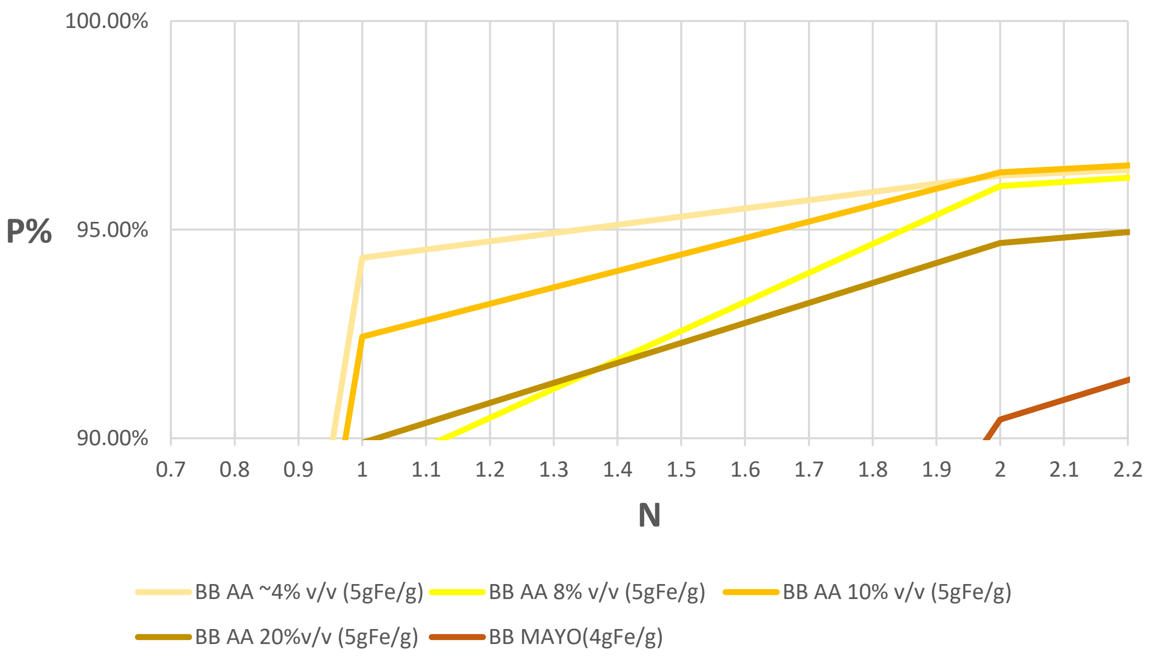
Controls

N_{90}



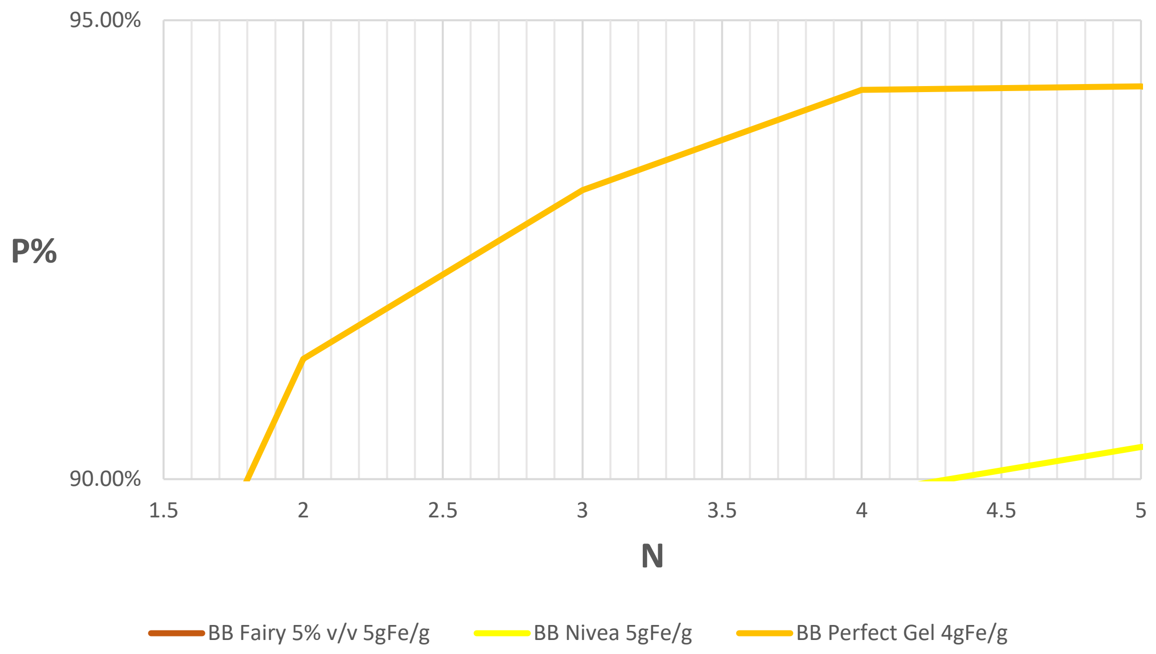
i. Pastes with an acetic acid component

N_{90}



