An Investigation into the Feasibility of Applying Magnetic Particle Technology to the Cleansing of Oiled Wildlife in the Field

John D. Orbell [1,2], Hien V. Dao [1]
Lawrence N. Ngeh [2] & Stephen W. Bigger [2]

The Animal Rehabilitation Technology (ART) Group

[1] Institute for Sustainability & Innovation (ISI)
[2]School of Molecular Sciences (SMS)
Victoria University (VU)

Prepared for:

THE AUSTRALIAN MARITIME SAFETY AUTHORITY

THE NATIONAL PLAN ENVIRONMENT WORKING GROUP

THE PHILLIP ISLAND NATURE PARK

December 2007

Table of Contents

Page

1 Background

The application of magnetic particle technology to environmental remediation in general, and to wildlife rehabilitation in particular, has been under investigation at Victoria University for a number of years, in collaboration with the Phillip Island Research Centre (PIRC). This work has achieved significant international attention (e.g. Copley, 1999; Pilcher, 2004) and is now at a stage where proof of principle work has been completed and peer reviewed (Orbell *et al.*, 1999, 2004, 2005, 2007; Dao *et al.*, 2006-a, 2006-b, 2006-c).

The use of magnetic particles for the cleansing of oiled feathers (and fur) promises a number of advantages in terms of time, labour and cost over conventional detergent-based methods. Such particles, unlike detergents, are non-toxic, non-irritating and recyclable. The method also offers the possibility of superior equipment mobility. Thus it has been demonstrated that finely divided iron powder is almost ideal for the removal (via magnetic harvesting) of a range of different oil types and oil/seawater emulsions from both feather clusters and from the plumage of whole birds, with minimal feather damage compared to detergent-based cleansing (Orbell *et al.*, 1999; 2004). More recently, this technique has been demonstrated to be capable of achieving 100% removal (Dao *et al.*, 2006-a) and has also been demonstrated to be effective with respect to weathered/tarry contamination (Orbell *et al.*, 2005; Dao *et al.*, 2006-b; 2006-c).

Although conventional detergent-based methods of cleansing have achieved some impressive success rates at a number of treatment centres worldwide, there remain problems relating to time and cost, and the detergents themselves can be damaging. Some of the cost results from the fact that the feathers remain damaged for a lengthy period of time after cleansing, requiring additional care of the animals in specialized facilities up to the time of release. Although actual costs for conventional rehabilitation vary widely depending on the nature and location of the event, it is clear that traditional detergent-based methods are inherently expensive and have the potential to generate high quantities of wastewater. Apart from this, it is generally not possible to include such a cumbersome procedure in initial stabilization protocols (in the field) since the required facilities are not transportable, and most of the pollution has to remain on the bird until the bird can be delivered to an appropriate treatment facility.

One of the goals to be explored in the research program is the development of a field procedure based on magnetic particle technology that would enable the bulk of the contamination to be removed upon first encounter, either prior to, concomitant with, or following, standard stabilization methods (fluid administration etc). The success of this would very much depend upon how stressful a magnetic cleansing protocol would be as a definitive cleansing procedure (compared to detergent in water cleansing). The application of magnetic cleansing in lieu of (or even in conjunction with) detergent in water cleansing, after the bird has been stabilized and transported to a treatment facility, is also an important consideration. At this stage, it is expected that effective magnetic cleansing would be expected to save time (e.g. reduced rinsing and drying time) and be more benign in terms of handling, hence resulting in less stress.

Given the successful proof of principle work that has been completed to date, there is now a requirement to move this research “into the field”. It is anticipated that “in the field” refers to on the shoreline, out at sea, or within a treatment facility (in lieu of or in conjunction with the detergent in water method).

This project therefore aims to conduct a feasibility study whereby a prototype methodology is applied to a controlled simulation of whole bird cleansing in the field. An evaluation with respect to cost and logistics (including waste disposal), relative to conventional detergent-based methods is to be carried out and technological developments are to be identified.

At the request of the project co-sponsors, AMSA, this report is structured around the project milestones.

2 Consultations

Milestone 1: **Complete consultations and preliminary (exploratory) experimental design relating to the simulation of a "field" setting and response.**

Preliminary consultations and discussions involved visits of the research team to the Australian Marine Oil Spill Centre Pty. Ltd. (AMOSC) and the Oil Response Company of Australia Pty. Ltd. (ORCA). In particular, the engineering aspects of the project were discussed in some detail, especially with respect to devising the most suitable method for applying the magnetic powder in the field and at a treatment facility and for the design and construction of the most appropriate magnetic harvesting device for these settings. Discussions were held on the technological requirements of possible devices to spray the iron powder in a field situation. Discussions also included the logistics of oiled wildlife response and key documentation and literature on relevant aspects of the project was obtained (IPIECA, 2004; Walraven, 2004-b).

Phillip Island Nature Park was consulted regularly throughout the project. Other contacts in relation to the project include Bristol University, Alpha Magnetics, the International Oil Pollution Compensation Fund and the International Bird Rescue Research Centre.

During the course of the project, the team also received feedback and advice from an Expert Advisory Panel of oiled wildlife responders convened by AMSA.

3 Materials

Milestone 2: **Identify and acquire the necessary materials for preliminary (exploratory) experiments in a simulated "field" setting.**

A supply of 50 kg of MH300 iron powder was supplied by Höganäs AB, Sweden. This is a more recently developed grade that is comparable to the optimal grade, MH300.29, developed by our research team (Dao *et al.*, 2006-a). Thirty high quality Little Penguin (*Eudyptula minor*) carcasses were acquired from Phillip Island Nature Park and kept in cold storage at Victoria University until required. Five litres of Diesel Oil was purchased. Other items of equipment (such as a magnetic harvester and top pan and analytical balances) were already in place as part of our existing research program.

4 Preliminary experiments

Milestone 3: **Carry out preliminary experiments utilizing one oil type and one bird species utilizing both conventional and detergent-based methods and magnetic cleansing. Collect comparative data relating to these experiments.**

Preliminary experiments on penguin feathers and plumage were carried out using Diesel Oil as a contaminant. This is consistent with the recommendation of the expert advisory panel to place an emphasis on this type of contaminant. This is particularly relevant to the removal of the more volatile toxic/corrosive components upon first encounter (i.e. the potential incorporation of magnetic cleansing into the stabililization protocol).

It was decided at this preliminary stage that, for this type of contaminant, it was not appropriate to conduct detergent - based cleansing, since the cleansing process is very difficult to track for such a colourless contaminant. However, benchmarking with detergent-based methods has been carried out a later stage utilizing both Diesel and Bunker Oils as the contaminant (please refer to *Milestone 6*).

Initial experiments were conducted on the weathering of diesel on feathers (see Section 4.1 below). This was followed by preliminary magnetic cleansing experiments, involving the removal of diesel from feather clusters. In the subsequent experimental phase, testing was done for the removal of Diesel Oil from the plumage of penguin carcasses. In these experiments, a carcass was totally immersed with diesel ("*worst-case scenario*") and then subject to controlled magnetic cleansing protocol.

All parameters of the cleansing process such as oil removal, cleansing time, iron powder consumption and waste created were recorded. Following the preliminary experiments, AMSA and the Expert Advisory Panel were invited to provide feedback to inform the development of further experiments.

4.1 The weathering of Diesel Oil

For the purpose of these experiments, weathering is considered to be the extent of evaporation of the more volatile fractions over time. In this regard, evaporation is considered to be the major process of weathering (Mullin & Champ, 2003), resulting in around 5-10% of oil weight lost for heavy crude oil spills, and 20-60% for lighter crude (NOAA, 1997) and around 40-65% for diesel (NOAA, 2007). Also, for wildlife contamination, it is not necessary for long-term, non-evaporative weathering processes to be considered since this would extend beyond the survival time of the animal. A similar procedure on the mimicking of oil weathering has been reported (Dao *et al.*, 2006-c)

In this study, the weathering process of Diesel Oil was simulated in the laboratory as follows: a cluster of feathers was immersed in a beaker of diesel. It was then left to hang in the air at room temperature for up to 8 days. The weight of the oiled feathers was monitored over time and this was taken to be a measure of the degree of weathering. For diesel, the evaporation rate is fairly high, resulting in around 10% after 8 hrs and 23% weight loss after 1 day. And 8 days of weathering results in the weight loss of 44%.

4.2 Experiments on feather clusters for Diesel Oil

Prior to carrying out the experiments on the removal of Diesel Oil from plumage, an investigation into the magnetic cleansing of this contaminant from *clusters of feathers* was conducted. These experiments were carried out in triplicate by an established gravimetric protocol (Orbell *et al.*, 1999). As expected, magnetic particles are very effective at removing diesel from feathers, showing an achievement of ca. 100% removal (*within experimental error*) after only 4 treatments, Fig. 1.

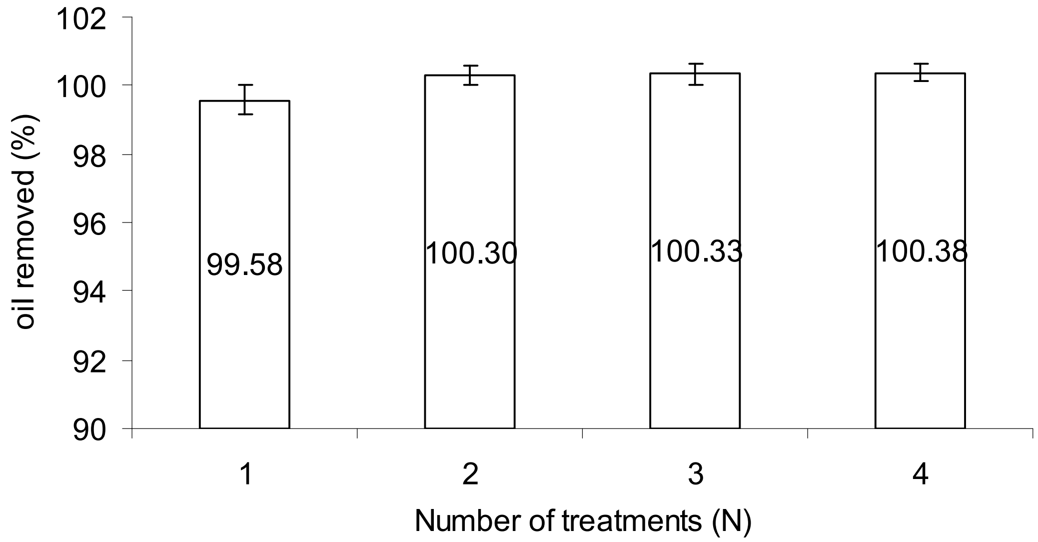

Figure 1: Histogram of Diesel Oil removal, F(%), from clusters of feathers as a function of the number of treatments, N. Error bars represent the standard error for three replicates. The data are presented in the Appendix, Table 1.

4.3 Experiments on whole-bird plumage for Diesel Oil

Having demonstrated the effectiveness of removal of Diesel Oil from feather clusters, the iron powder, grade MH300, was then applied to the removal of this contaminant from the plumage of whole penguin carcasses. In these experiments, a carcass was totally immersed with diesel representing a "worst-case-scenario" of 100% coverage and then subjected to the magnetic cleansing protocol. All parameters of the cleansing process such as oil removal, cleansing time, iron powder consumption and waste created were recorded. Experiments were carried out in triplicate using three penguin carcasses, with body weights ranging from 570 to 730 g.

The method for the gravimetric determination of contaminant removal, time cleansing and iron powder consumption for the magnetic cleansing of a bird carcass that is fully saturated with Diesel Oil is described as follows. A pre-weighed penguin carcass, f_1, was immersed into a container of diesel for 5 min, Fig. 2 and then removed from the container. It was then allowed to drain off the oil until no dripping was observed, which usually takes around 30 min, Fig. 3. The oiled bird was re-weighed, f_2, on a tarred tray and was then removed from the tray and the residual quantity, r, was recorded. Hence, the weight of the oil-laden bird, f_3, for further experimentation was given by:

$$f_3 = f_2 - r \qquad (1.1)$$

The contaminated bird was then completely covered and rubbed with magnetic particles by immersing it into a pre-weighed container of iron powder, m_1, e.g. 2 kg, Fig. 4, in order for absorption and adsorption of the contaminant to occur. The oil-laden iron powders were then harvested from the plumage using a magnetic tester. The stripped bird was then re-weighed, f_4. The percentage removal of the contaminant, F (%), was calculated using Equation 1.2

$$F\ (\%) = [(f_3 - f_4) / (f_3 - f_1)] \times 100\% \qquad (1.2)$$

A number of applications (N) were performed until a constant value of F (%) was achieved. For Diesel Oil, only 8 treatments were needed. After each treatment, the container of iron powder was weighed, m_2, and the iron powder consumption, M, was calculated from Equation 1.3.

$$M = m_1 - m_2 \qquad (1.3)$$

A timer was used to record cleansing time for each treatment, including time for covering and rubbing as well as harvesting off the particles from the plumage. All experiments were carried out in three replicates and at 295 K.

It is noted that since diesel is transparent it can be quite difficult to see the difference between before cleansing, Fig. 3 and after cleansing, Fig. 5. However, a difference in relation to the wettability of the plumage can be noticed between these two pictures, reflecting the fact (*determined quantitatively*) that the oil is mostly removed magnetically.

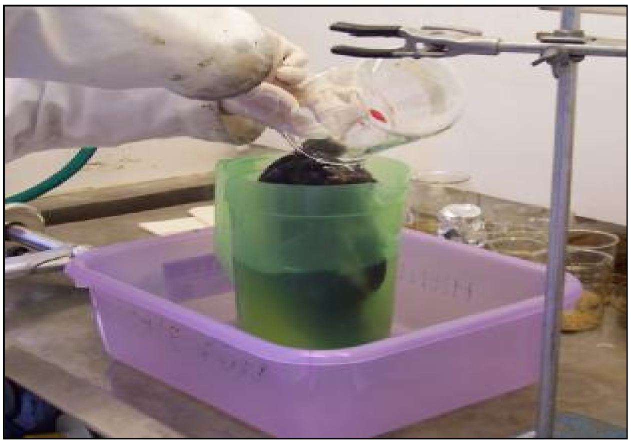

Figure 2: The penguin carcass is immersed into a container of Diesel Oil

Figure 3: The oiled bird is left to drain until dripping ceases

Figure 4: The oiled carcass is covered with iron powder by immersing it into a container of powder

Figure 5: The bird after cleansing

The results of these preliminary experiments on Diesel Oil for the 100% coverage scenario are presented in Fig. 6.

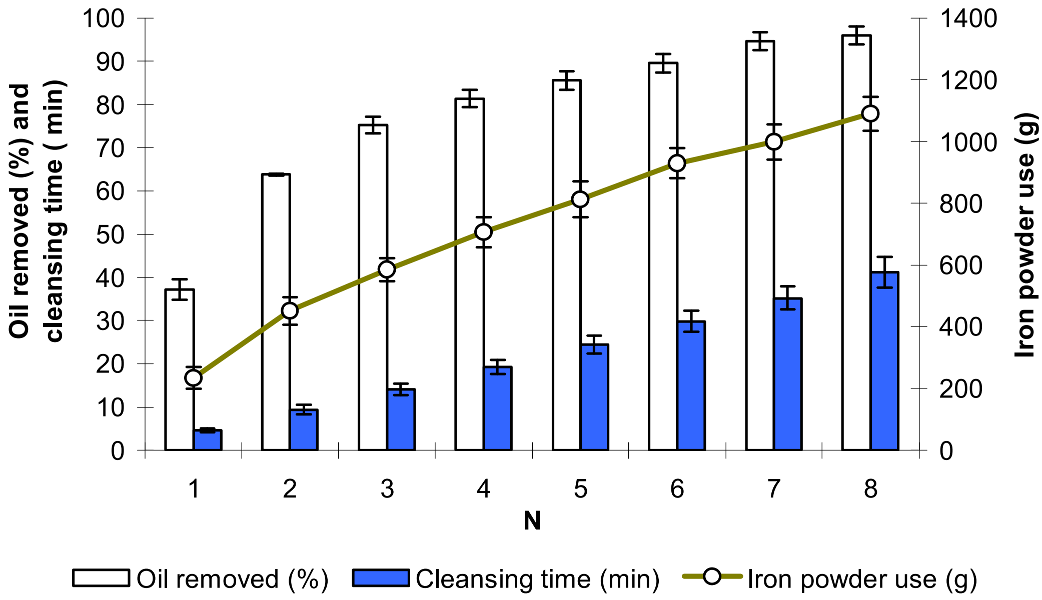

Figure 6: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of **100% Diesel Oil coverage** from plumage. Error bars represent the standard error for three replicates. The data are presented in the Appendix, Table 2. The individual profiles corresponding to each parameter are also presented in the Appendix, Tables 3 to 5.

As can be seen from Fig. 6, oil removal increases as the number of treatments increases. After one treatment it is 37% and increases to 75% after 3 treatments and to 96% after 8 treatments. In terms of cleansing time, this also increases with an increase in the number of treatments, ranging from 5 min for one treatment to 14 min for 3 treatments to 41 min for 8 treatments. As with the above two parameters, the iron powder consumption also increases with increasing the number of treatments. After one treatment 234 g is needed, rising to 585g after 3 treatments and, by the end of the process, 1090 g of iron powder has been consumed. Finally, the waste created (diesel laden iron powder) for the whole process is 1230 g. It is also worth noting that for these kinds of experiments (*worst-case scenario*), the amount of Diesel Oil adsorbed by a bird ranges from 126 to 162 g, depending on the body weight of the carcass. Note that, after 41 min (8 treatments), using 1090 g of iron powder, 96% of the diesel, (equivalent to ~ 137 g) is removed.

5 Technological considerations

<u>*Milestone 4*</u>*:* **Identify and implement any desirable technological developments for magnetic cleansing.**

A "*second-generation*" magnetic harvesting device powered by compressed air was designed and a prototype device constructed for this project, Fig. 7. It was designed to be one-handed as opposed to existing devices that require two hands for operation ("*first generation*") (Orbell *et al.*, 1997). The device utilizes a rare earth permanent magnet that can be switched on and off mechanically. It was found during our experiments that, for ergonomic reasons, it is necessary to provide power to the on/off switch. If this power were to be provided by the muscles of the human hand it has been determined that, certainly for repetitive use, the device would be unsuitable. Other features that have been incorporated into this device include its light weight, its rapid on/off response and its controlled recoil upon switching off - this effectively projects the contaminant-laden powder into an appropriate receptacle, greatly assisting in the quantification of the waste. Another variation to this device involves the use of a solenoid to power the on/off switch. The successful improvement of the magnetic harvesting device represents a major advance and is anticipated to significantly facilitate future development of the magnetic cleansing technique. In this regard, we have also identified the need for a device to apply the magnetic powder and suitable equipment for its storage before and after application.

