CHAPTER 8

PROJECT SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In this dissertation an attempt was made to explain and offer a more detailed understanding of some of the basic aspects of ferrofluids and key parameters involved in their manufacture. This was performed because, although the process for ferrofluid synthesis appears to be relatively simple, many of the steps in the manufacture are not understood fully.

In Chapter 3, parameters that could affect the production of magnetite were discussed and an investigation was conducted to confirm what the preferred conditions are for the production of magnetite. From the investigations, it appears that magnetite is produced through the formation of green rust complexes. The green rusts are produced from ferrihydrites and iron (II) ions. Magnetite is then produced by the dehydroxylation of the green rusts. The following parameters favour the formation of magnetite: high pH, rapid addition of ammonium hydroxide solution, a rapid stirrer speed and sufficient ammonium hydroxide to ensure that the pH is in the correct range for the dehydroxylation of green rusts and for the prevention of formation of non-magnetic oxides.

In Chapter 4, the CFD software, CFX was used to determine the suitability of sedimentation funnels for the washing and concentration of the magnetite precipitate. A base case funnel containing only water was modelled using CFX-4.3. From preliminary results obtained from CFX-4, it appears that the inflowing liquid churns up material that may have settled at the base of the funnel. A possible method to eliminate this would be to insert a baffle plate at the funnel entrance. The streamline plots of the solution obtained in CFX-5 confirmed the results obtained in CFX-4. It was realised, when performing the multi-phase flow modelling that it would be necessary to incorporate the magnetic field if the correct solid particle size is to be used. Without the additional body force, the nanometre size particles follow the flow of the main fluid. It was initially recommended that the funnel geometry be modified such that the flow into the funnel does not disturb the particles at the base of the funnel. The magnetic field could then be incorporated into the model. The four funnels in series could then be modelled as a unit once convergence on an optimised funnel has been obtained. A new concept was, however, proposed as an alternative to the sedimentation funnels and the CFD study was suspended.

In Chapter 5, the WHIMS was discussed as an alternative to the method of the sedimentation funnels for the washing and concentration of magnetite precipitate. A prototype of the WHIMS was built to determine whether or not it would be suitable for this purpose. Furthermore, a qualitative estimation of the suitability of three mesh types was determined. It was found from the test work that the WHIMS will function effectively in the washing and concentration of the magnetite precipitate. The percentage magnetite retained on the three types of mesh is similar for all three cases, however, Mesh 3 (a high carbon woven wire screen with a 5 mm aperture and a wire of 3.15 mm diameter) exhibits the lowest loss of magnetite. It is recommended that Mesh 3 be used initially. It is suspected that the outlet flow rate from the WHIMS during washing cycles could be increased with a lower loss of precipitate when using Mesh 3 as compared to the other mesh types. This implies that a greater number of washing cycles could be performed in the allowable cycle time per volume if the WHIMS were used in a process that manufactures ferrofluid continuously. It is further recommended if Mesh 3 is used, that the flushing time for rinsing magnetite from the mesh be increased. If the flushing time is increased, it may be possible to wash Mesh 3 better. If it is found that Mesh 3 clogs easily and it is not possible to remove the magnetite, Mesh 2 (a galvanised woven wire screen with a 10 mm aperture and a wire of 4 mm diameter) should be used instead. Mesh 2 loses less magnetite than Mesh 1 (an expanded metal sheet with 8 X 20 mm diamond shape openings, a gap of 2 mm between openings and a thickness of 1.2 mm) whilst retaining a similar percentage as Mesh 1. The flushing time when using Mesh 2 may be lower than that required to flush Mesh 3. This allows for a slower draining time or outlet velocity from the mesh which may decrease the percentage magnetite loss. The outlet velocity for the testwork was approximately 3 l/min. If this flow rate is reduced, the entrainment of magnetite out of the WHIMS may be reduced. There will be a compromise between an increase in flushing time versus a slower draining time and the number of washing cycles that can be performed. This is because the volume of the WHIMS is fixed and a washing cycle must occur within a specified period of time. Increasing both the flushing time and decreasing the outlet time may require a larger funnel.

In Chapter 6, the stability requirements in terms of particle coating with surfactant were discussed. The investigation into the optimum quantity of surfactant required for steric stabilisation showed that as the percentage oleic acid increases, the volume of magnetite remaining suspended above the ferrofluid appears to decrease. It is possible, however, that too high a percentage of oleic acid would result in a fluid of unacceptably high viscosity. It is recommended that an estimate be made of the volume of oleic acid molecules required to coat a magnetite particle of a certain diameter. An initial estimate of the maximum percentage surfactant required could then be established.

In the final chapter, Chapter 7, the use of a packed column for the peptization stage of the ferrofluid production was investigated. This chapter documented the procedure of mathematical optimisation using the dynamic trajectory method to determine the optimum dimensions of such a column that would result in maximum heat transfer. Various scenarios were investigated. It was found that in the simple case where the residence time and geometric diameter to height constraint is ignored the solution converges where the height and diameter of the column are a maximum and the bead diameter is a minimum. This would provide the greatest surface area thus promoting heat transfer and ensuring that the solid particles are transferred from the aqueous to the organic phase. The residence time in this case if the values of the variables obtained as a solution are substituted back into the equations would, however, result in a completely unacceptable residence time of over 16 hours. The resultant product would be viscous and much of the organic phase may have evaporated. When including the residence time considerations and the height to diameter ratio as an inequality constraint, various valid solutions were obtained for different starting values of the variables. This is because there are a number of combinations of height to diameter that would be below 2/3 that would still give the same surface area and acceptable residence time. When the height to diameter ratio is included as an equality constraint and when finite differences are used for calculation of the gradient, it is found that the column diameter would be approximately 0.39 m, the height would be approximately 0.59 m and the bead diameter 5 mm. The bead diameter is at its smallest size to give the largest surface area. The surface area available for reaction is approximately 52.22 m^2. With the additional constraints, there is approximately 32 times less surface area available for reaction and heat transfer. An area for further study would be to consider the number of beads required to fill the column to be a discrete value. The bead diameter could also be considered a discrete variable, as the glass beads are available commercially in certain specific sizes. The problem could be reformulated accordingly. The column height and diameter are relatively flexible as a glass blower could manufacture a column to a required specification. It would, however, be cheapest to purchase a standard commercially available glass column.

In summary then, various aspects and key parameters of ferrofluid manufacture were discussed and investigated in this dissertation. Additional information was provided regarding the preferred parameters for the formation of magnetite, precipitate washing and concentration, the volume of surfactant required for coating magnetite particles and the optimum method for heat transfer in the peptization reaction. This information clarifies some of the aspects in the production of this fascinating substance.