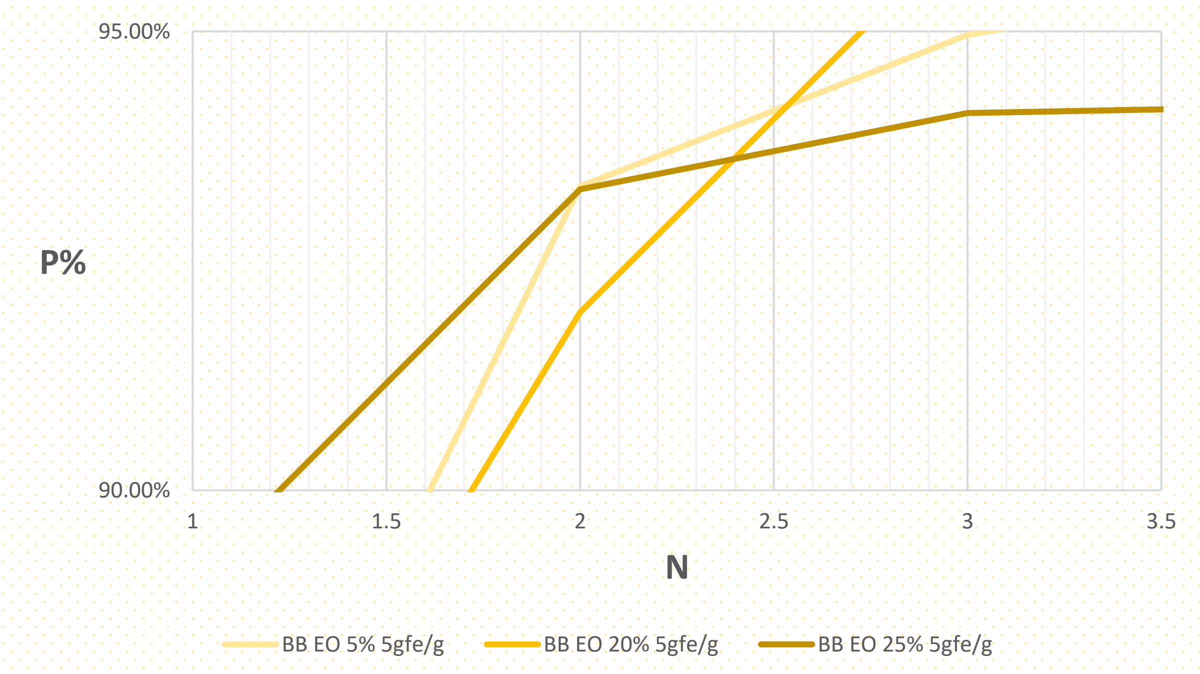
ii. Pastes with a commercial cleansing product

N_{90}



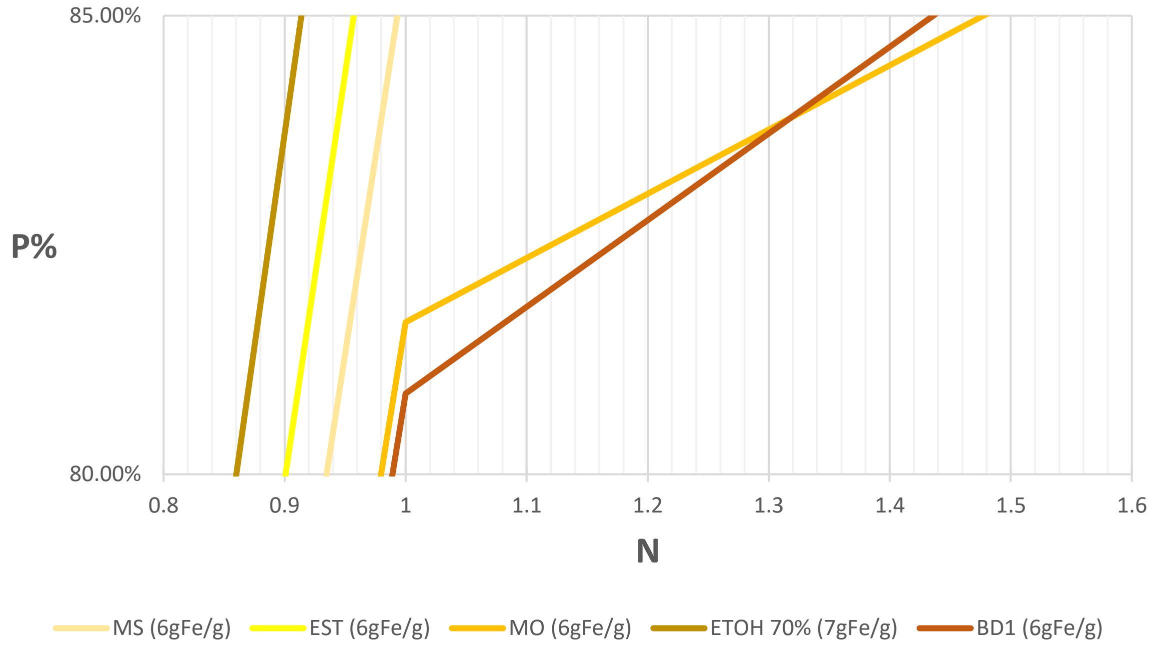
iii. Pastes with a eucalyptus oil component