During the preliminary experiments, the way in which iron powder was applied onto the bird was identified as an important consideration. In this regard, the iron powder consumption reported in the preliminary experiments represents only those particles that were involved in stripping the oil from the carcass. However, a quantity of iron powder remained unaccounted for in the bottom of the container (Fig. 4). In order to obtain a more accurate measure of iron powder consumption, in the absence of the development of a suitable application device, subsequent experiments involved the application of the iron powder by hand. Further work on the technological aspects of magnetic cleansing is underway within our group, but is beyond the scope of this project.

Figure 7: The "third generation" magnetic harvester

6 Experimental design - for comparative investigations

<u>*Milestone 5*</u> **Based on an evaluation of the preliminary experiments, establish a prototype magnetic cleansing field method. Identify and acquire necessary materials for these experiments.**

A protocol was developed for magnetically cleansing varying amounts of Diesel and Bunker Oils from penguin whole bird models (carcases) and for tracking relevant parameters, i.e. oil removal, cleansing time and iron powder consumption with respect to number of treatments and waste created for the whole process.

In addition to Diesel Oil, two heavy Bunker Oils ("Bunker Oil 1" and "Bunker Oil 2") were acquired for use in the following experiments. The viscosities at 295 K (measured by a rheometer for different shear rates of 5, 10, 20 and 50 s^{-1}) were approx. 2600cSt (Bunker Oil 1) and 3200cSt (Bunker Oil 2).

Following the identification of technological improvements based on the preliminary experiments (see Sections 4 and 5 above), an additional magnetic tester (with a more powerful magnetic) and an air compressor to operate the one-handed magnetic harvester were acquired.

In order to better reflect scenarios in the field, in consultation with the Expert Advisory Panel, it was decided to include in our experimental design an important additional parameter; namely, different degrees of contaminant coverage. A consideration of the *amount* of oiling (i.e. oil coverage) is critical with respect to the overall effect of contamination, self-cleaning prospects and survival chances of oiled seabirds (MME, 2006). This has resulted in considerably more experiments that have needed to be conducted and that were not initially anticipated. Since such gravimetric experiments are very time consuming, it has been necessary to limit the experiments to penguin plumage alone. This does not compromise the investigation since, from previous work, magnetic removal of oil from penguin feathers has been found to be comparable to removal from duck feathers (Orbell *et al.*, 2004). The choice of penguin plumage is also considered to be more relevant to our collaboration with the Phillip Island Nature Park; penguin carcasses were available from this source.

7 Magnetic cleansing experiments with different coverages of Diesel and Bunker Oils

<u>*Milestone 6:*</u> **Apply this method to penguin and duck carcasses contaminated with a wide range of contaminants. Collect and record relevant observations and data that will allow a comparison to be made with conventional detergent-based methods, especially in relation to the removal of the bulk of the contamination upon first encounter.**

Refer to the previous section with respect to the exclusion of duck carcasses from the experiments. Therefore, experiments were conducted only on penguin carcasses, for both magnetic cleansing and for detergent-based methods.

Based on the results of the preliminary work, further experiments were carried out on penguin carcasses using Diesel Oil and two types of heavy bunker oil (Bunker Oil 1 and Bunker Oil 2). For each of the contaminants, experiments were conducted for different contaminant coverages. For our priority contaminant, namely Diesel Oil, experiments were conducted for 10%, 20%, 50%, 70% and 100% coverages (by weight). A 100% coverage represents total immersion – a "*worst case*" scenario.

Similarly, for Bunker Oil 1, experiments were conducted for 10%, 20%, 50%, 70% and 100% coverage (by weight). For Bunker Oil 2, only 50% coverage was considered. These experiments are more representative of what might occur in the field where birds are not necessarily fully contaminated with oil. As with the preliminary testing, cleansing time, oil removal, iron powder use and waste created were also recorded. Photographs were taken of all stages of the experiments.

Benchmarking experiments using detergent-based methods have been carried out for both Diesel Oil and Bunker Oil 1. These experiments were carried out at the Phillip Island Nature Park (PINP) and the Werribee Campus of Victoria University, for 10%, 50%, 70% and 100% coverages for both contaminants. The relevant parameters for the detergent cleaning process (time, water and detergent use) were recorded. These experiments were also photographed and videoed.

7.1 Experiments with Diesel Oil

The methodology and the experimental results for the removal of 100% coverage (total immersion) of Diesel Oil from penguin are described in Section 4.

For "*non-worst case*" scenario experiments using Diesel Oil, a carcass was subjected to different levels of oil coverage, namely 10%, 20%, 50% and 70% (by weight) and then subjected to magnetic cleansing.

In order to be able to consistently apply the different levels of oil coverage (10%, 20%, 50% and 70%) to carcasses of varying sizes, a coverage methodology was developed. Experiments showed a high correlation between carcass body weight and oil saturation (100% coverage), Fig. 8. Given this calibration curve, for a given carcass weight, it is possible to estimate the amount of oil needed to achieve 100% coverage - and hence fractional coverages. For example, for a bird with a body weight of 620 g, the weight of oil required for saturation is (0.2339 x 620) – 8.6546 = 136.4 g. Therefore, 10% coverage by weight requires 136.4 x 0.1 = 13.64 g of oil to be applied.

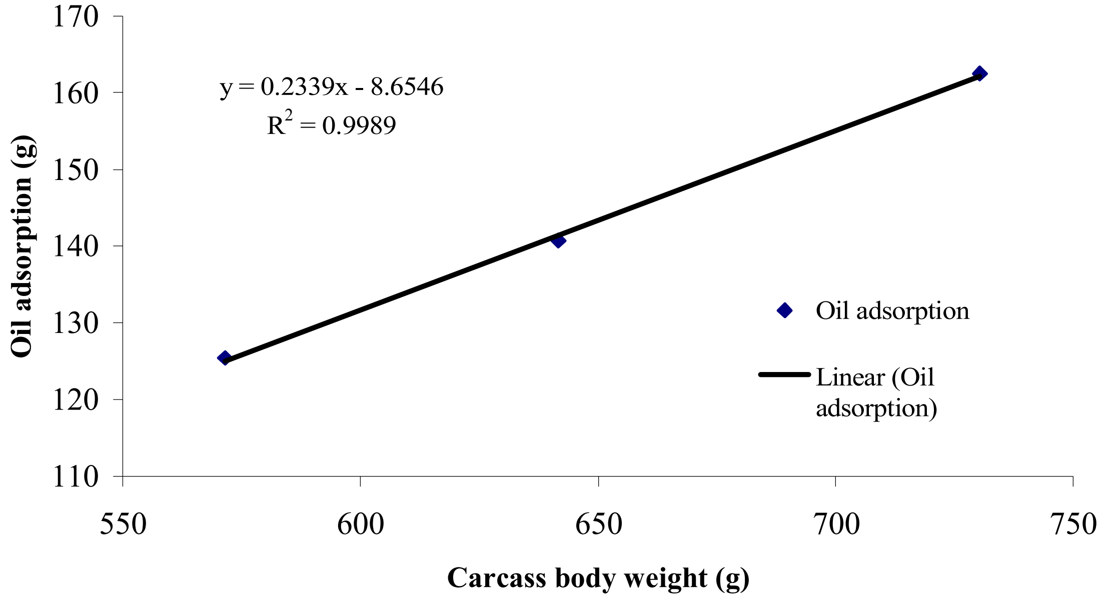

Figure 8: Correlation between 100% oil coverage and carcass body weight, including regression equation and calibration curve; p-value = 0.0214. The data are presented in the Appendix, Table 6.

The method for the gravimetric determination of contaminant removal, cleansing time and iron powder consumption, for the "*non-worst case scenario*" experiments, is described as follows. A penguin carcass was weighed, p_1, using a top loading balance. A known amount of oil for a specific % coverage (determined as described previously) was carefully poured onto the plumage, Fig. 9. Five minutes were allowed for the oil to fully penetrate into the plumage. The oiled carcass was then re-weighed, p_2. Iron powder was then applied to the plumage, and the oiled carcass covered with iron powder was left for about 1.5 min to allow sequestering of the contaminant to occur, Fig. 10. The oiled carcass covered with iron powder was weighed, p_3. The oil-laden iron powder was then removed using a magnetic tester and the bird was re-weighed, p_4. The percentage removal of the contaminant, P (%), was calculated using Equation 1.4.

$$P (\%) = [(p_3 - p_4)/(p_3 - p_1)] \times 100\% \qquad (1.4)$$

A number of applications (N) were performed until a maximum value of P (%) was achieved. For Diesel Oil, only 9 treatments were needed and the treated carcass was photographed and is shown in Fig. 11. The iron powder consumption for each treatment, I, was calculated from Equation 1.5

$$I = p_3 - p_2 \qquad (1.5)$$

As with the "*worst-case scenario*" experiments, a timer was used to record time for each treatment, including time for covering, rubbing magnetic particles, and stripping them off the plumage. All experiments were carried out in triplicate and at 295 K.

Figure 9: The carcass is to be contaminated with an amount of Diesel Oil from the beaker to provide 50% coverage.

Figure 10: The oiled carcass is covered with iron powder.

Figure 11: The oiled carcass after magnetic cleansing (9 treatments)

The results of the experiments for Diesel Oil, for 10%, 20%, 50% and 70% coverage are presented in Figs. 12 - 15. For each coverage, parameters relating to the initial and the final treatments are summarized in Table 1.

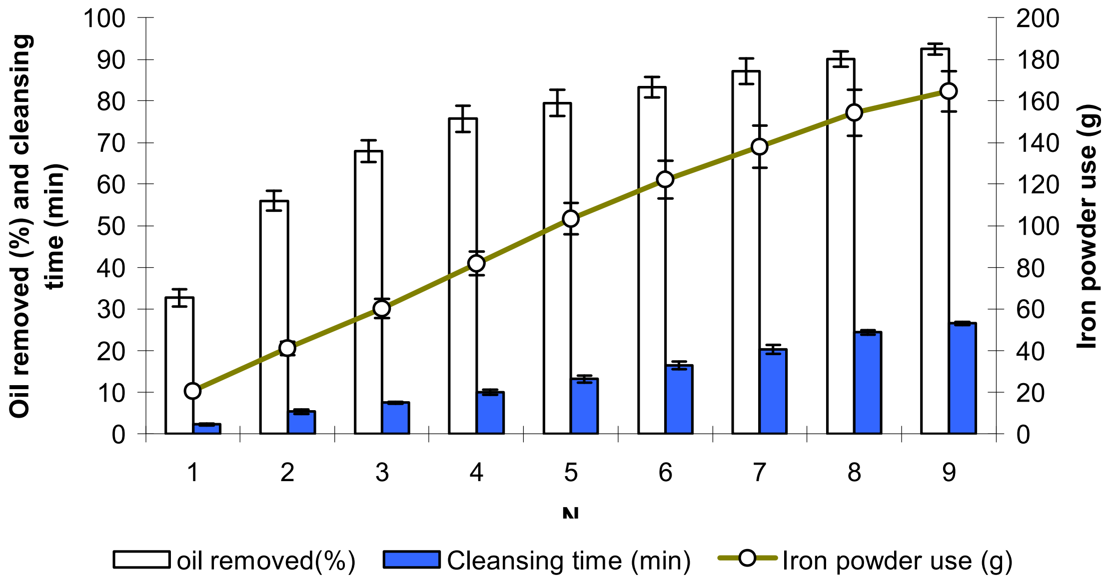

Figure 12: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of **10% Diesel Oil coverage (**by mass) from plumage. Error bars represent the standard error for three replicates. The data are presented in the Appendix, Table 7. The individual profiles corresponding to each parameter are presented in the Appendix, Tables 8 to 10.

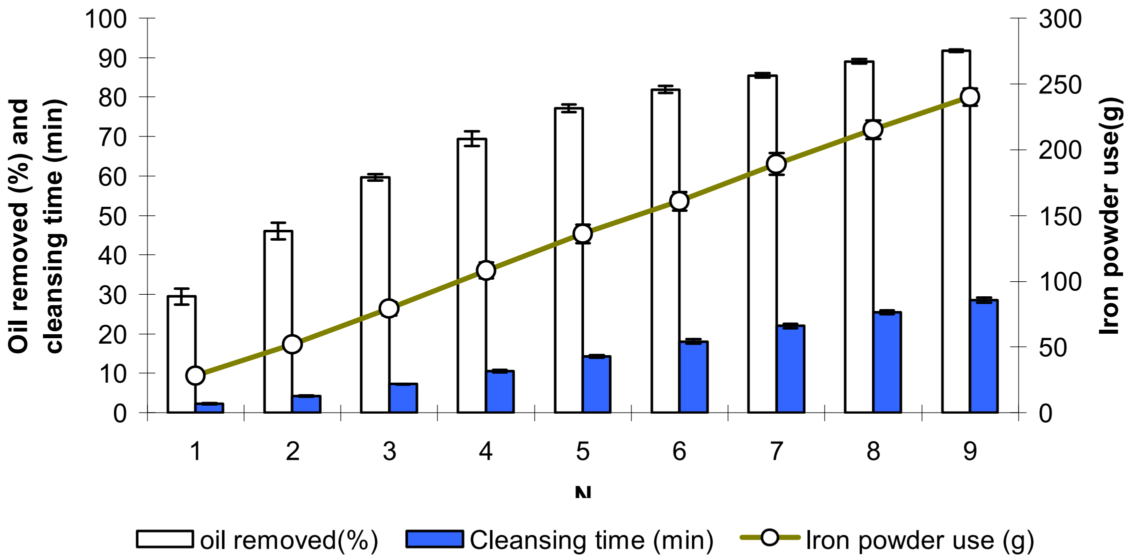

Figure 13: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of **20% Diesel Oil coverage** (by mass) from plumage. Error bars represent the standard error for three replicates. The data are presented in the Appendix, Table 11. The individual profiles corresponding to each parameter are presented in the Appendix, Tables 12 to 14.

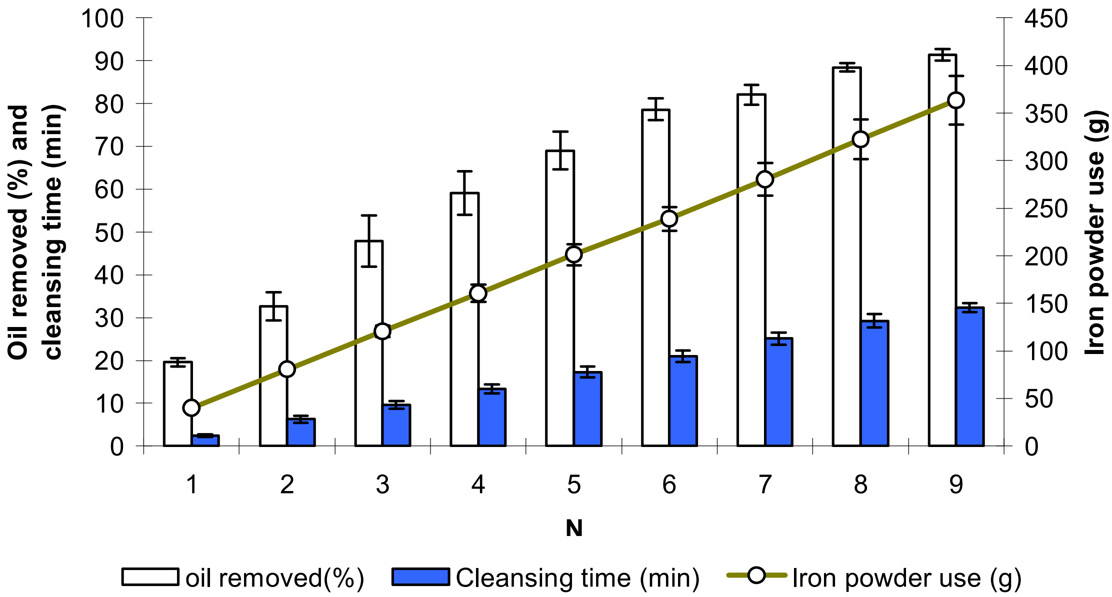

Figure 14: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of **50% Diesel Oil coverage** (by mass) from plumage. Error bars represent the standard error for three replicates. The data are presented in the Appendix, Table 15. The individual profiles corresponding to each parameter are presented in the Appendix, Tables 16 to 18.

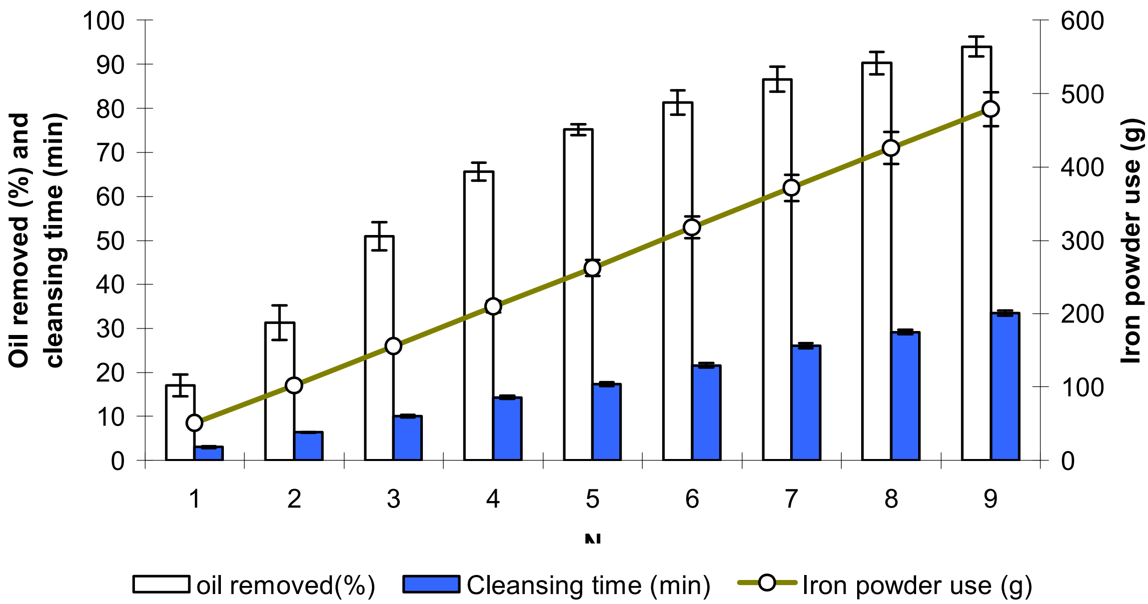

Figure 15: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of **70% Diesel Oil coverage** (by mass) from plumage. Error bars represent the standard error for three replicates. The data are presented in Table 19 in the Appendix. The individual profiles corresponding to each parameter are presented in the Appendix, Tables 20 to 22.

Table 1: Oil removal, cleansing time, iron powder use and waste created for the removal of different Diesel Oil coverages from penguin plumage.

Oil coverage	Initial (first) treatment			Final treatment			Waste created (g)
	% Removal	Cleansing time (min)	Iron powder use (g)	% Removal	Cleansing time (min)	Iron powder use (g)	
10%	32.7	2.3	20.6	92.5	26.5	167.4	178.1
20%	29.5	2.3	28.1	91.8	28.6	240.1	261
50%	19.6	2.5	39.9	91.3	32.3	363.6	415
70%	17.1	3.1	50.8	94	33.5	478.4	545

7.2 Different levels of Diesel Oil coverage

The correlation of each of the magnetic cleansing parameters (i.e. final oil removal, cleansing time and iron powder use) with the Diesel Oil coverage, 10%, 20%, 50%, 70% and 100%, has been examined and the results are presented in Figs. 16-18. The purpose of this study is not only to find out whether or not there is any correlation, but also to develop a method to interpolate the data, especially with respect to cleansing time and/or iron powder consumption for different levels of contamination coverage.

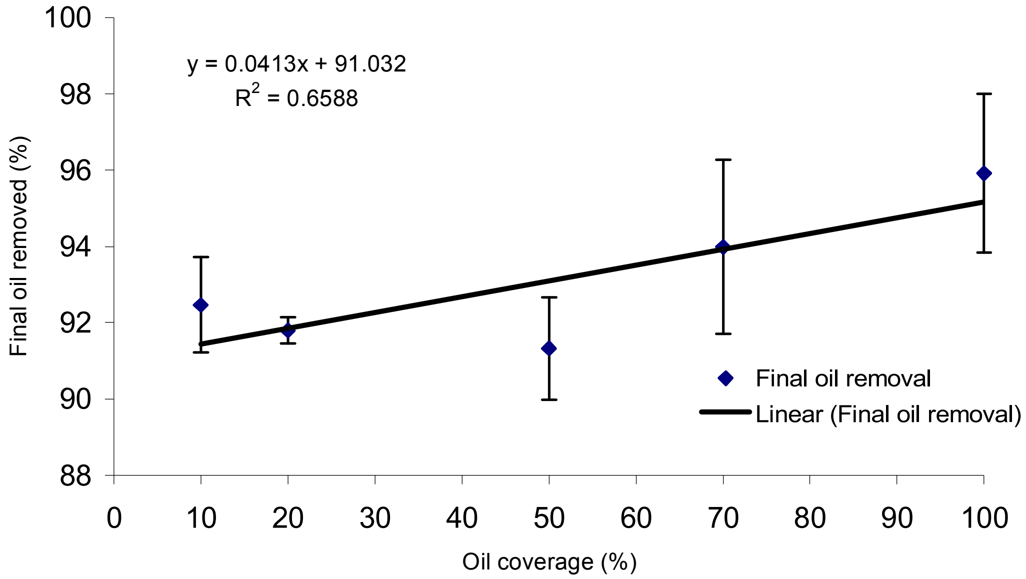

Figure 16: Correlation between final oil removed (%) and oil coverage (%), including regression equation and calibration curve; p-value = 0.0953. Error bars represent the standard error for three replicates. The data are presented in the Appendix, Table 23.

Fig. 16 suggests that the final oil removal is not significantly correlated with oil coverage. It should be noted here that the data for the 100% coverage experiment has been included in the correlation study in spite of the fact that the method of application of the iron powder was different to that of the other coverages (see Sections 4 & 7).

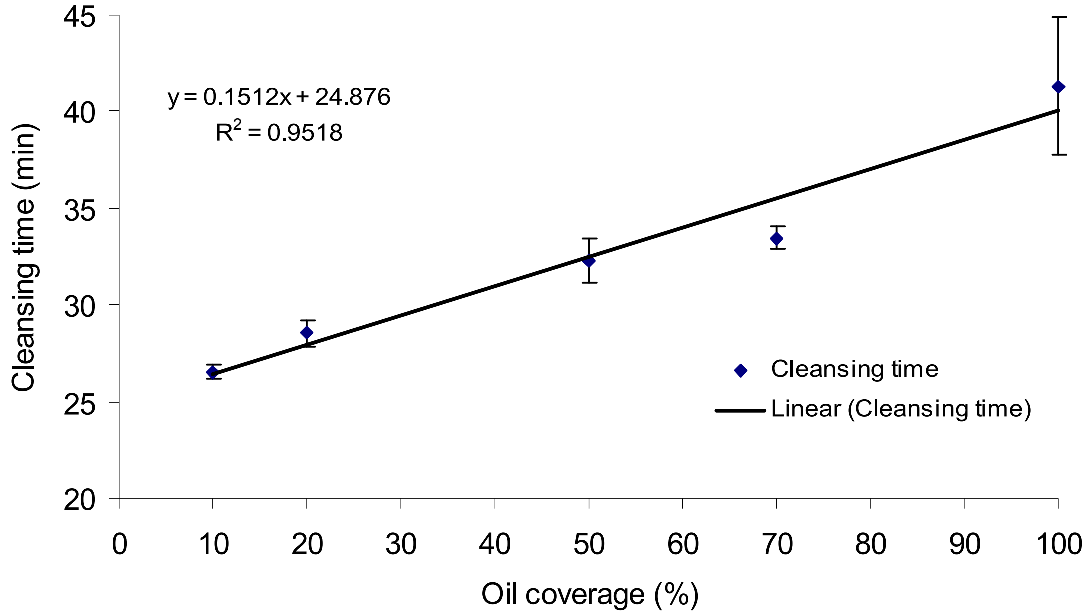

Figure 17: Correlation between cleansing time (min) and oil coverage (%), including regression equation and calibration curve; p-value = 0.0046. Error bars represent the standard error for three replicates. The data are presented in the Appendix, Table 23.

From Figs. 17 and 18 it can be seen that both the cleansing time and iron powder usage are correlated with oil coverage. These correlations enable the interpolation of the data on cleansing time and iron powder usage for different contamination coverages.

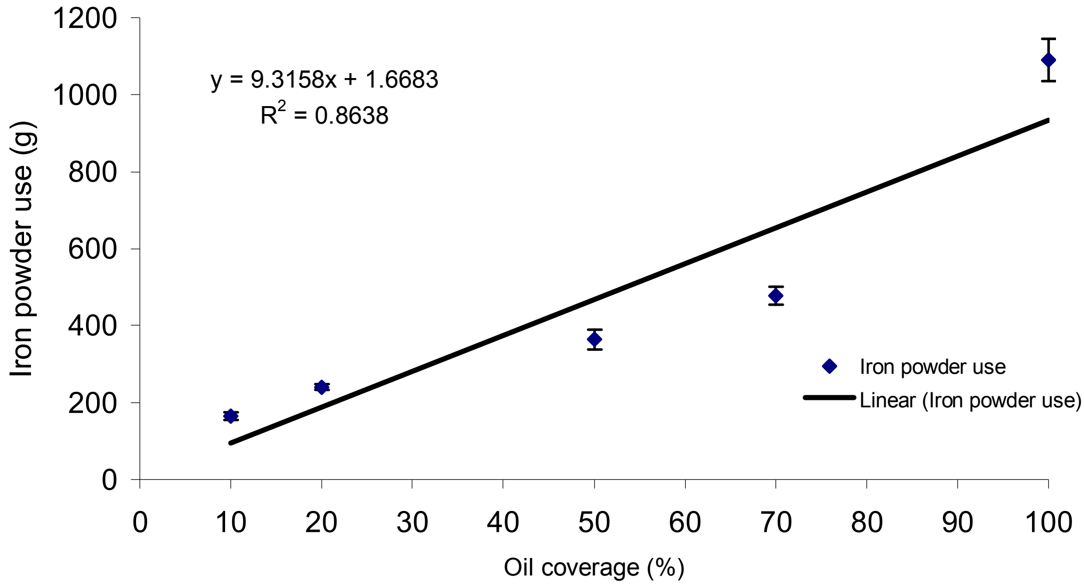

Figure 18: Correlation between iron powder consumption (g) and oil coverage (%), including regression equation and calibration curve; p-value = 0.0223. Error bars represent the standard error for three replicates. The data are presented in the Appendix, Table 23.

7.3 Experiments with Bunker Oils

For Bunker Oil 1 (viscosity = 2600 cSt at 295 K) experiments were conducted for 10%, 20%, 50%, 70% and 100% coverage (by weight). It was also considered informative to obtain some data on a slightly more viscous oil, Bunker Oil 2 (viscosity = 3200 cSt at 295 K), at 50% coverage only. As with the Diesel Oil experiments, these experiments were limited to penguin plumage only. Preliminary investigations on feather clusters and weathering were not deemed necessary here since such work has been conducted previously for a similar contaminant (Dao, 2007). Due to the limited availability of carcasses and to the time consuming nature of such experiments, only the 20% coverage experiments were conducted in replicate (triplicate). The percentage errors calculated from these results were then used as estimates of the errors in the experiments for the other coverages.

A coverage methodology was developed for Bunker Oil, in which a pre-weighed carcass was totally immersed into a container of the oil and drained. The oiled carcass was weighed again and the amount of oil adsorbed by the carcass was calculated. Assuming that the linear relationship between oil absorption and carcase weight found for Diesel Oil (Section 6 & 7) also exists for other oils, the calculated oil to body weight ratio can be used to estimate other coverages. For example, for 100% coverage of Bunker Oil 1, the oil to body weight ratio for a single representative carcass is 0.155. Therefore, for a given carcass weight, the amount of oil to achieve 100% coverage can be calculated. From this, the amounts of oil to achieve other fractional coverages can be obtained.

The methodology for the gravimetric determination of oil removal, cleansing time and iron powder consumption for the magnetic cleansing of Bunker Oil from plumage is similar to that for the Diesel Oil experiments described previously.

Previous work on heavy oils (Dao, 2007) and preliminary testing with Bunker Oil 1 during this project has indicated that removal of such contaminants from penguin plumage can be enhanced by the judicious use of a pre-conditioning (pre-treatment) agent. Therefore, it was decided that a pre-treatment agent be used to optimise the magnetic cleansing process with respect to accelerating oil removal and hence reducing cleansing time. The pre-conditioner used here is methyl oleate, since this has been shown (quantitatively) to be one of the more effective pre-conditioners for magnetic oil removal (Dao, 2007). This pre-treatment agent was also reported to be used elsewhere for detergent-based techniques (Bryndza *et al.*, 1991; OWCN, 1999; OWCN, 2003-a, USFWS, 2002; Walraven, 2004-a; Massey, 2006). However, it has come to our attention that there are concerns about the toxicity of this chemical to animals when it is heated up to 313 K (Mike Short, *Personal communication*). Therefore, in the field, it might not be advisable to warm the methyl oleate prior to applying it to oiled birds.

7.3.1 Experiments with Bunker Oil 1

10% coverage

The results of the experiments on the removal of 10% coverage of Bunker Oil 1 from penguin plumage are presented in Fig. 19. Photographs of the cleansing process are shown in Figs. 20-23.

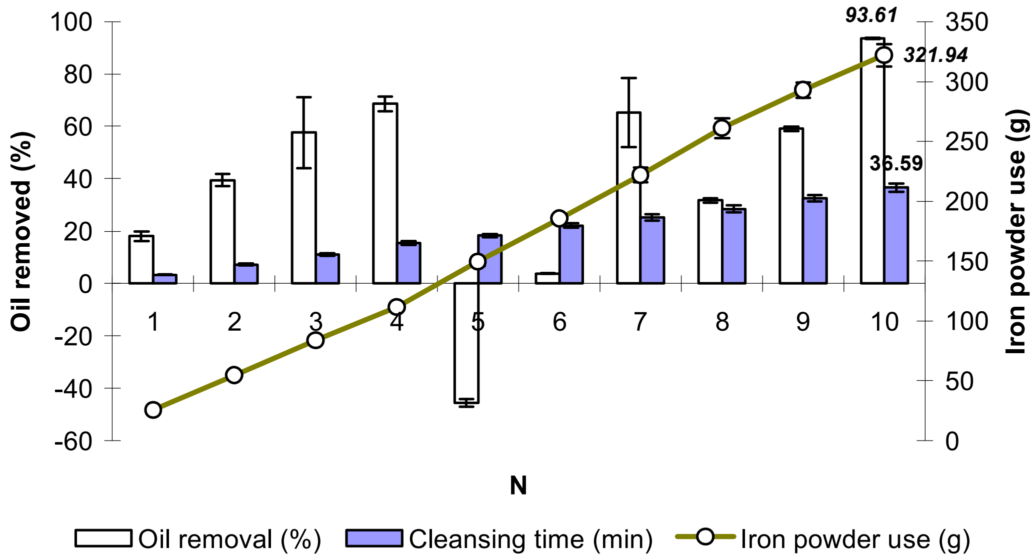

Figure 19: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of **10% Bunker Oil 1 coverage** (by weight) from plumage. Methyl oleate is applied at N=5 and N=8. The data are presented in the Appendix, Table 24. Error bars for the % oil removal values represent estimates based on the triplicate measurements for the 20% coverage experiments.

For 10% coverage, it can be seen from Fig. 19 that cleansing time and iron powder use increase as the number of treatments increases. After one treatment, at 3.2 min, a removal of 18.1% is obtained at the expense of 25.7 g of iron powder. Note that the negative percentage removals at N=5 and N=8 are due to the fact that the pre-conditioning agent (methyl oleate; 15–20 mL) is applied at these points, which affects the gravimetric result. It should also be noted that the use of a pre-conditioner also necessitates its removal; this has been accounted for in the data shown in Fig 19. After 10 treatments, the final removal is 93.6% (equivalent to 10.4 g of oil removed), the iron powder consumption is 322.4 g and the cleansing time is 36.6 min. Finally, the waste created (oil/pre-conditioner-laden iron powder) for the whole process weighs 332.4 g.

Figure 20: Clean, dry, unoiled carcass

Figure 21: The carcass contaminated with Bunker Oil 1 (10% coverage)

Figure 22: The carcass after 4 treatments

Figure 23: The carcass after 10 treatments

20% coverage

The results of the experiments on the removal of 20% coverage of Bunker Oil 1 from penguin plumage are presented in Fig. 24, and photographs of the cleansing process are shown in Figs. 25-28. These experiments were conducted in triplicate.

For 20% coverage, it can be seen from Fig. 24 that cleansing time and iron powder use increase as the number of treatments increases. After one treatment, a removal of 14.2% is achieved, with cleansing time and iron powder use being 4.3 min and 30.2 g respectively. Methyl oleate was applied at N=3 and N=7 (hence the dips in the histogram bars at these points) and a final removal of 93% (~ 21.3 g oil removed) is achieved after ten treatments , 47.6 min and the usage of 466.8 g of iron powder. The whole cleansing process creates around 500 g of oil and pre-conditioner-laden iron powder.

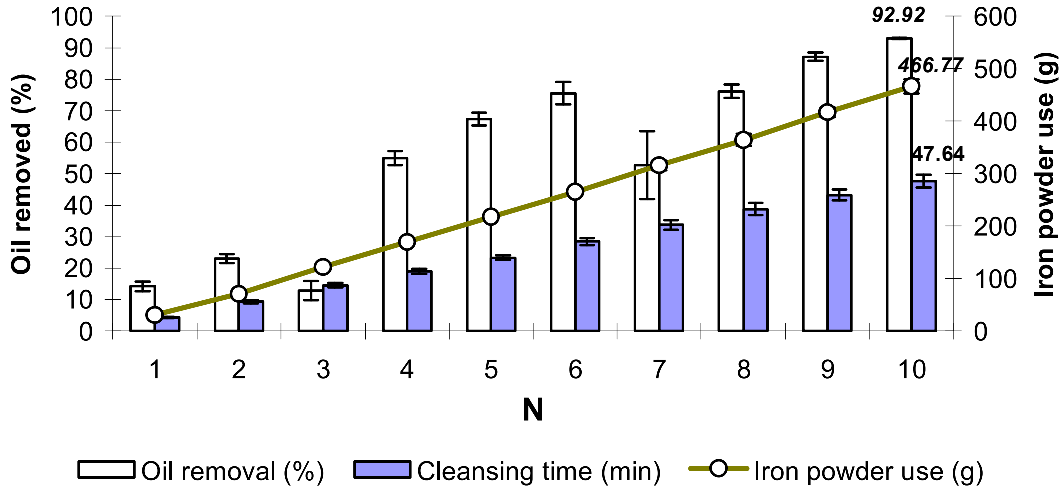

Figure 24: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of **20% Bunker Oil 1 coverage** (by weight) from plumage. Methyl oleate is applied at N=3 and N=7 and error bars represent the standard error for three replicates. The data are presented in the Appendix, Table 25. The individual profiles corresponding to each parameter are also presented in the Appendix, Tables 26 – 28.

Figure 25: Cleaned, dry, unoiled carcass

Figure 26: The carcass is contaminated with Bunker Oil 1 (20% coverage)

Figure 27: The carcass after 6 treatments

Figure 28: The carcass after 10 treatments

50% coverage

The results of the experiments on the removal of 50% coverage of Bunker Oil 1 from penguin plumage are presented in Fig. 29, and the photographs of the cleansing process are shown in Figs. 30-33.

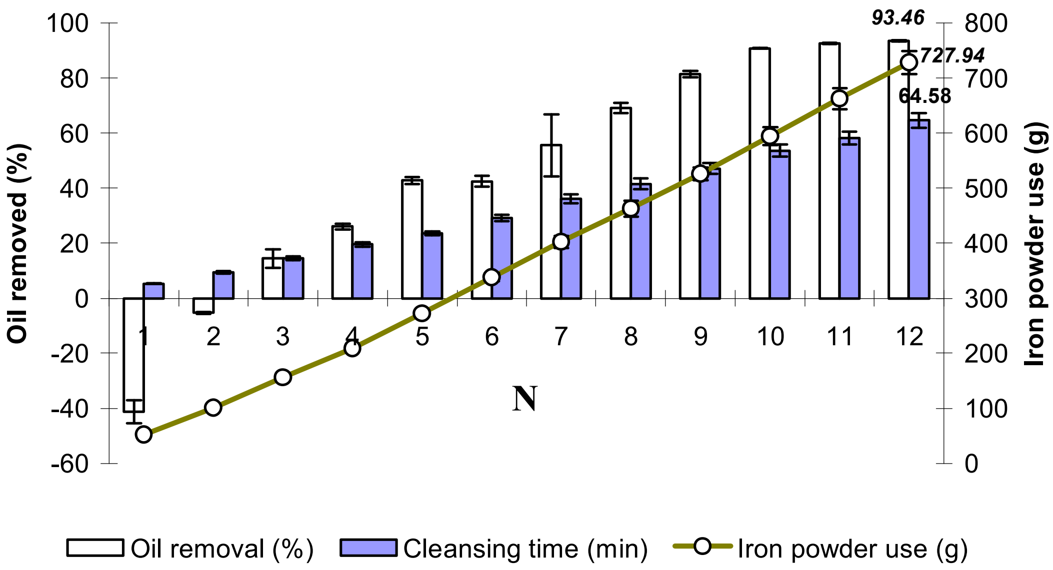

Figure 29: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of **50% Bunker Oil 1** coverage (by w) from plumage. Methyl oleate is applied at N=1 and N=6. Error bars for the % oil removal values represent estimates based on the triplicate measurements for the 20% coverage experiments. The data are presented in the Appendix, Table 29.