N_{90} and N_{95}

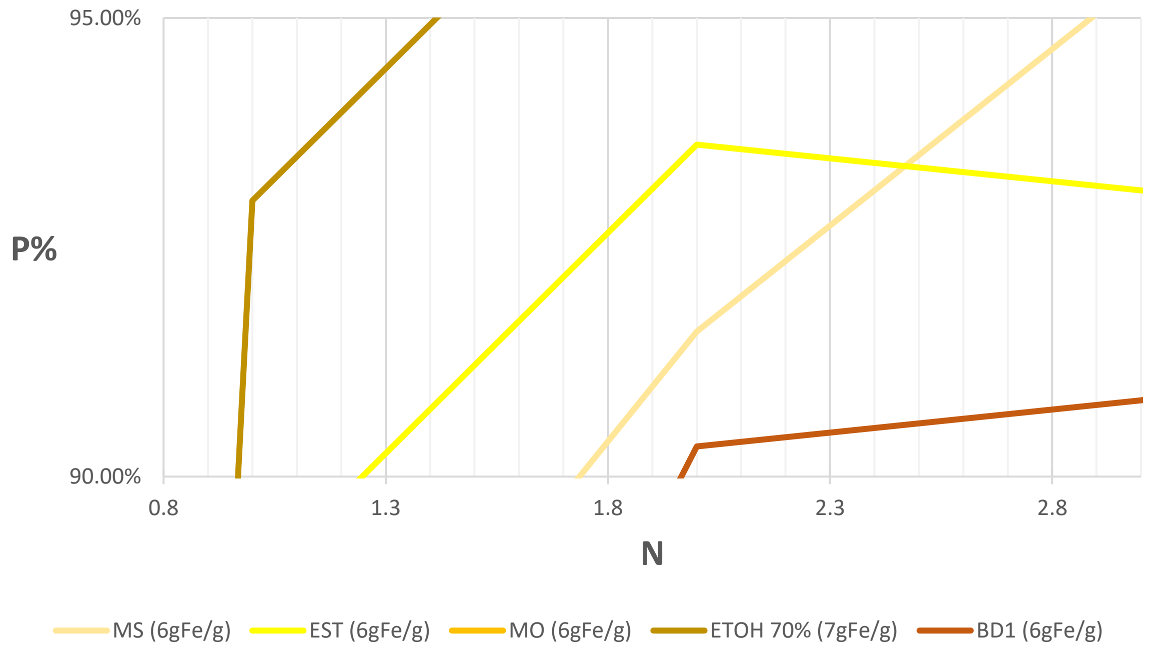


iv. Pastes with a conventional PTA agent (6gFe/g)