For 50% coverage, as can be seen from Fig. 29, oil removal, cleansing time and iron powder use increase as the number of treatments increases. For this, more challenging removal, methyl oleate is applied at the beginning of the cleansing process. After one treatment, for reasons discussed previously, the nominal removal is negative. After 3 treatments a removal of 14.4% is achieved after ~15 min and with the usage of 155.9 g of iron powder. After 12 treatments, the removal is 93.5% (~ 26 g of oil removed), consuming 727.9 g of iron powder. Some 30 mL of methyl oleate is consumed. The whole cleansing process takes 64.6 min and creates around 754.2 g of oil/pre-conditioner-laden iron powder.

Figure 30: Clean, dry, unoiled carcass

Figure 31: The carcass contaminated with Bunker Oil 1 (50% coverage)

Figure 32: After 5 treatments

Figure 33: After 12 treatments

70% coverage

The results of the experiments on the removal of 70% coverage of Bunker Oil 1 from penguin plumage are presented in Fig. 34 and the photographs of the cleansing process are shown in Figs. 35-38.

For 70% coverage, it can be seen from Fig. 34 that, oil removal, cleansing time and iron powder use increase as the number of treatments increases. As with 50% coverage, methyl oleate is applied at the beginning of the cleansing process, at N=1. After 3 treatments a removal of 22.3% is achieved after 15.2 min, with the usage of 218.4 g of iron powder. The pre-conditioner is then applied once more at N= 6. After 12 treatments, the removal is ~ 91% (~ 41 g of oil removed), consuming 1043.6 g of iron powder. The whole cleansing process consumes some 30 mL of methyl oleate, takes 82.2 min and creates around 1087.9 g of oil/pre-conditioner-laden iron powder.

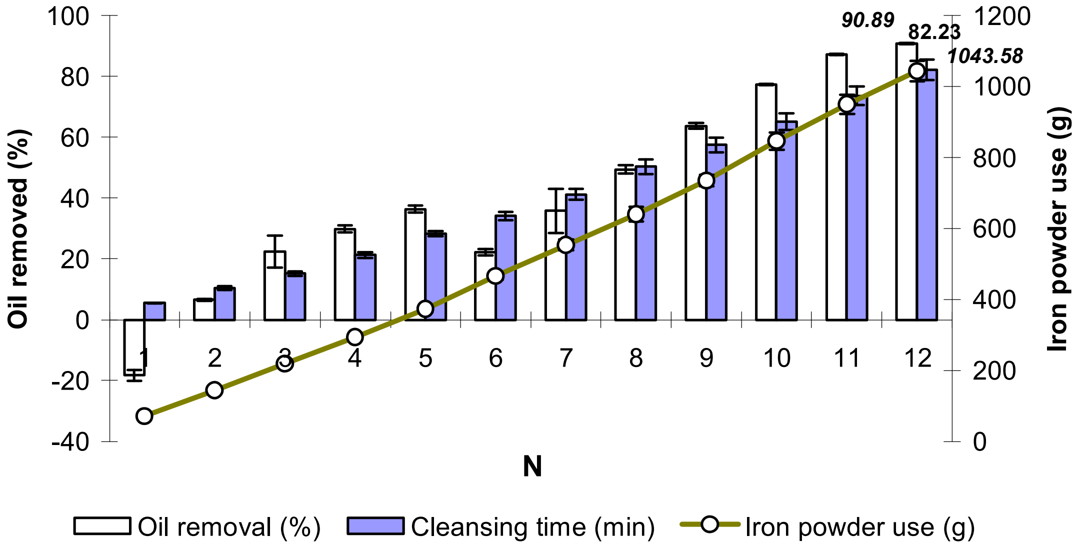

Figure 34: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of **70% Bunker Oil 1** coverage (by mass) from plumage. Methyl oleate is applied at N=1 and 6. Error bars for the % oil removal values represent estimates based on the triplicate measurements for the 20% coverage experiments. The data are presented in the Appendix, Table 30.

Figure 35: Clean, dry, unoiled carcass

Figure 36: The carcass contaminated with Bunker Oil 1 (70% coverage)

Figure 37: After 5 treatments

Figure 38: After 12 treatments

100% coverage

The results of the experiments on the removal of 100% coverage of Bunker Oil 1 from penguin plumage are presented in Fig. 39, and the photographs of the cleansing process are shown in Figs. 40-43.

For 100% coverage, as can be seen from Fig. 39, oil removal, cleansing time and iron powder use increase as the number of treatments increases. Methyl oleate is applied at the beginning of the cleansing process, N=1, and once more at N=6. After 3 treatments a removal of 13.5% is achieved after ~23.4 min with the consumption of 405.6 g of iron powder. After 12 treatments, the removal is 89.5% (~ 103 g of oil removed), consuming 1902.9 g of iron powder. The whole cleansing process consumes some 40 mL of methyl oleate, takes 95.5 min and creates around 2015 g of oil/pre-conditioner-laden iron powder.

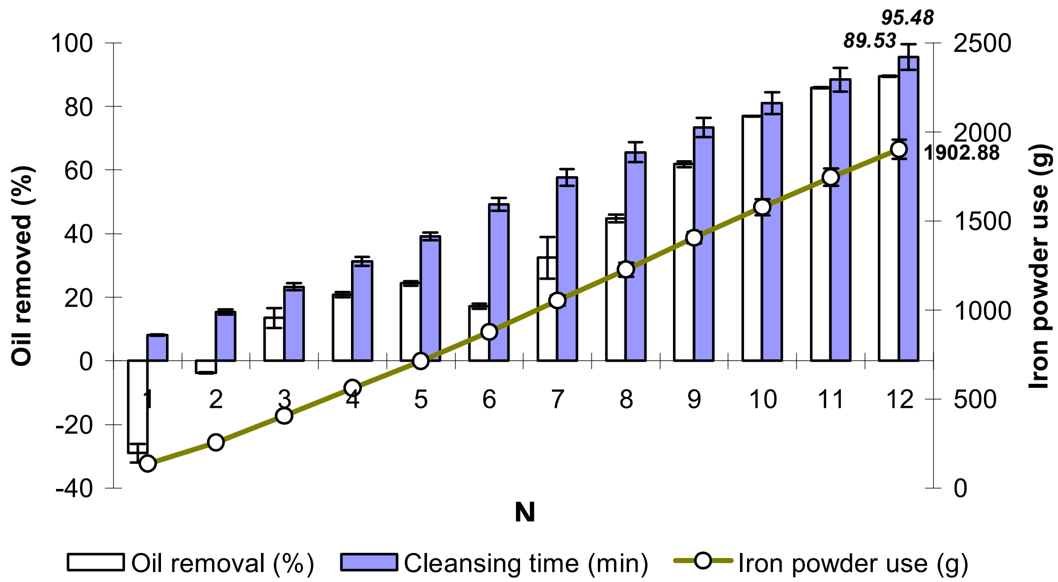

Figure 39: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of 100% **Bunker Oil 1 coverage** (by mass) from plumage. Methyl oleate is applied at N=1 and N=6. Error bars for the % oil removal values represent estimates based on the triplicate measurements for the 20% coverage experiments. The data are presented in the Appendix, Table 31.

Figure 40: Clean, dry, unoiled carcass

Figure 41: The carcass contaminated with Bunker Oil 1 (100% coverage)

Figure 42: After 5 treatments

Figure 43: After 12 treatments

7.3.2 Experiments with Bunker Oil 2

The results of the experiments for the magnetic removal of Bunker Oil 2 (50% coverage) from penguin plumage are presented in Fig. 44. The photographs of the cleansing process are shown in Figs. 45-48.

As for the previous Bunker Oil 1 experiment, methyl oleate was applied as a pre-conditioner at the beginning of the treatment process, N=1, and once more at N=6. Consequently, after one treatment the nominal removal is negative. After 3 treatments 8.2% of contaminant (oil and pre-conditioner) has been removed, 17.2 min have elapsed and 185.3 g of iron powder have been consumed. After 14 treatments, the removal is 93.2% (~ 32 g of oil removed) with the usage of 941.7 g of iron powder. The whole cleansing process takes 86.7 min and creates around 975.9 g of oil and pre-conditioner-laden iron powder. A comparison of the relevant parameters between Bunker Oils 1 & 2 for 50% coverage is given in Table 2.

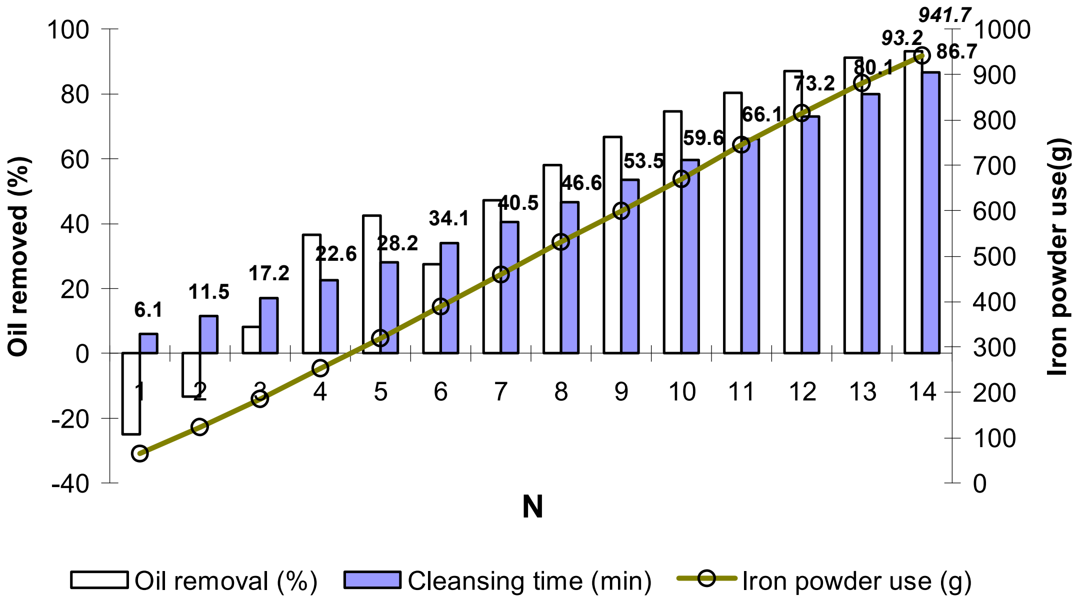

Figure 44: Histogram of oil removal (%), cleansing time (min) and iron powder consumption (g) as a function of the number of treatments, N, for the removal of **50% Bunker Oil 2 coverage** (by mass) from plumage. Methyl oleate is applied at N=1 and N=6. The data are presented in the Appendix, Table 32.

Figure 45: Clean, dry, unoiled carcass

Figure 46: The carcass contaminated with Bunker Oil 2 (50% coverage)

Figure 47: After 5 treatments

Figure 48: After 14 treatments

Table 2: Comparison of final oil removal, cleansing time, iron powder use and waste create for the removal of 50% coverage from penguin plumage between Bunker Oil 1 and Bunker Oil 2.

Oil	Final removal (%)	Cleansing time (min)	Iron powder use (g)	Waste created (g)
Bunker Oil 1	93.5	64.6	727.9	754.2
Bunker Oil 2	93.2	86.7	941.7	975.9

7.4 Different levels of Bunker Oil 1 coverage

As with the Diesel Oil experiments (Section 7.2), the correlation of each of the magnetic cleansing parameters with Bunker Oil 1 coverage has been examined and the results are presented in Figs. 49 - 51.

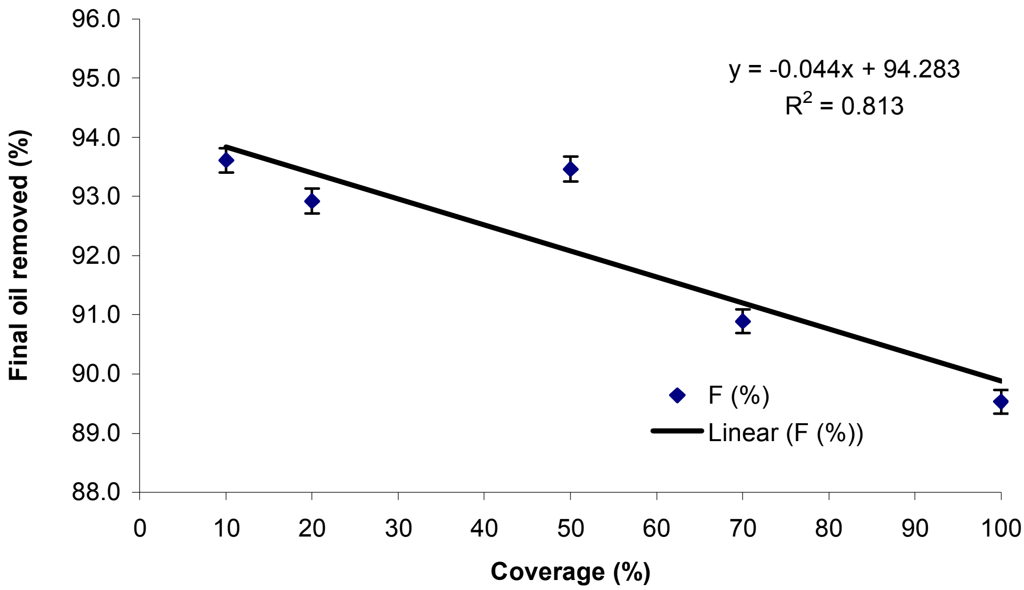

Figure 49: Correlation between final oil removal (%) and oil coverage (%), including regression equation and calibration curve; p-value= 0.0365. Error bars for the % oil removal values represent standard error estimates based on triplicate measurements for the 20% coverage experiments. The data are presented in the Appendix, Table 33.

Fig. 49 indicates a correlation between final oil removal and oil coverage. Specifically, the final removal decreases as the oil coverage increases. This correlation can be used for the interpolation of final oil removal for different contamination coverage.

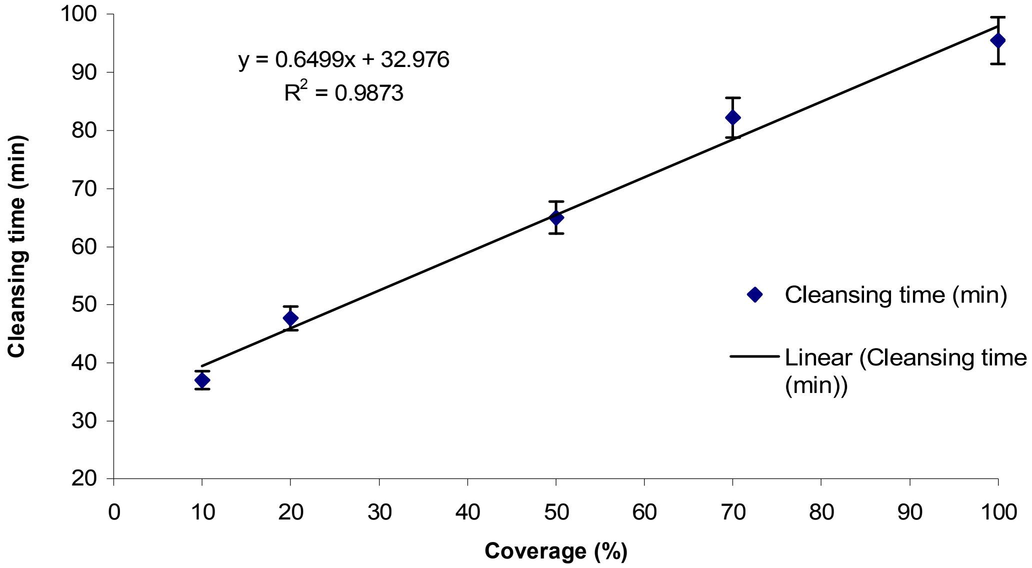

Figure 50: Correlation between cleansing time (min) and oil coverage (%), including regression equation and calibration curve; p-value= 0.0006. Error bars represent standard error estimates based on triplicate measurements for the 20% coverage experiments. The data are presented in the Appendix, Table 33.

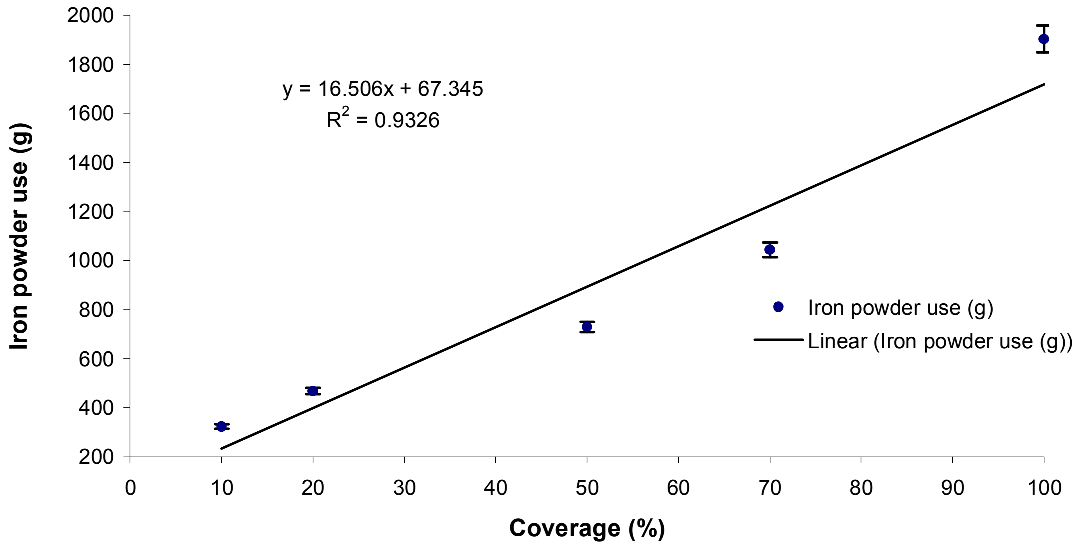

Figure 51: Correlation between iron powder use (g) and oil coverage (%), including regression equation and calibration curve; p-value= 0.0076. Error bars represent standard error estimates based on triplicate measurements for the 20% coverage experiments. The data are presented in the Appendix, Table 33.

From Figs. 50 and 51, as with Diesel Oil, there is a good correlation between oil coverage and both cleansing time and iron powder use. These correlations enable the interpolation of data on cleansing time and iron powder consumption to be made for different oil coverages.

7.5 Comparison between Diesel Oil and Bunker Oil 1 for different levels of contamination coverage

Comparisons of the relevant parameters; namely, final % oil removal, cleansing time and iron powder usage, between Diesel Oil and Bunker Oil 1 for different levels of coverage (10%, 20%, 50%, 70% and 100%) are depicted in Figs. 52 - 54.