N_{80} and N_{85}

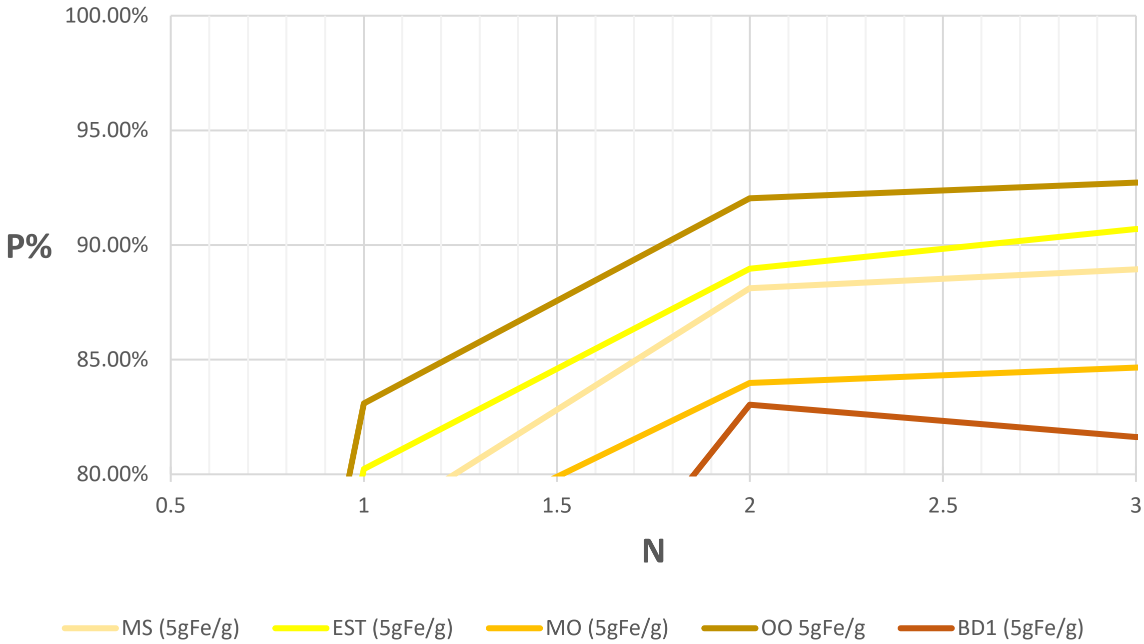


N_{90} and N_{95}

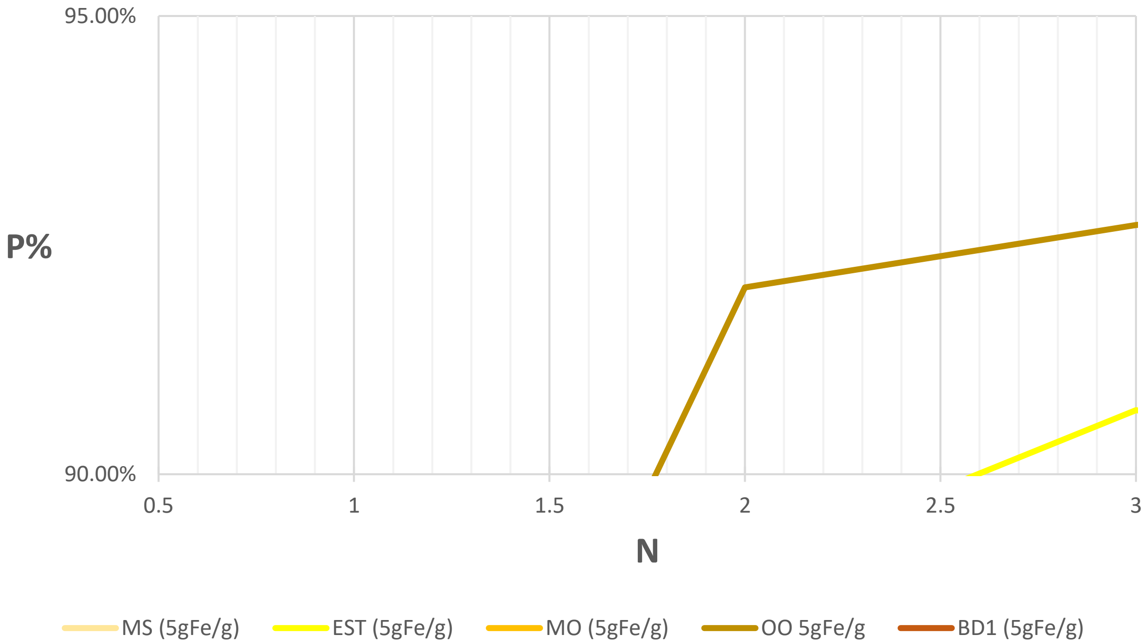


Pastes with a conventional PTA agent (5gFe/g)