It can be seen from Fig. 52 that for 10%, 20% and 50% coverages, the final oil removals for both Diesel Oil and Bunker Oil 1 are comparable, *albeit* slightly higher for Bunker Oil 1 (20% and 50%), within estimated experimental error. However, for 70 and 100% coverages, the reverse was found to be true with the final oil removals being significantly higher for Diesel Oil than for Bunker Oil 1. An ANOVA test (at $\alpha = 0.05$; $F = 0.768$; p-value= 0.406) show that, for all coverages, the difference in the final removals between these two oils is not statistically significant at the 5% level.

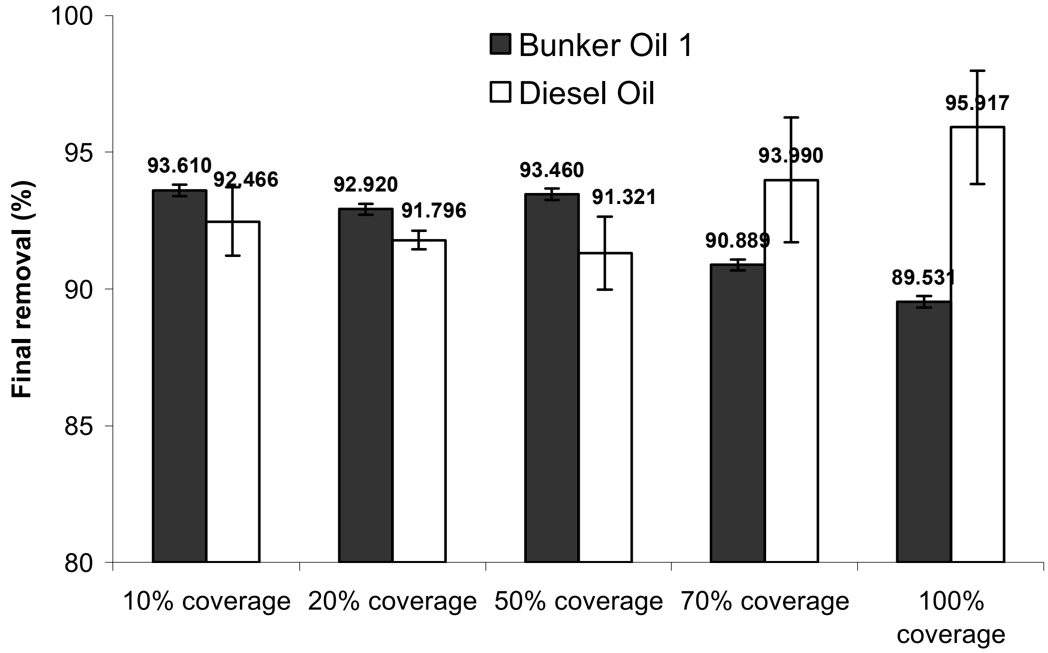

Figure 52: Comparison of the final oil removal between Diesel Oil and Bunker Oil 1. The error bars for Bunker Oil 1 represent the standard errors derived from the 20% coverage experiments for three replicates. The error bars for Diesel Oil represent the standard error for three replicates. The data are presented in the Appendix, Table 34.

Regarding cleansing time, Fig. 53 indicates that it is significantly higher for Bunker Oil 1 than for Diesel Oil for all coverages. This is also confirmed by the results of an ANOVA test (at $\alpha = 0.05$; $F = 8.944$; p-value = 0.017), showing a significant difference in cleansing time between these two contaminants. For iron powder consumption, Fig. 54 shows that it is significantly higher for Bunker Oil 1 than for Diesel Oil for all coverages. This is confirmed by an ANOVA test for these data (at $\alpha = 0.05$; $F = 1.706$; p-value = 0.228).

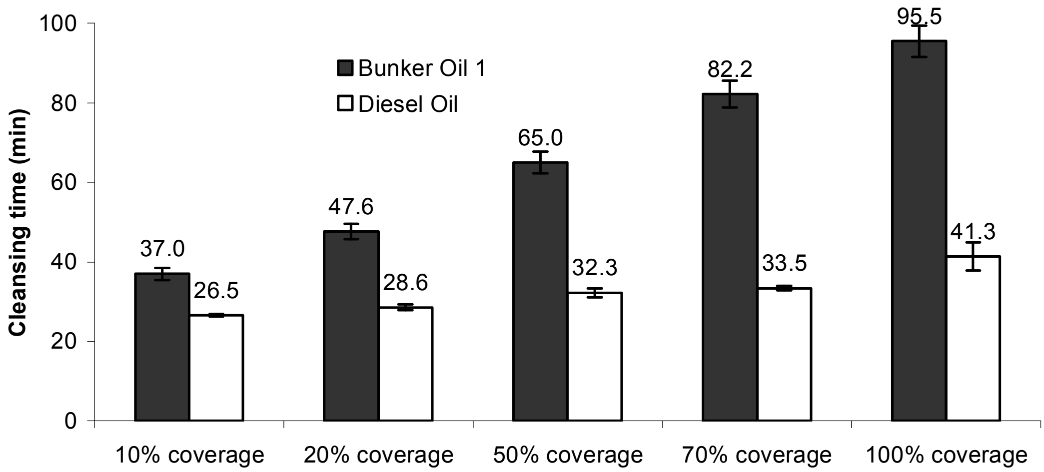

Figure 53: Comparison of the cleansing time between Diesel Oil and Bunker Oil 1 for the whole process. The error bars for Bunker Oil 1 represent the estimated standard errors for three replicates derived from the 20% coverage experiments. The error bars for Diesel Oil represent the standard error for three replicates. The data are presented in the Appendix, Table 35.

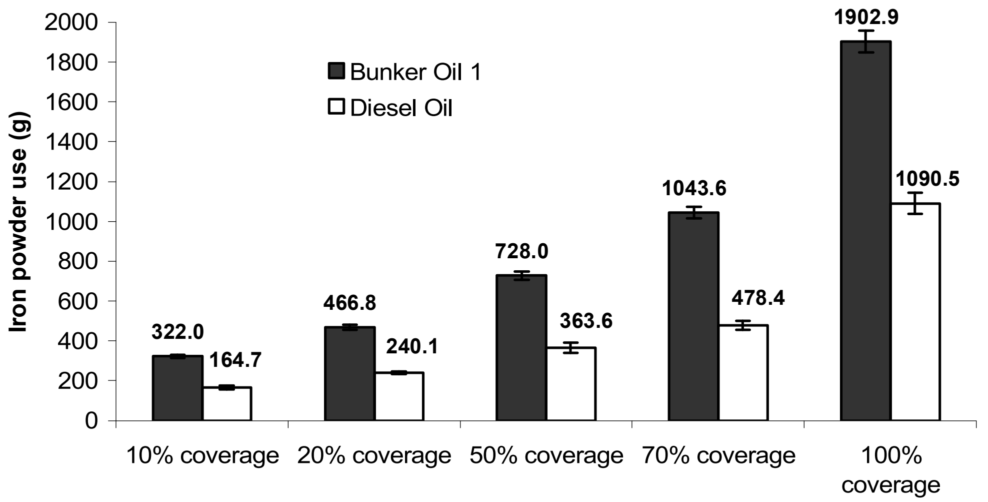

Figure 54: Comparison of iron powder use between Diesel Oil and Bunker Oil 1 for the whole process. The error bars for Bunker Oil 1 represent the estimated standard error for three replicates derived from the 20% coverage experiments and the error bars for Diesel Oil represent the standard error for three replicates. The data are presented in the Appendix, Table 36.

8 Benchmarking studies – the cleansing of Diesel Oil and Bunker Oil from whole-bird plumage using detergent-based techniques

In order to achieve some benchmark of magnetic cleansing with detergent cleansing, controlled detergent based cleansing experiments were conducted for 10%, 50%, 70% and 100% coverages of penguin carcasses for both Diesel Oil and Bunker Oil 1. The first cleaning session, using Bunker Oil 1 (at 10% coverage) was carried out by an experienced wildlife rehabilitator, Ms. Margaret Healy, at PINP - with John Orbell, Peter Dann, Hien Dao and Lawrence Ngeh in attendance. Three subsequent sessions (for 50%, 70% and 100% coverage of these contaminants) were conducted by Hien Dao and Lawrence Ngeh, also at PINP. Washing sessions for 70% and 100% coverage of both contaminants were carried out at the Werribee campus, Victoria University. The change in location resulted in difference water usage since, at Victoria University; washing was carried out in a tub with a capacity of 20 L, whilst the tub used at PINP is 35 L. An additional two replicates of washing for 50% Bunker Oil 1 coverage were conducted. This was to allow percentage errors to be estimated for the parameters of relevance in the detergent cleansing process. The detergent used was DivoPlus V2™. This is considered to be an optimum cleansing agent by PINP wildlife rehabilitators (Roz Jessop and Margaret Healy, *personal communication*). The detergent-based cleansing reported here is limited to two steps, washing and rinsing i.e. drying time is excluded. This important consideration will be discussed in Section 10 in relation to cost comparisons. To enable comparison with the magnetic cleansing method, relevant parameters associated with detergent-based cleaning were recorded; namely, time, water use, detergent use and wastewater creation. The water use was determined by monitoring the number of "tubs" of water used after having established the capacity of the tub(s) (35 L and 20 L). The detergent use was determined by monitoring the number of "cups" used after having established that the capacity of a single cup was 270 mL. In all of these experiments, an effort was made to maintain as much consistency as possible and to minimize resources. The process was photographed and videoed.

8.1 Experiments with Diesel Oil

10% coverage

For the removal of 10% coverage of Diesel Oil from penguin plumage, 140 L of water and 270 mL of washing detergent were consumed - for washing and rinsing. The process took 15.31 min and two persons were involved in the washing process. The amount of wastewater created is considered to be equal to the water use and, therefore, is 140 L. Relevant photographs are shown in Fig. 55.

Figure 55: Cleaning of a penguin carcass contaminated with estimated 10% of Diesel Oil coverage, using detergent-based techniques, (a) clean, unoiled carcass; (b) carcass contaminated with oil; (c) carcass being washed; (d) carcass after washing and rinsing.

50% coverage

For the removal of 50% coverage of Diesel Oil from penguin plumage, 175 L of water and 420 mL of washing detergent were used - for washing and rinsing. The process took 20 min and two persons were involved in the washing process. The amount of wastewater created is considered to be equal to the water use and, therefore, is 175 L. Relevant photographs are shown in Fig. 56.

Figure 56: Cleaning of a penguin carcass contaminated with estimated 50% of Diesel Oil coverage, using detergent-based techniques, (a) clean, unoiled carcass; (b) carcass contaminated with oil; (c) carcass being washed; (d) carcass after washing and rinsing.

<u>70% coverage</u>

For the removal of 70% coverage of Diesel Oil from penguin plumage, 120 L of water and 810 mL of washing detergent were used - for washing and rinsing. The process took 21.46 min and two persons were involved in the washing process. The amount of wastewater created is considered to be equal to the water use and, therefore, is 120 L. Relevant photographs are shown in Fig. 57.

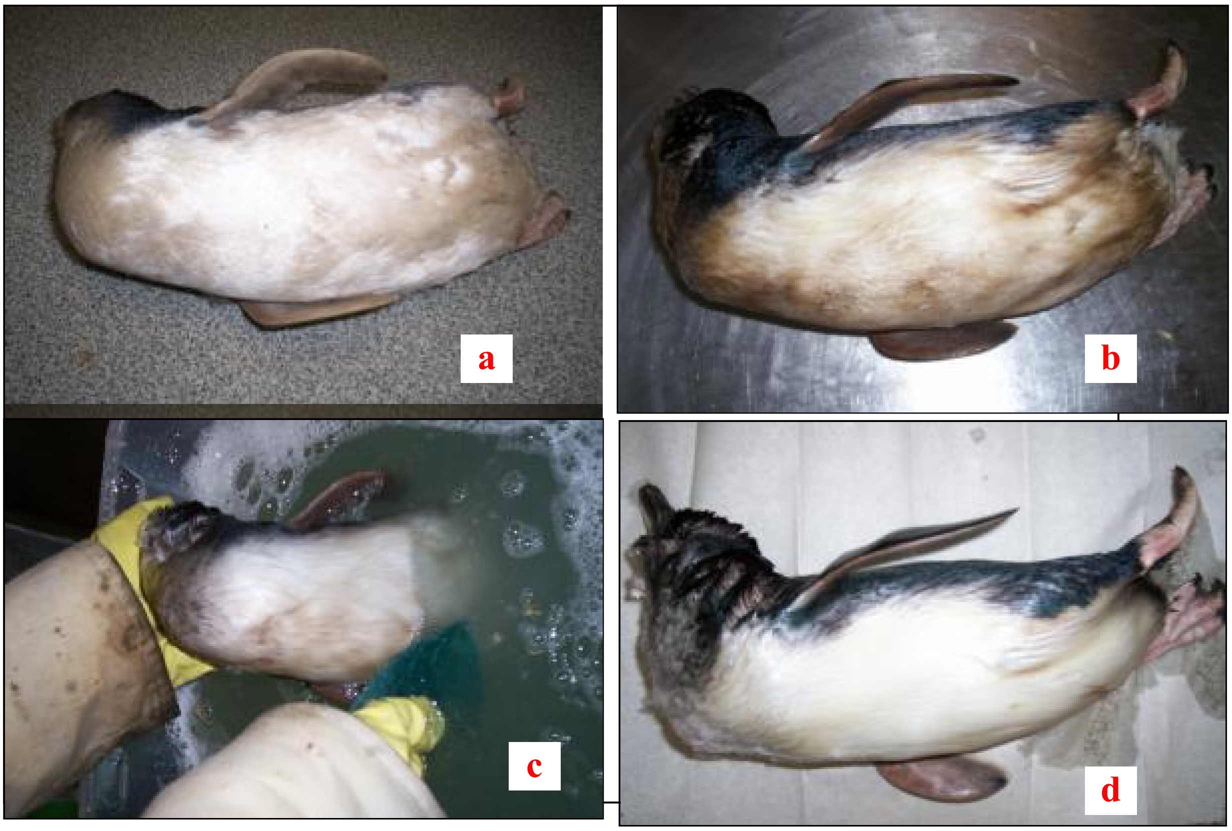

Figure 57: Cleaning of a penguin carcass contaminated with estimated 70% of Diesel Oil coverage, using detergent-based techniques, (a) clean, unoiled carcass; (b) carcass contaminated with oil; (c) carcass being washed; (d) carcass after washing and rinsing.

<u>100% coverage</u>

For the removal of 100% coverage of Diesel Oil from penguin plumage, 140 L of water and 1080 mL of washing detergent were used - for washing and rinsing. The process took 25.25 min and two persons were involved in the washing process. The amount of wastewater created is considered to be equal to the water use and, therefore, is 140 L. Relevant photographs are shown in Fig. 58.

Figure 58: Cleaning of a penguin carcass contaminated with estimated 100% of Diesel Oil coverage, using detergent-based techniques, (a) clean, unoiled carcass; (b) carcass contaminated with oil; (c) carcass being washed; (d) carcass after washing and rinsing.

8.2 Experiments with Bunker Oil 1

10% coverage

For the removal of 10% coverage of Bunker Oil 1 from penguin plumage, 140 L of water and 540 mL of washing detergent are used for washing and rinsing. The process took 10.36 min and two persons were involved in the washing process. The amount of wastewater created is considered to be equal to the water use and, therefore, is 140 L. Relevant photographs are shown in Fig. 59.

Figure 59: Cleaning of a penguin carcass contaminated with an estimated 10% of Bunker Oil 1, using detergent-based techniques, (a) clean, unoiled carcass; (b) carcass being washed; (c) rinsing carcass; (d) carcass after washing, rinsing and quick drying with towel.

<u>50% coverage (replicate 1 that was carried out at PINP)</u>

For the removal of 50% coverage of Bunker Oil 1 from penguin plumage, 245 L of water and 540 mL of washing detergent were used for washing and rinsing. The process took 22.51 min and two persons were involved in the washing process. The amount of wastewater created is considered to be equal to the water use and, therefore, is 245 L. These results are comparable to the time and water use reported by Frink and Crozer-Jones (1990) who state that a 20-minute washing (bird and contaminant unspecified) usually consumes from 304 to 380 L of water. Relevant photographs are shown in Fig. 60.

Figure 60: Cleansing of a penguin carcass contaminated with estimated 50% of Bunker Oil 1 coverage (Replicate 1), using detergent-based techniques, (a) clean, unoiled carcass; (b) carcass contaminated with oil; (c) carcass being washed; (d) carcass after washing and rinsing.

<u>50% coverage (replicate 2 that was carried out at Victoria University)</u>

For the removal of 50% coverage of Bunker Oil 1 from penguin plumage, 120 L of water and 810 mL of washing detergent are used for washing and rinsing. The process took 24.19 min and two persons were involved in the washing process. The amount of wastewater created is considered to be equal to the water use and, therefore, is 120 litres. Relevant photographs are shown in Fig. 61.

<u>50% coverage (replicate 3 that was carried out at Victoria University)</u>

For the removal of 50% coverage of Bunker Oil 1 from penguin plumage, 110 L of water and 675 mL of washing detergent are used for washing and rinsing. The process took 20.25 min and two persons were involved in the washing process. The amount of wastewater created is considered to be equal to the water use and, therefore, is 110 litres. Relevant photographs are shown in Fig. 62.

The three replicate experiments that were carried out for the removal of 50% coverage of Bunker Oil 1 from penguin plumage are informative. Some of the relevant parameters are, not unexpectedly, quite variable. The water usage (and hence waste) ranges from 110 to 245 L , the detergent usage ranges from 540 to 810 mL and the cleansing time (more consistent) ranges from ~20 to 24 minutes. From inspection, the same level of cleansing was achieved in each case, Figs. 60 – 62. This data suggests that there is considerable scope for the minimization of water usage (and hence waste) and also of the detergent itself.