N_{80}

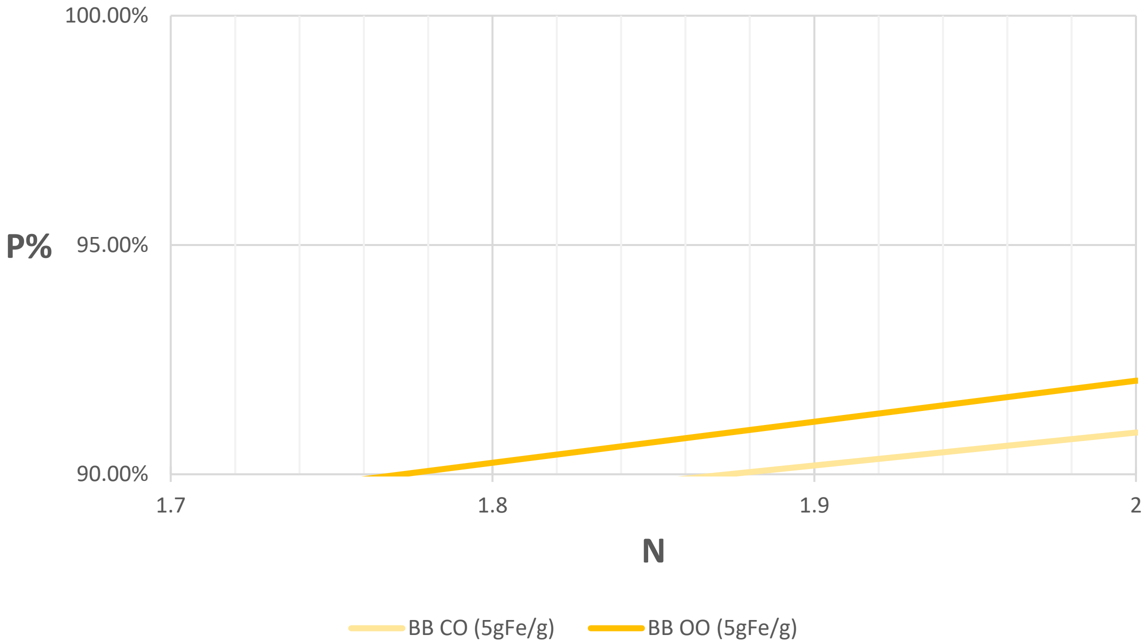


N_{90} and N_{95}



v. Pastes with a vegetable oil component

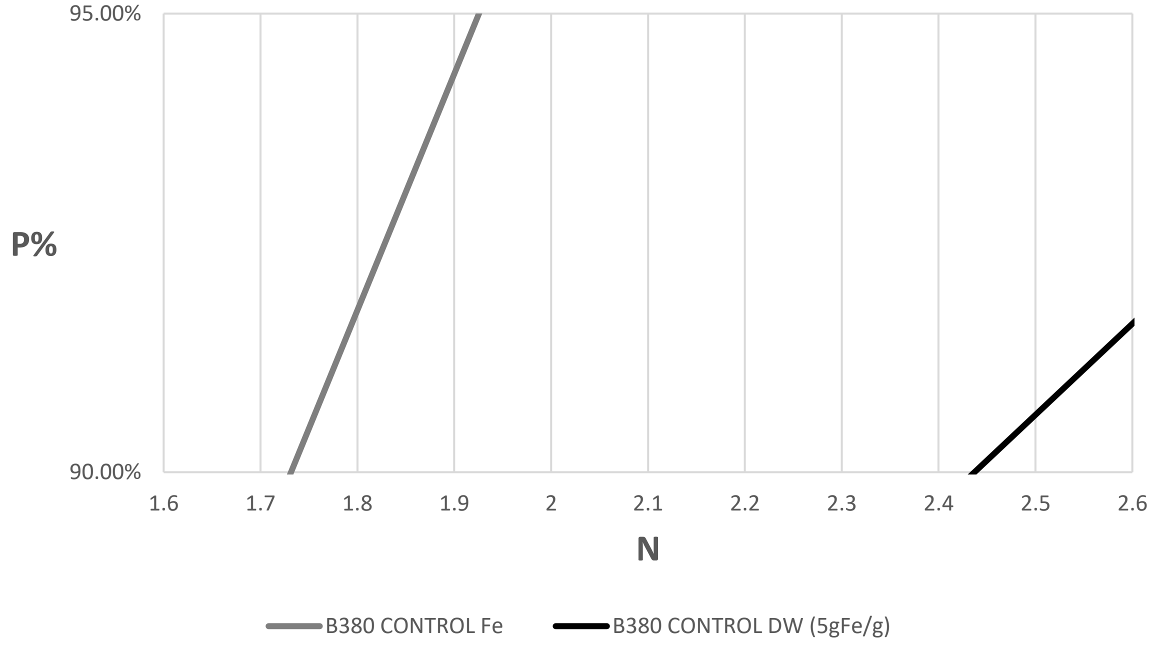
N_{90}



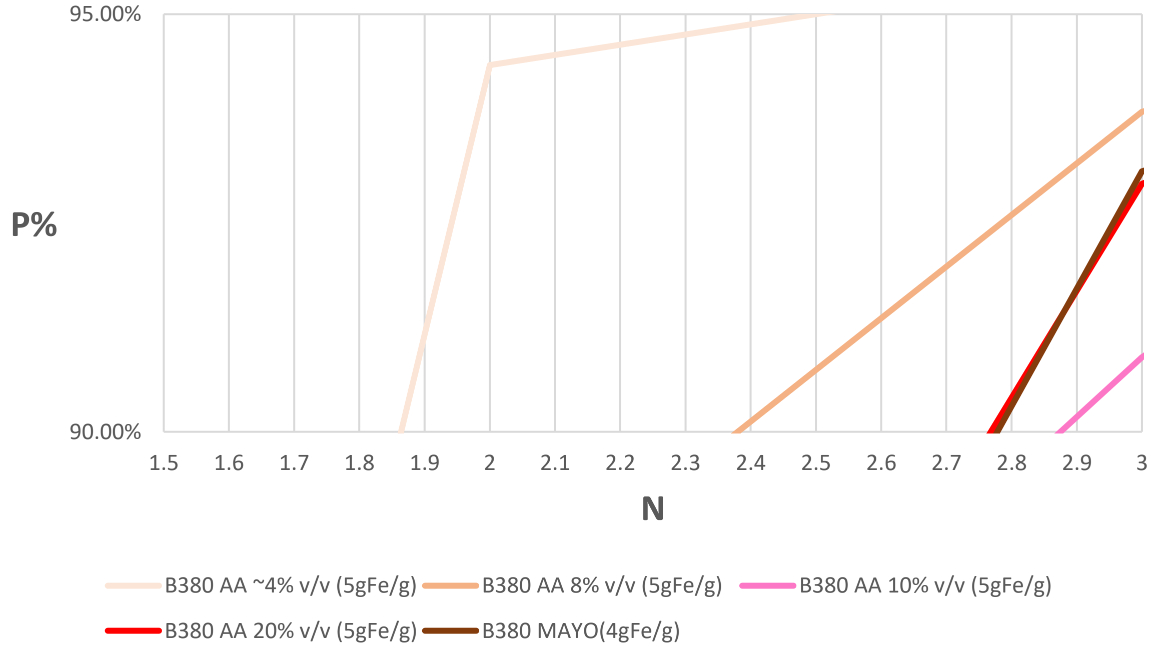
Appendix F

N values – Bunker 380

Controls

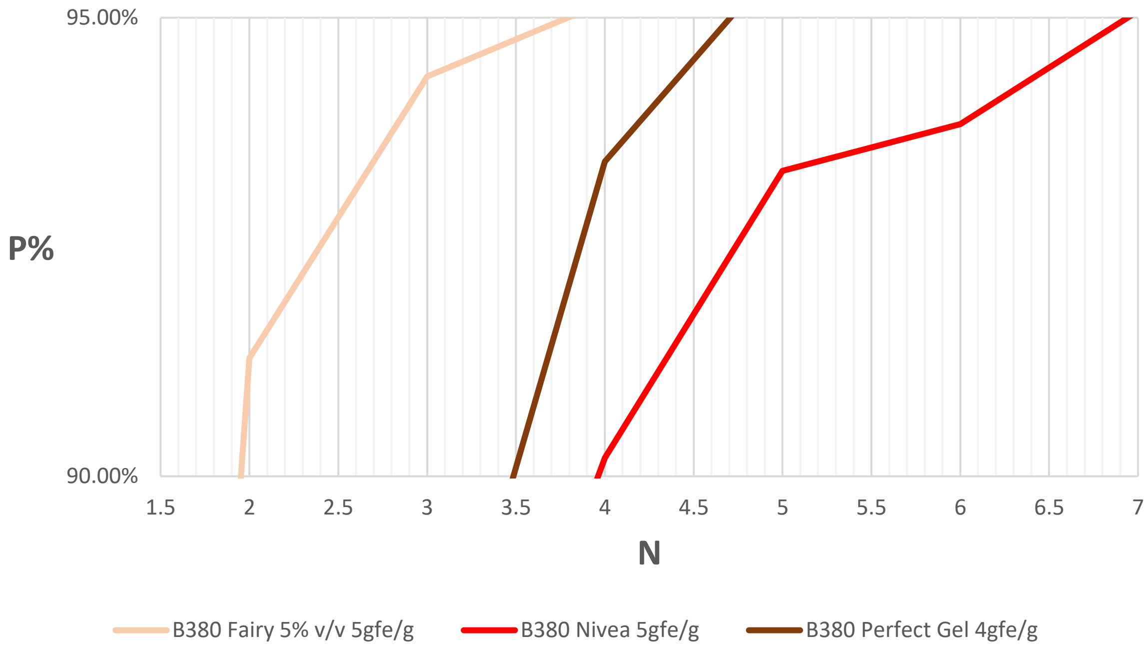


i. Pastes with an acetic acid component



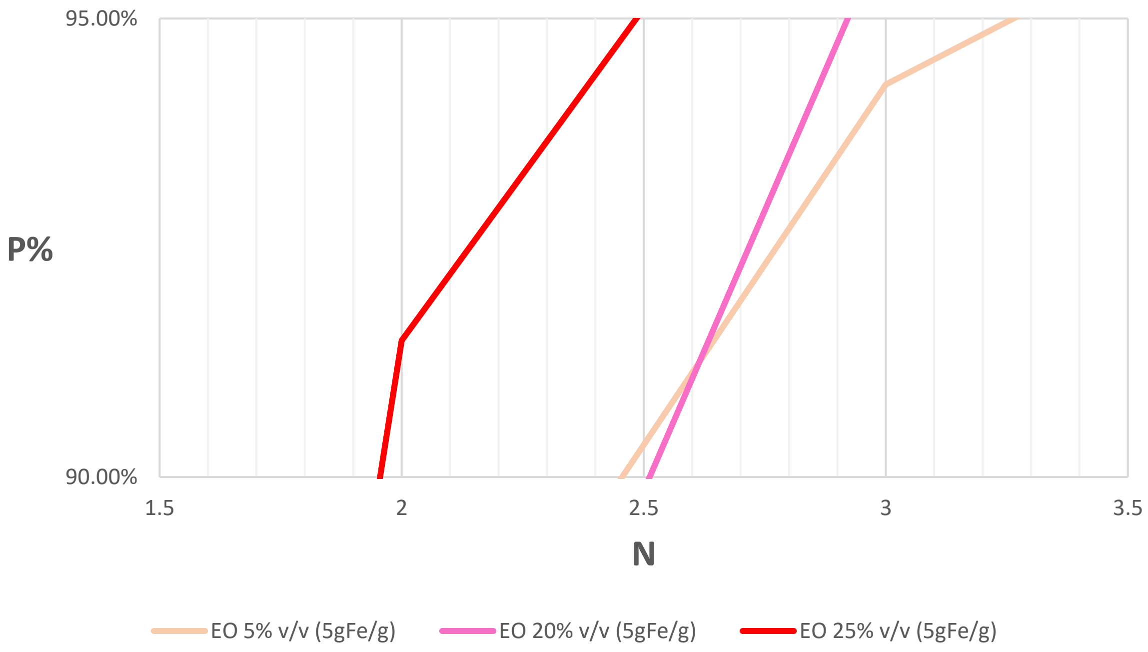
ii. Pastes with a commercial cleansing product