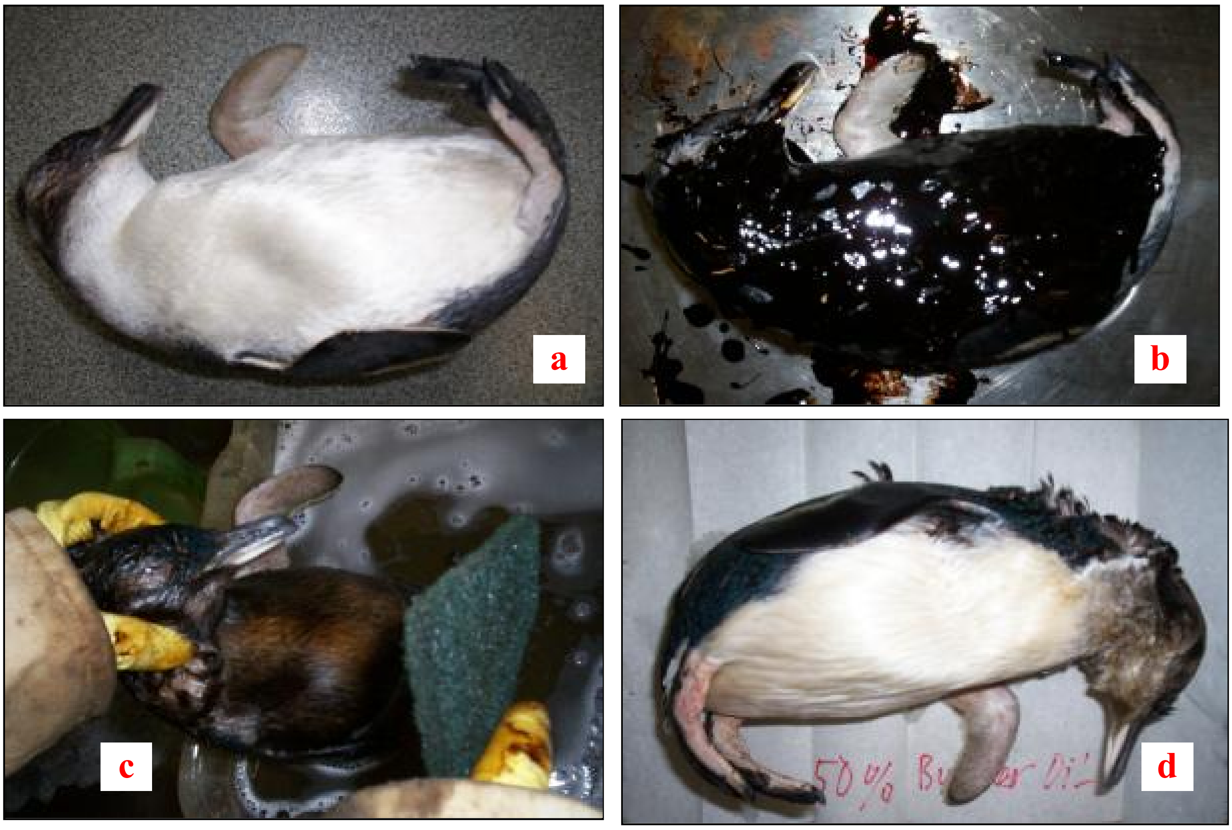

Figure 61: Cleansing of a penguin carcass contaminated with estimated 50% of Bunker Oil 1 coverage (Replicate 2), using detergent-based techniques, (a) clean, unoiled carcass; (b) carcass contaminated with oil; (c) carcass being washed; (d) carcass after washing and rinsing.

Figure 62: Cleansing of a penguin carcass contaminated with estimated 50% of Bunker Oil 1 coverage (Replicate 3), using detergent-based techniques, (a) clean, unoiled carcass; (b) carcass contaminated with oil; (c) carcass after washing and rinsing.

70% coverage

For the removal of 70% coverage of Bunker Oil 1 from penguin plumage, 130 litres of water and 1080 mL of washing detergent were used for washing and rinsing. The process took 27.05 min and two persons were involved in the washing process. The amount of wastewater created is considered to be equal to the water use and, therefore, is 130 litres. Relevant photographs are shown in Fig. 63.

Figure 63: Cleansing of a penguin carcass contaminated with estimated 70% of Bunker Oil 1 coverage, using detergent-based techniques, (a) clean, unoiled carcass; (b) carcass contaminated with oil; (c) carcass being washed; (d) carcass after washing and rinsing.

100% coverage

For the removal of 100% coverage of Bunker Oil 1 from penguin plumage, 160 litres of water and 1210 mL of washing detergent were used for washing and rinsing. The process took 32.4 min and two persons were involved in the washing process. The amount of wastewater created is considered to be equal to the water use and, therefore, is 160 litres. Relevant photographs are shown in Fig. 64.

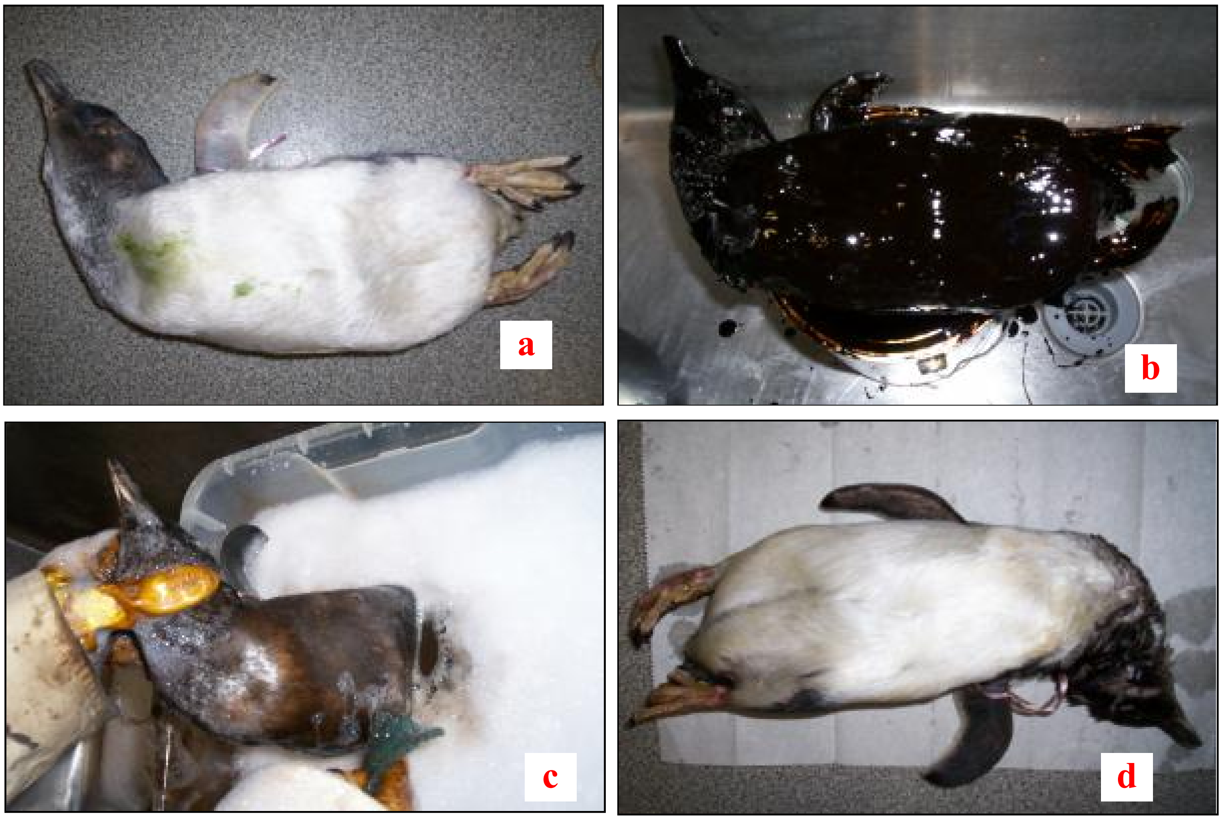

Figure 64: Cleansing of a penguin carcass contaminated with estimated 100% of Bunker Oil 1 coverage, using detergent-based techniques, (a) clean, unoiled carcass; (b) carcass contaminated with oil; (c) carcass being washed; (d) carcass after washing and rinsing.

9 Reclamation considerations for oil-laden iron powder

9.1 Reclamation of Diesel Oil-contaminated iron powder

For the purposes of the current project, the relative disposal costs of contaminant-laden iron particles and contaminant/detergent-laden waste water are to be compared (Section 10).

The magnetic cleansing method has the potential advantage of being able to separate the particles and the contaminant, since the latter is physically adsorbed onto the particles. Experiments have been carried out in this regard to demonstrate that Diesel oil contaminated iron powder can by recycled by centrifugation followed by solvent (hexane) extraction and air drying. This method has been used elsewhere (Christodoulou, 2002). The centrifuge employed is Beckman J2-HS. All centrifugations were carried out at a rotor speed of 10000 rpm and at temperature of 295K, for around 20 - 25 min. This separation may be observed in Fig. 65 for Diesel Oil –laden iron powder.

The amount of Diesel oil before and after centrifugation was determined gravimetrically and by Gas Chromatography. For sample 1, before centrifugation, the % (by weight) of oil in the iron powder was determined to be 8.35. After 20 minutes of centrifugation the % of contaminant reduced to 3.16. The second sample had the 5.33% of oil in iron powder before centrifugation and reduced to 1.88% after centrifugation. For the third sample, the % of oil in the iron powder was 6.1% and 2.01% before and after centrifugation, respectively. The centrifuged iron powder was then washed three times with hexane and left to air dry in a fume hood for a week. Fig. 66 (a) shows the recycled iron powder (Diesel oil contaminated iron powder after centrifugation, solvent extraction and air-drying). The recycled iron powder was then evaluated for the removal of Diesel Oil from feather clusters. The removal results were then compared with that of the original iron powder, Fig. 67. As can be seen from Fig. 67, the recycled iron powder (from Diesel Oil experiments) is as effective as the original iron powder in the removal of Diesel Oil from feathers.

9.2 Reclamation of Bunker Oil 1 contaminated iron powder

As with Diesel Oil, the same technique (centrifugation followed by solvent extraction and air drying) was also employed to in the recycling of Bunker Oil 1 laden iron powder, Fig. 65. It is, however, worth noting that the % by weight of oil in iron powder after centrifugation could not be determined due to the fact that methyl oleate, which had been used as pre-conditioner in the magnetic cleansing, was also present in the separation. The centrifuged iron powder was then washed with hexane up to four times, and then left to air dry in a fume hood for a week. The recycled iron powder (Bunker Oil 1 contaminated iron powder after centrifugation, solvent extraction and air-drying) is shown in Fig. 66 (c). The recycled iron powder was then evaluated for the removal of Diesel Oil from feather clusters. A comparison of Diesel Oil removal from feathers for recycled iron powder (Bunker Oil 1) and the original iron powder is displayed in Fig. 67. Again, the recycled iron powder (from Bunker Oil 1 experiments) is effective at removing Diesel from feathers, being comparable with the original iron powder.

Figure 65: Bottles of Diesel Oil and Bunker Oil 1 laden iron powders after centrifugation

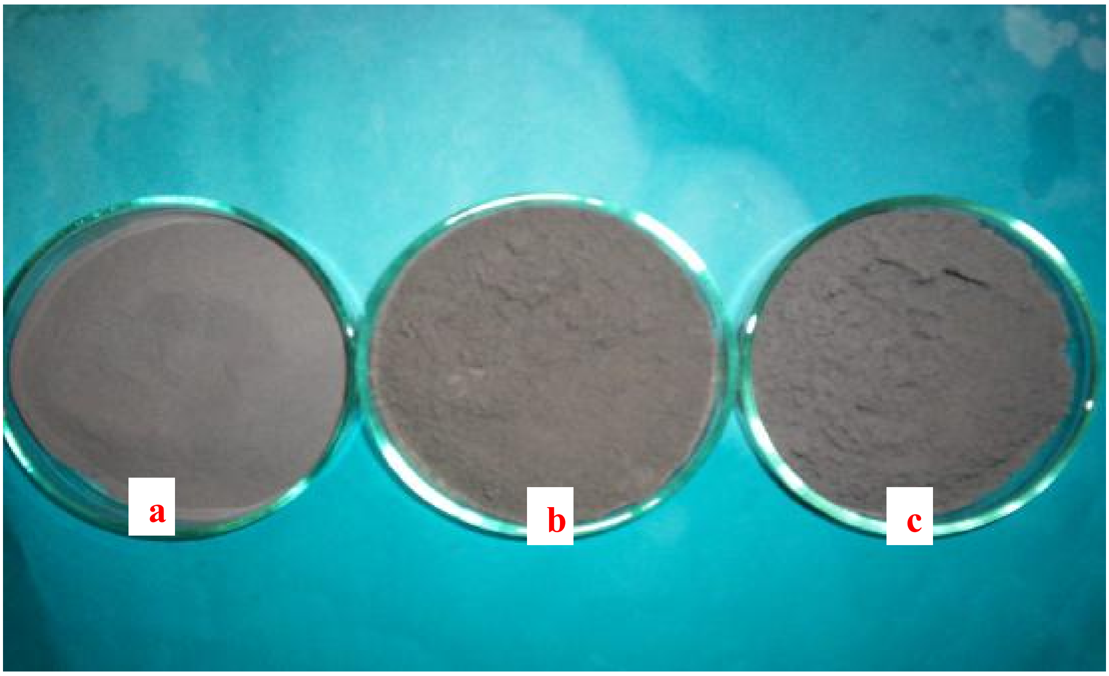

Figure 66: (a) Original iron powder; (b) recycled iron powder (from Diesel Oil experiments); (b) recycled iron powder (from Bunker Oil 1 experiments).

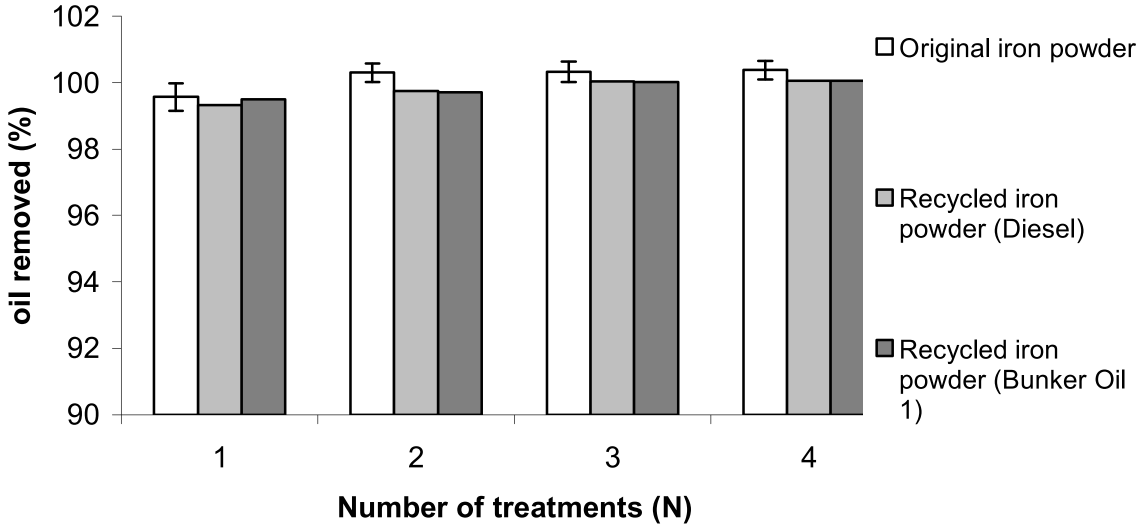

Figure 67: Comparison of Diesel Oil removal, F(%), from clusters of feathers as a function of the number of treatments, N, amongst original iron powder, recycled iron powder (from Diesel Oil experiments) and recycled iron powder (from Bunker Oil 1 experiments). Error bars represent the standard error for three replicates.

Apart from centrifugation and solvent extraction techniques, iron powder (magnetic particles) contaminated with oil can be disposed of by incineration (RSNA, 2004).

10 Cost comparisons between magnetic and detergent cleansing method

10.1 Animal welfare considerations

There are several basic steps involved in the rescue and rehabilitation of oil-contaminated birds (Welte and Frink, 1991; Frink and Crozer-Jones, 1986; 1990; OWCN, 1999; USFWS, 2002). Removal of contamination upon first encounter is usually not an option using conventional detergent-based methods. Prior to cleaning, birds should be stabilised so that they are alert and responsive, have normal body temperature and hydration and have weight and blood indicators (packed cell volume and total protein) within the normal range for the species, age and sex (Walraven, 2004-b). It is expected that the process of stabilisation will be retained, but be complemented by an *additional* stabilisation technique involving the removal of the bulk of the contamination upon first encounter - by magnetic cleansing. This would require the optimization of portable field equipment (underway) and training in the use of such equipment. The immediate (even partial) removal of contamination is very important with respect to the lighter toxic/corrosive fractions that exist in oils such as such diesel or aviation fuel (Mazet *et al*. 2002; Short, 2004). This is considered desirable for conventional treatments and is described as a "*quick wash*" (Clark *et al*, 1997; Mazet *et al*. 2002; Short, 2004; Massey, 2006). However, for detergent based methods, this cannot be carried out effectively in the field (USFWS, 2002).

When a bird has been transported to a treatment centre, it is envisaged that there will be two options for removing the residual contamination, namely the detergent–based method and magnetic cleansing. In this regard, it is not known to what extent oil contamination needs to be reduced on the plumage to allow a particular bird to be successfully released (Peter Dann, *Personal communication*). Such knowledge could have important implications for the magnetic cleansing method (or other methods) since magnetic cleansing has been shown not to be damaging to the feathers *per se*, unlike the detergent-based method (Ngeh, 2002).

Within the scope of this project, where live animals have not been used, it has not been possible to fully address relevant animal welfare considerations, although the issues discussed previously should be borne in mind when considering the results.

10.2 Cost and logistics considerations

One objective of this project was to conduct a comparison between magnetic and detergent-based cleansing (on whole bird models) with respect to logistics and the basic parameters involved, i.e. cost of materials and time and disposal of waste.

For both magnetic cleansing and detergent-based methods, for varying degrees of coverage and for contrasting contaminants, total comparative costs involved in materials, labour and waste disposal have been estimated. Costs of materials have been sourced from relevant suppliers, the costs associated with waste treatment/disposal have been provided by relevant companies and labour costs are assigned at $ 25/hour. Details are as follows:

Iron powder, provided by Höganäs AB - Australian Metal Powder Supplies P/L (phone: 02 96816155; fax: 02 96816092), $ 5.5/ kg.

Washing detergent, DivoPlus V2 ™, $57.4 per 15 litre container (~ $4/L), provided by JohnsonDiversey Australia Ltd (phone: 02 97570300, fax: 02 97255767; freephone: 1800 251 738).

Methyl oleate (used as a pre-conditioner), Victorian Chemical Company (phone: 03 93017000; fax: 03 93097966), $103.50 per 20 litre can (~ $ 5/L).

Water and electricity use is $ 0.91/ m^3 and $ 0.138 /kWh, respectively.

Waste disposal: From our experiments, the oil concentration in the wastewater from detergent-based cleansing ranges from 0.11 mL/L (15 mL oil / 140 litres of water) to 0.4 mL/L (70 mL oil / 175 litres of water), depending on the oil coverage. Similarly, the oil residue in the oil-laden iron powder, which is created during the magnetic cleansing, is from 5-14% (by weight), again depending on the coverage. These types of wastes are categorised as toxic wastes and must be treated and disposed of accordingly. The cost of treatment and disposal for oily and detergent wastewater is $70 for a 200 litre drum ($ 0.35 for 1 litre), and that for oil-contaminated iron powder the cost is $8/kg (Dolomatrix Aust Ltd, 83 Laverton North, 3026 Victoria, phone: 03 9369 4222).

Labour costs for a (non-volunteer) rehabilitator are based on $25/h/person. It is expected that two persons need to be involved cleansing of one oiled bird, for both techniques (Frink and Crozer-Jones, 1986).

The number of affected birds involved in different oil spill incidents will vary. Therefore, our calculations are presented on a per bird basis.