N_{90} and N_{95}



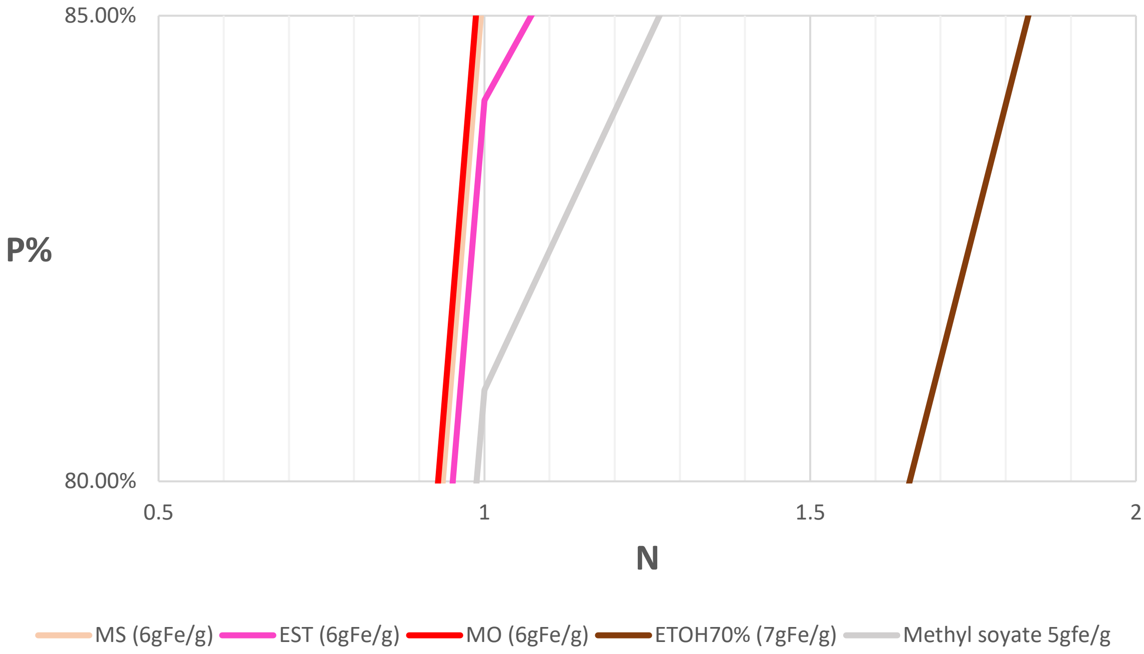
iii. Pastes with a eucalyptus component

N_{90} and N_{95}

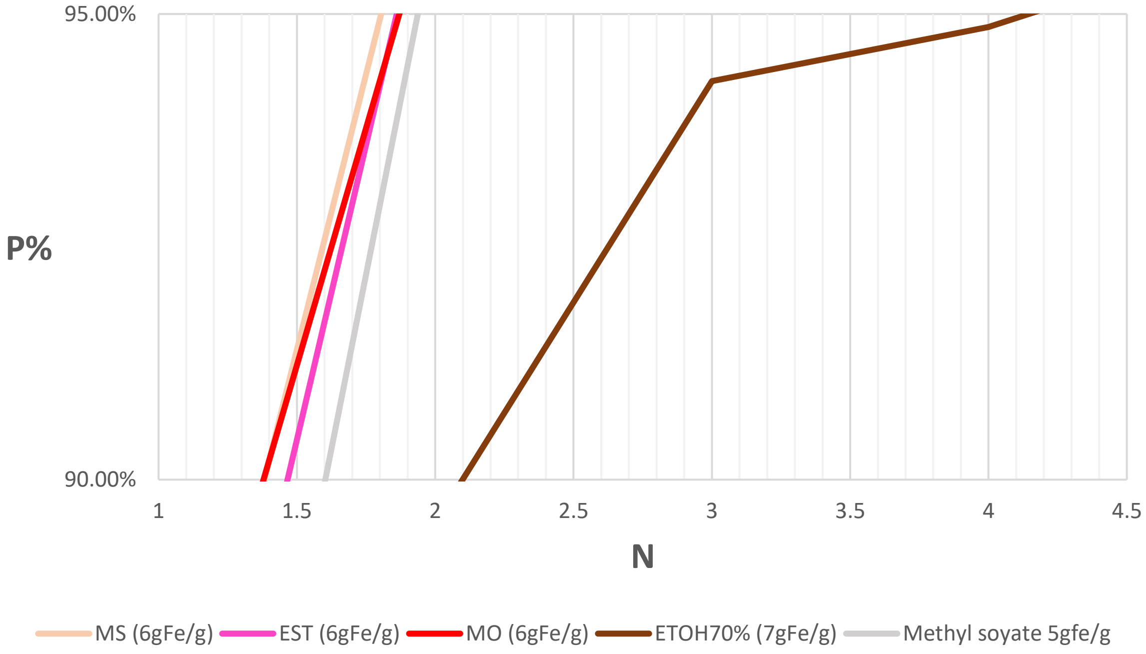


iv. Pastes with a conventional PTA component

N_{80} and N_{85}