Tables 3-10 present the estimated costs for the magnetic cleansing of one bird (penguin) contaminated with 10%, 50%, 70% and 100% coverages for both Diesel and Bunker Oil 1.

Tables 11-18 present the estimated costs associated with the detergent cleaning of one bird (penguin) contaminated with 10%, 50%, 70% and 100% coverages for both Diesel and Bunker Oil 1.

Table 3: Costs for **magnetic cleansing** of one bird contaminated with **10% Diesel Oil.** Errors are represented by the standard errors (SE) for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Iron powder	0.167 ± 0.009 kg	5.5 / kg	0.92
Power consumption (for running the air compressor)	1.5kWh x (26.5/60)	0.138/kWh	0.09
Treatment and disposal of oil-laden iron powder as prescribed solid waste	0.178 ± 0.009 kg	8/kg	1.42
Labour cost (2 persons)	26.5 ± 0.34 min x 2 persons	25/ hr	22.08
Total			**24.52** (± 0.41)

Table 4: Costs for **magnetic cleansing** of one bird contaminated with **50% Diesel Oil.** Errors are represented by the standard errors (SE) for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Iron powder	0.364 ± 0.025 kg	5.5 / kg	2.00
Power consumption (for running the air compressor)	1.5kWh x (32.3/60)	0.138/kWh	0.11
Treatment and disposal of oil-laden iron powder as prescribed solid waste	0.415 ± 0.025 kg	8/kg	3.32
Labour cost (2 persons)	32.3 ± 1.1 min x 2 persons	25/ hr	26.92
Total			**32.35** (± 1.26)

Table 5: Costs for **magnetic cleansing** of one bird contaminated with **70% Diesel Oil.** Errors are represented by the standard errors (SE) for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Iron powder	0.478 ± 0.023 kg	5.5 / kg	2.63
Power consumption (for running the air compressor)	1.5kW x (33.5/60)	0.138/kW	0.12
Treatment and disposal of oil-laden iron powder as prescribed solid waste	0.545 ± 0.023 kg	8/kg	4.36
Man power (2 persons)	33.5 ± 0.56 min x 2 persons	25/ h	27.92
Total			**35.02** (± 0.78)

Table 6: Costs for **magnetic cleansing** of one bird contaminated with **100% Diesel Oil.** Errors are represented by the standard errors (SE) for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Iron powder	1.09 ± 0.054 kg	5.5 / kg	6.00
Power consumption (for running the air compressor)	1.5kW x (41.3/60)	0.138/kW	0.14
Treatment and disposal of oil-laden iron powder as prescribed solid waste	1.23 ± 0.054	8/kg	9.84
Man power (2 persons)	41.3 min ± 3.53 x 2 persons	25/ h	34.42
Total			**50.39** (± 3.67)

Table 7: Costs for **magnetic cleansing** of one bird contaminated with **10% Bunker Oil 1**. Errors are represented by the standard errors (SE) adopted from the 20% Bunker Oil 1 coverage experiments for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Iron powder	0.322 ± 0.009 kg	5.5 / kg	1.77
Methyl oleate as pre-treatment agent	25 mL	5/1000 mL	0.13
Power consumption (for running the air compressor)	1.5kWh x (36.6/60)	0.138/kWh	0.13
Treatment and disposal of oil-laden iron powder as prescribed solid waste	0.332 ± 0.009 kg	8/kg	2.66
Labour cost (2 persons)	36.6 ± 1.53 min x 2 persons	25/ hr	30.50
Total			**33.41** (± 1.40)

Table 8: Costs for **magnetic cleansing** of one bird contaminated with **50% Bunker Oil 1**. Errors are represented by the standard errors (SE) adopted from the 20% Bunker Oil 1 coverage experiments for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Iron powder	0.730 ± 0.02 kg	5.5 / kg	4.01
Methyl oleate as pre-treatment agent	30 mL	5/1000 mL	0.15
Power consumption (for running the air compressor)	1.5kWh x (65/60)	0.138/kWh	0.22
Treatment and disposal of oil-laden iron powder as prescribed solid waste	0.754 ± 0.02 kg	8/kg	6.03
Labour cost (2 persons)	65 ± 2.7 min x 2 persons	25/ hr	54.17
Total			**60.57** (± 2.52)

Table 9: Costs for **<u>magnetic cleansing</u>** of one bird contaminated with <u>70% **Bunker Oil 1**</u>. Errors are represented by the standard errors (SE) adopted from the 20% Bunker Oil 1 coverage experiments for three replicates.

Item	**Quantity**	**Rate ($/x)**	**Cost ($)/bird**
Iron powder	1.043 ± 0.03 kg	5.5 / kg	5.74
Methyl oleate as pre-treatment agent	30 mL	5/1000 mL	0.15
Power consumption (for running the air compressor)	1.5kW x (82.2/60)	0.138/kW	0.28
Treatment and disposal of oil-laden iron powder as prescribed solid waste	1.087 ± 0.03 kg	8/kg	8.70
Man power (2 persons)	82.2 ± 3.4 min x 2 persons	25/ h	68.50
Total			**77.63** (± 3.24)

Table 10: Costs for **<u>magnetic cleansing</u>** of one bird contaminated with **<u>100% Bunker Oil 1</u>**. Errors are represented by the standard errors (SE) adopted from the 20% Bunker Oil 1 coverage experiments for three replicates.

Item	**Quantity**	**Rate ($/x)**	**Cost ($)/bird**
Iron powder	1.903 ± 0.054 kg	5.5 / kg	10.47
Methyl oleate as pre-treatment agent	40 mL	5/1000 mL	0.20
Power consumption (for running the air compressor)	1.5kW x (95.5/60)	0.138/kW	0.33
Treatment and disposal of oil-laden iron powder as prescribed solid waste	2.015 ± 0.054 kg	8/kg	16.12
Man power (2 persons)	95.5 min ± 4 x 2 persons	25/ h	79.58
Total			**96.23** (± 4.06)

Table 11: Costs for **<u>detergent-based cleaning</u>** of one bird contaminated with **<u>10% Diesel Oil.</u>** Errors are represented by the standard errors (SE) adopted from the 50% Bunker Oil 1 coverage experiments for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Water	0.140 ± 0.038 m^3	0.91/ m^3	0.13
Detergent	270 ± 31.18 mL	4/1000 mL	1.08
Treatment and disposal of oily and detergent wastewater	140 ± 38.4 L	0.35/ L	49.00
Labour cost (2 persons)	15.31 ± 0.78 min x 2 persons	25/ hr	12.76
Total			**62.97** (± 14.11)

Table 12: Costs for **<u>detergent-based cleaning</u>** of one bird contaminated with **<u>50% Diesel Oil</u>.** Errors are represented by the standard errors (SE) adopted from the 50% Bunker Oil 1 coverage experiments for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Water	0.175 ± 0.048 m^3	0.91/ m^3	0.16
Detergent	420 ± 48.5mL	4/1000 mL	1.68
Treatment and disposal of oily and detergent wastewater	175 ± 48 L	0.35/ L	61.25
Labour cost (2 persons)	20 min ± 1.02 x 2 persons	25/ hr	16.67
Total			**79.76** (± 17.9)

Table 13: Costs for **<u>detergent-based cleaning</u>** of one bird contaminated with **<u>70% Diesel Oil</u>.** Errors are represented by the standard errors (SE) adopted from the 50% Bunker Oil 1 coverage experiments for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Water	0.12 ± 0.033 m^3	0.91/ m3	0.11
Detergent	810 ± 93.53 mL	4/1000 mL	3.24
Treatment and disposal of oily and detergent wastewater	120 ± 32.91 L	0.35/ L	42.00
Man power	21.46 ± 1.097 min x 2 persons	25/h	17.88
Total			**63.23** (± 12.73)

Table 14: Costs for **detergent-based cleaning** of one bird contaminated with **100% Diesel Oil.** Errors are represented by the standard errors (SE) adopted from the 50% Bunker Oil 1 coverage experiments for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Water	0.14 ± 0.038 m^3	0.91/ m3	0.13
Detergent	1080 ± 124.71 mL	4/1000 mL	4.32
Treatment and disposal of oily and detergent wastewater	140 ± 38.4 L	0.35/ L	49.00
Man power	25.25 ± 1.29 min x 2 persons	25/h	21.04
Total			**74.49** (± 15.06)

Table 15: Costs for **detergent-based cleaning** of one bird contaminated with **10% Bunker Oil 1.** Errors are represented by the standard errors (SE) adopted from the 50% Bunker Oil 1 coverage experiments for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Water	0.140 ± 0.038 m^3	0.91/ m^3	0.13
Detergent	540 ± 62.35 mL	4/1000 mL	2.16
Treatment and disposal of oily and detergent wastewater	140 ± 38.4 L	0.35/ L	49.00
Labour cost (2 persons)	10.36 ± 0.53 min x 2 persons	25/ hr	8.63
Total			**59.92** (± 14.17)

Table 16: Costs for **detergent-based cleaning** of one bird contaminated with **50% Bunker Oil 1.** Errors are represented by the standard errors (SE) for three replicates (Kirkup, 1994).

Item	Replicate 1	Replicate 2	Replicate 1	Quantity	Rate ($/x)	Cost ($)/bird
Water	0.245 m^3	0.12 m^3	0.11 m^3	0.16 ± 0.043 m^3	0.91/ m^3	0.15
Detergent	540 mL	810 mL	650 mL	675 ± 77.94 mL	4/1000 mL	2.7
Treatment and disposal of oily and detergent wastewater	245 L	120 L	110 L	150.33 ± 43.43 L	0.35/ L	55.30
Labour cost (2 persons)	22.51 min	24.19 min	20.25 min	22.32 ± 1.14 min	25/ hr	18.60
Total						**76.75** (± 17.28)

Table 17: Costs for **detergent-based cleaning** of one bird contaminated with **70% Bunker Oil 1.** Errors are represented by the standard errors (SE) adopted from the 50% Bunker Oil 1 coverage experiments for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Water	0.13 ± 0.036 m^3	0.91/ m3	0.12
Detergent	1080 ± 124.71 mL	4/1000 mL	4.32
Treatment and disposal of oily and detergent wastewater	130 ± 35.66 L	0.35/ L	45.50
Man power	27.05 ± 1.38 min x 2 persons	25/h	22.54
Total			**72.48** (± 14.16)

Table 18: Costs for **detergent-based cleaning** of one bird contaminated with **100% Bunker Oil 1**. Errors are represented by the standard errors (SE) adopted from the 50% Bunker Oil 1 coverage experiments for three replicates.

Item	Quantity	Rate ($/x)	Cost ($)/bird
Water	0.16 ± 0.043 m^3	0.91/ m^3	0.15
Detergent	1210 ± 139.72 mL	4/1000 mL	4.84
Treatment and disposal of oily and detergent wastewater	160 ± 43.89 L	0.35/ L	56.00
Man power	32.4 ± 1.66 min x 2 persons	25/h	27.00
Total			**87.99** (± 17.34)

Fig. 68 compares the magnetic cleansing cost per bird between Diesel Oil and Bunker Oil 1 for 10%, 50%, 70% and 100% coverages. From this data, it is clear that for all coverages the magnetic cleansing costs are significantly higher for Bunker Oil 1 than for Diesel Oil.

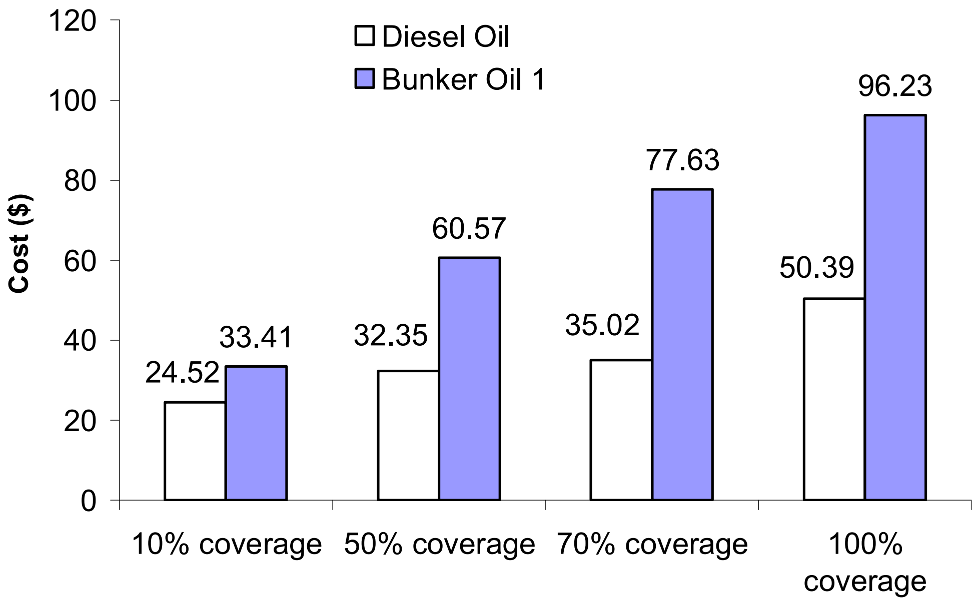

Figure 68: Cost comparisons between Diesel Oil and Bunker Oil 1 associated with the **magnetic cleansing** of one bird (penguin) for different coverages.

Fig.69 compares the detergent cleaning cost per bird between Diesel Oil and Bunker Oil 1 for 10%, 50%, 70% and 100% coverages. From this data, given the sizeable errors associated with the detergent cleansing method (20 – 24 %, mainly due to the variation in water usage) the detergent method costs are comparable for both Diesel Oil and Bunker Oil 1.

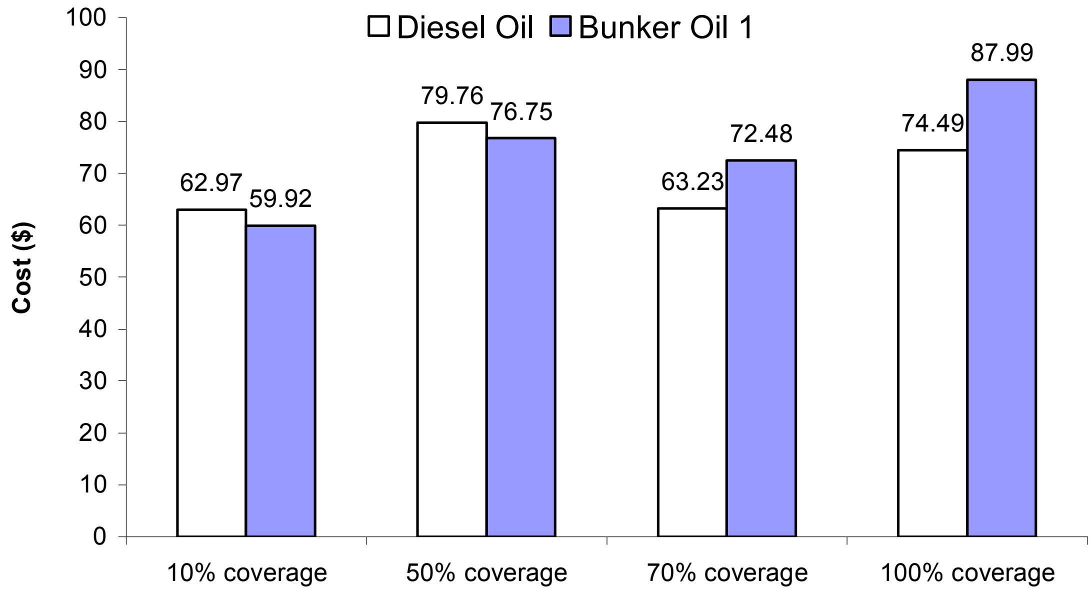

Figure 69: Cost comparisons between Diesel Oil and Bunker Oil 1 associated with the **detergent cleaning** of one bird (penguin) for different coverages.

Figs. 70- 71 summarize the comparative costs between the two different methods, for the cleansing of one bird (penguin) contaminated with different coverages (10%, 50%, 70% and 100%) for both Diesel and Bunker Oil 1. With reference to Fig. 70, the detergent-based method is significantly more expensive than the magnetic-based method for the cleansing of a bird contaminated with Diesel Oil. For Bunker Oil 1, Fig. 71 indicates that for 10% and 50% coverages, the cleaning costs are significantly higher for the detergent-based method than for the magnetic-based method. However, for 70% and 100% coverages the cleaning costs are slightly higher for the magnetic method than for the detergent method.

The major component of the cost for the detergent based method, as is evident from an examination of the data in Tables 11 - 18 is the treatment and disposal cost of the oily and detergent-contaminated wastewater. Without such costs, the detergent-based method would be comparable, if not cheaper, than the magnetic cleansing. On the other hand, an examination the data in Tables 3 – 10 shows that the major component of the magnetic cleansing method is the labour cost with the treatment and disposal cost of the contaminant-laden iron powder being relatively inexpensive.

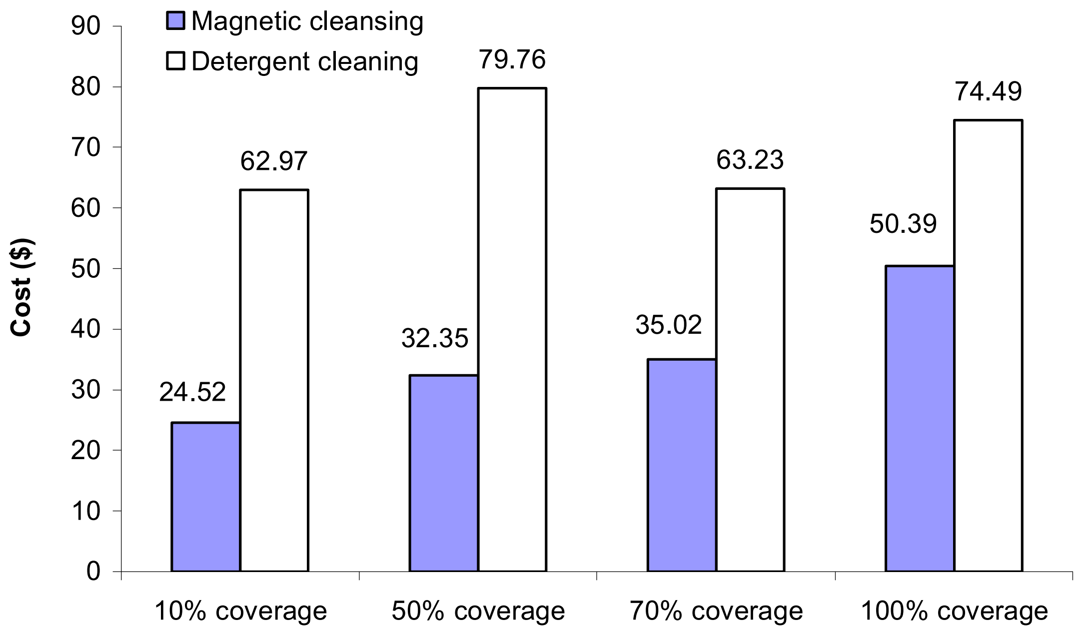

Figure 70: Cost comparisons between methods associated with the cleansing of one bird (penguin) contaminated with different Diesel Oil coverages. Estimated errors are enumerated in Tables 3 – 18.