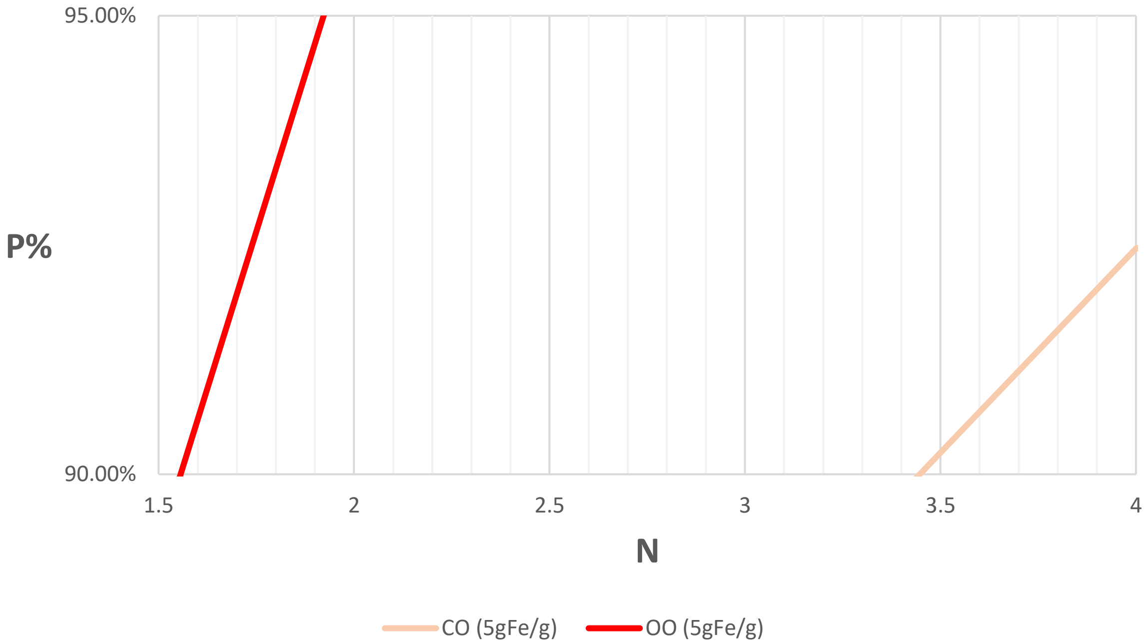


N_{90} and N_{95}



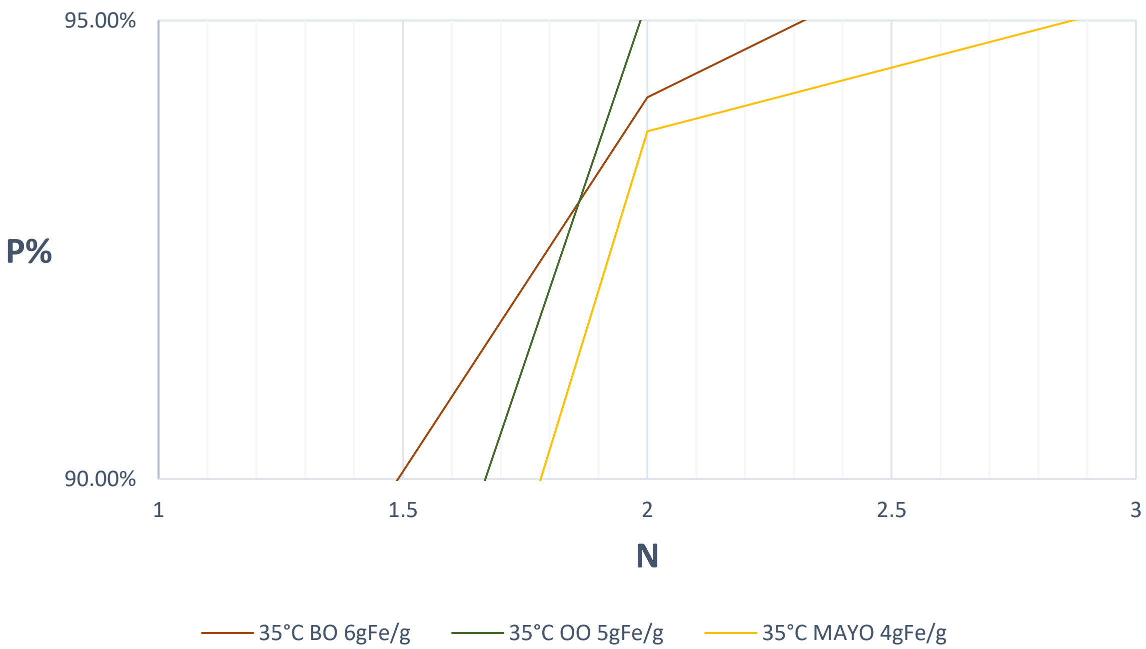
v. Pastes with a vegetable oil component

N_{90} and N_{95}



Heated pastes

N_{90} and N_{95}



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