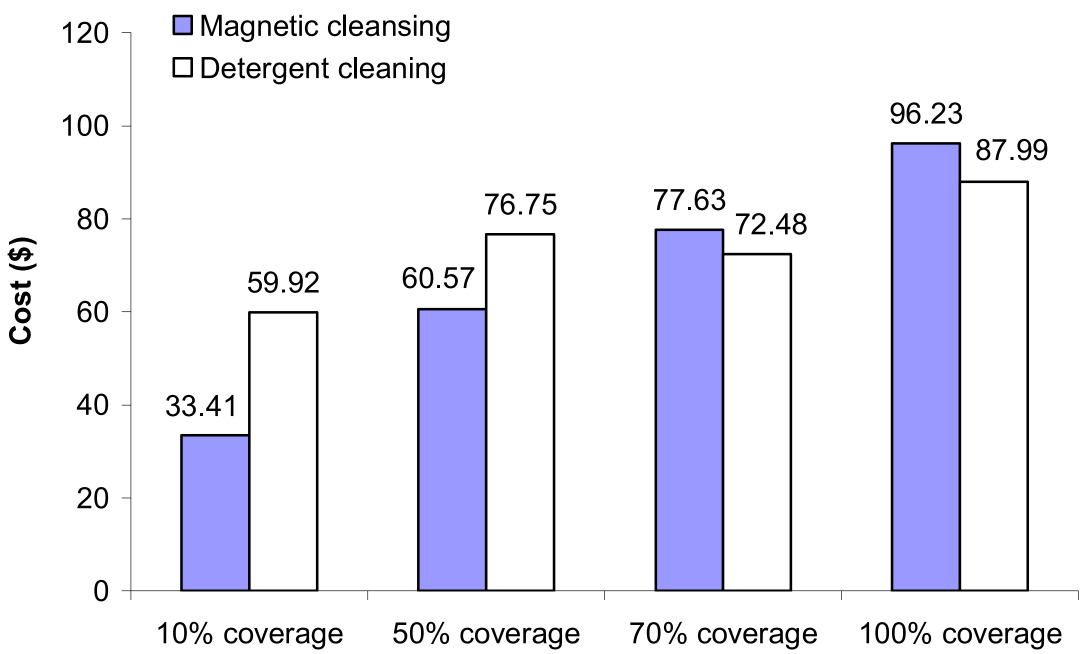

Figure 71: Cost comparison between methods associated with the cleansing of one bird (penguin) contaminated with different Bunker Oil 1 coverages. Estimated errors are enumerated in Tables 3 – 18.

There are, of course, other considerations apart from just financial costs. Iron powder is, admittedly, weighty. However, under certain circumstances, such as at a treatment centre or where the method would involve only an initial treatment as part of a stabilization protocol in the field, our results suggest that this could be entirely manageable. Consideration of one or more potential scenarios can help to illustrate this.

For example, assume that a portable field device is available consisting of an iron powder applicator and a magnetic harvester (powered by compressed air or battery powered, see Fig. 7). This technological development is currently underway within our group and it is evident from this work that such equipment could be made to be readily portable. It is also assumed that wildlife rescue personnel would be available who have been trained in the use of such equipment. Say we have 100 birds contaminated with a substance such as Diesel Oil. Assuming a worst case scenario of 100% contamination for each bird, from the results of Fig. 6 of this report, an initial magnetic cleansing (analogous to a "*quick wash*") upon first encountering a bird would remove ~37% of the lighter end (more toxic/corrosive) hydrocarbons in ~5 minutes, using ~ 234g of iron powder per bird. The total amount of iron powder required would therefore be ~23.4 kg. The total amount of Diesel Oil - laden iron powder to be disposed of would be ~28.7 kg (this is approximately equivalent in weight to half a bag of cement). The total time invested for all 100 birds would be ~500 mins (i.e. ~8.3 hrs). This time would almost certainly be distributed over a number of rescuers and is entirely manageable. In this regard, "follow up studies of the 'Treasure birds' have shown that the removal of the oil before it can be ingested is probably a critical factor in long term reproductive success" (Roz Jessop, *Personal communication*). It has also been shown that immediate or early removal of the oil is a critical component for increased survival rates of affected animals (Mazet *et al*., 2002; OWCN, 2003-b) and breeding success (Barham *et al*. 2007).

At a treatment centre, the magnetic cleansing apparatus would be similar, but not necessarily identical to the portable field equipment. It is likely that, at a treatment centre, more iron powder would be required since the objective would be to remove as much of the contaminant as possible. This would not necessarily be a problem since the iron powder could be held in stock and would not need to be transported. The magnetic cleansing method itself could offer real logistic advantages over the detergent based method (especially as the technology improves) since the birds would not have to be dried – it has been suggested that the provision of a drying area can become a real bottleneck in the rehabilitation process (Roz Jessop, *Personal communication*). In addition, in contrast to the use of detergent, the magnetic cleansing process is less damaging to the feathers (Ngeh, 2002) and it is possible that a bird could be successfully released into the wild with an, as yet undetermined, amount of contaminant still remaining on its plumage (Peter Dann, *Personal communication*).

The results obtained in this research project indicate that the complete removal of contamination from a bird is more time consuming using the magnetic method compared to the detergent based method, Table 19. However, under the current experimental design, the overall times for the magnetic cleansing procedures are expected to be artificially inflated compared to those for the detergent based method, since the former are obtained from a summation of a number of individual steps (treatments), whereas the latter represent the time taken for one continuous operation. It should also be appreciated that the magnetic cleansing equipment that has been used in these experiments is still at a very early stage of development.

11 Summary and recommendations

The results of our experiments to date have indicated that the application of magnetic particle technology to the cleansing of oiled wildlife has the potential for further development, primarily as part of an initial stabilization protocol and, possibly, as an alternative to detergent based cleansing at treatment facilities. Our recommendation, at this stage, would be to focus on the former application, given that this is a role that cannot be filled by conventional detergent-based cleansing methods. With respect to both scenarios, there is an imperative to advance the development of the appropriate technology. Such work is currently under way.

The work reported herein, based on the parameters considered, indicate that magnetic cleansing could offer potential cost savings over traditional detergent-based methods. Although the cleansing time (factored into the labor costs) for the magnetic method is, at this very early stage of technological development, longer than that for the detergent based method (*vide supra*), this is more than compensated for by the relative disposal costs. It is expected that the parameters of the magnetic cleansing process (namely: oil removal, cleansing time and iron powder use) will be improved considerably with further technological development of the equipment and improvements in experimental design.

A comparisons between detergent cleaning and magnetic cleansing for all the relevant parameters, based on the experiments conducted herein, are summarized in Table 19.

Table 19: Comparisons between the two methods for the clean(s)ing of one bird (penguin) contaminated with different contamination coverage (10 and 50%) for Diesel Oil and Bunker Oil 1. Removal of the detergent-based cleaning is undetermined and assumed to be ca. 100%.

Method	**Removal (%)**	**Clean(s)ing time (min)**	**Iron powder used (kg)**	**Water used (L)**	**Detergent used (mL)**	**Pre-treatment agent used (mL)**	**Waste water created (L)**	**Contaminant-laden iron powder created (kg)**	**Total cost ($)/bird**
	10% Diesel Oil coverage								
Detergent-based cleaning	assumed 100	15.3		140	270		140		62.97
Magnetic cleansing	92.5	26.5	0.17					0.18	24.52
	50% Diesel Oil coverage								
Detergent-based cleaning	assumed 100	20.0		175	420		175		79.76
Magnetic cleansing	91.3	32.3	0.36					0.42	32.35
	10% Bunker Oil 1 coverage								
Detergent-based cleaning	assumed 100	10.4		140	540		140		59.92
Magnetic cleansing	93.6	36.6	0.32			25		0.33	33.41
	50% Bunker Oil 1 coverage								
Detergent-based cleaning	assumed 100	22.5		245	540		245		106.59
Magnetic cleansing	93.5	64.6	0.73			30		0.75	60.57

12 Additional comments in relation to this project.

This project has facilitated progress in related, parallel research efforts. For example, our attention to the use of pre-conditioning agents has led to the development of an assay based on this technology in order to quantify relative pre-conditioner effectiveness. This assay has proven to be highly sensitive and has been successfully benchmarked against reliable anecdotal evidence.

During our consultations and visits relating to this project, we have also initiated a program to apply magnetic particle technology to the removal of contamination from rock (Orbell *et al.*, *2007)* and from mammalian fur (submitted to *Marine Mammal Science*).

Professor Orbell attended the Spillcon2007 conference in Perth from 26/3 to 30/3/2007. A number of very useful contacts were made with companies who have expressed an interest in collaborating in the further development of the magnetic cleansing technique.

Finally, Professor John Orbell and Dr. Lawrence Ngeh delivered two oral presentations at the 9th International Effects of Oil on Wildlife Conference, Monterey, California, U.S.A., June 25-29, 2007, entitled: “The potential for the application of magnetic particle technology to wildlife rehabilitation in the field” and “A quantitative assay for relative pre-conditioner effectiveness in wildlife rehabilitation”
The support of AMSA and the Phillip Island Nature Park was duly acknowledged in these presentations. This work was very well received by the delegates and valuable discussions ensued and important contacts were established.

13 Acknowledgements

We would like to thank the following organisations and people:

The Australian Maritime Safety Authority (AMSA), the Phillip Island Nature Park (PINP) and Victoria University (VU) for the provision of funds and facilities in order to carry out this project.

We are most appreciative for the advice and assistance provided by Lisa Holman and Trevor Gilbert of AMSA and the wise council provided by members of the National Plan Working Group. Namely; Roz Jessop (PINP), Mike Short (Queensland Parks and Wildlife Service) and Richard Norman (Massey University).

We also greatly appreciate the valuable advice provided to us by David Ball (Department of Primary Industries), Tom Budd and colleagues at the Australian Marine Oil Spill Centre (AMOS) and Ben Cropley and colleagues at the Oil Spill Response Company of Australia (OSRCA).

Many thanks are due to our collaborators at PINP, including Peter Dann, Roz Jessop, Marg Healy and Tanya Murray.

Thanks are also due to Gordon Bartlett for providing technical assistance, Stephen Weir, Representative of Höganäs AB Sweden in Australia, for the provision of substantial quantities of iron powder free of charge and to Chris Leckie, Victorian Chemical Company, for the provision of methyl oleate.

We would like to thank the Shell Oil Company Pty Ltd, for the provision of Bunker Oil.

Finally, we would like to express our sincere gratitude to the technical staff of the School of Molecular Sciences (SMS) and to the members of the Institute for Sustainability and Innovation (ISI), Victoria University (VU), for their patience, enthusiasm, co-operation and support.

14 References

1. Barham, PJ, Underhill LG, Crawford RJM, Leshoro TM. 2007. 'Differences in breeding success between African Penguins (*Spheniscus demersus*) that were and were not oiled in the *MV Treasure* oil-spill in 2000', *Emu*, vol. 107. pp.7-13.

2. Bryndza, HE, Foster, JP, McCartney, JH, Lundberg, B, Lober, JC 1991, 'Surfactant efficacy in removal of petrochemicals from feathers', Contribution No.4523 from the Central Research and Development Department and the Petrochemicals Department of the E.I. Du pont de Nemours &Co. Inc, Experimental Station, Wilmington, Delaware, 19880-0328 and Contribution No.8702 from Tri-Sate Bird Rescue and Research Inc., Box 1713, Wilmington, Delaware, 19899.

3. Christodoulou, NC 2002, *Porous and magnetic, inorganic based composite materials used as a sorbent for cleaning water and the environment from oil spill*, International patent: PCT/CY00/00003.

4. Clark, RB, Evans, S, Palmer, N 1997, *Review of the effectiveness of, and management procedures for, the rehabilitation (treatment, cleaning and release) of oiled birds with reference to the Sea Empress oil spill*, Sea Empress Environment Evaluation Committee (SEEEC) contract Report 243.

5. Copley, J 1999, 'Squeaky-clean: Magnets could help wildlife recover from oil slicks', *New Scientist*, 11.

6. Dao, HV, Ngeh, LN, Bigger, SW, Orbell, JD 2006-a, 'Achievement of 100% removal of oil from feathers employing magnetic particle technology', *J. Environ. Eng.*, vol. 132, no. 5, pp. 555-559.

7. Dao, HV, Maher, LA, Ngeh, LN, Bigger, SW, Orbell, JD, Healy, M, Jessop, R & Dann, P 2006-b, 'Removal of petroleum tar from bird feathers utilising magnetic particles', *Environ. Chem. Letters,* vol. 4, no. 2, pp. 111-113.

8. Dao, HV, Ngeh, LN, Bigger, SW, Orbell, JD, Healy, M, Jessop, R & Dann, P 2006-c, 'Magnetic cleansing of weathered/tarry oiled feathers - the role of pre-conditioners', *Mar. Pollut. Bull.*, vol. 52, no. 12, pp. 1591-1594.

9. Dao, HV 2007, 'An investigation into factors affecting the efficacy of oil removal from wildlife using magnetic particle technology', PhD Thesis, Victoria University, Australia, 351 pp.

10. Frink, L & Crozer-Jones, B 1986, 'Oiled bird rehabilitation: Fact and fallacy', *J. Wild. Rehabil.*, vol. 5, pp. 68-79.

11. Frink, L & Crozer-Jones, B 1990, 'Rehabilitation of oil contaminated birds', *J. Wild. Rehabil.*, vol. 8, pp. 23-34.

12. International Petroleum Industry Environmental Conservation Association (IPIECA) 2004, *A guide to oiled wildlife response planning*, IPIECA Report Series, Volume 13.

13. Kirkup, L 1994, *Experimental methods: An introduction to the analysis and presentation of data,* John Wiley & Sons, Brisbane, Australia.

14. Massey GJ, 2006, 'Summary of an oiled bird response', *J. Exotic Pet Medicine,* vol. 15, no. 1, pp. 33-39.

15. Mazet JAK, Newman, SH, Gilardi, KVK, Tseng, FS, Holcomb, JB, Jessup, DA, Michael, H, Ziccardi, MH 2002, 'Advances in Oiled Bird Emergency Medicine and Management', *J. Avian Medicine and Surgery,* vol. 16, No. 2, pp. 146-149.

16. Marine Ecology and Evolution, Royal Netherlands Institute for Sea Research (MME). 2006. *Seabirds and oil*, http://www.nioz.nl/public/mee/birds/birds-oil.pdf.

17. Mullin, JV & Champ, MA 2003, 'Introduction/overview to in situ burning of oil spills', *Spill Sci. & Technol. Bull*., vol. 8, no. 4, pp. 323-330.

18. National Oceanic Atmospheric Administration (NOAA) 1997, *Oil behaviour and toxicity,* viewed 12 August 2004, <http://response.restoration.noaa.gov/oilaids/response/pdfs/meterey/chapter2.pdf>

19. National Oceanic Atmospheric Administration (NOAA) 2007, *Fact sheets: Small diesel spills,* viewed 12 February 2007, <http://archive.orr.noaa.gov/oilaids/diesel.pdf>.

20. Ngeh, LN 2002, 'The Development of Magnetic Particles Technology in Environmental Rehabilitation', Ph.D. Thesis, School of Life Sciences, Victoria University, Melbourne, Australia, 186pp.

21. Oiled Wildlife Care Network (OWCN) 1999, *Protocol for the care of oil affected birds,* Wildlife Health Centre, University of California, Davis, U.S.A.

22. Oiled Wildlife Care Network (OWCN) 2003-a, *Protocol for the care of oil affected marine mammals,* Wildlife Health Centre, University of California, Davis, U.S.A.

23. Oiled Wildlife Care Network (OWCN) 2003-b, *Identification of the critical components of oiled seabird rescue and rehabilitation. A summary report of the current research and established protocols of oiled wildlife rehabilitation,* Wildlife Health Centre, University of California, Davis, U.S.A.

24. Orbell, JD, Godinho, L, Bigger, SW, Nguyen, TM, Ngeh, LN 1997, 'Oil spill remediation using magnetic particles: An experiment in environmental technology', *J. Chem. Edu.,* vol. 74, no. 12, pp. 1446 –1448.

25. Orbell, JD, Tan, EK, Coutts, MC, Bigger, SW & Ngeh, LN 1999, 'Cleansing oiled feathers-magnetically', *Mar. Pollut. Bull*, vol. 38, pp. 219-221.

26. Orbell, JD, Ngeh, LN, Bigger, SW, Zabinskas, M, Zheng, M, Healy, M, Jessop, R. & Dann, P 2004, 'Whole-bird models for the magnetic cleansing of oiled feathers', *Mar. Pollut. Bull.*, vol. 48, pp. 336-340.

27. Orbell, JD, Dao, HV, Ngeh, LN, Bigger, SW, Healy, M, Jessop, R. & Dann, P 2005, 'Acute temperature dependency in the cleansing of tarry feathers utilizing magnetic particles', *Environ. Chem. Letters.,* vol. 3, no. 1, pp. 25-27.

28. Orbell, JD, Dao, HV, Ngeh, LN, Bigger, SW 2007, 'Magnetic particle technology in environmental remediation and wildlife rehabilitation', the *Environmentalist* vol. 27, no.1, pp. 175 -182.

29. Orbell, JD, Dao, HV, Kapadia, J, Ngeh, LN, Bigger, SW, Healy, M, Jessop, R. & Dann, P. 'An investigation into the removal of oil from rock utilising magnetic particle technology', *Mar. Pollut. Bull. vol. 54, pp. 1958-1961.*

30. Pilcher, HR 2004, 'Oil-drenched birds get dry cleaned', Nature, 1-2.

31. Russian Science News Agency (RSNA) 2004, *Magnetic trap for oil,* viewed 15 July 2004, <http://www.informnauka.ru/eng/2004/2004-03-05-041_4_e.htm>.

32. Short, M 2004, Cleaning and drying of oiled wildlife- Techniques and Timing, *Proceedings (on a CD Rom) of the workshop on Improving Oiled Wildlife Preparedness and Response in Australia*, Australian Maritime Safety Authority (AMSA), Australia.

33. US Fish and Wildlife Service (USFWS) 2002, *Best practices for migratory bird care during oil spill response,* US Fish and Wildlife Service, USA.

34. Walraven, E 2004-a, 'Australian involvement in the prestige incident, Spain wildlife treatment and rehabilitation'*, Proceedings of the Spillcon conference*, Australia.

35. Walraven, E 2004-b, *Field manual: rescue and rehabilitation of oiled birds*, Zoological Parks Board of NSW, Mosman, Australia. 192.pp

36. Welte, S, Fink, L 1991, *Rescue and rehabilitation of oiled birds - Waterfowl management handbook. Fish and Wildlife Leaflet 13.2.8,* Tri-State Bird Rescue and Research, Inc. P.O. Box 289, Wilmington, USA.