STUDIES OF MAGNETIC FILTRATION TECHNIQUES TO PURIFY POTABLE WATER AND WASTE WATER

A project report

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By

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TO MY PARENTS:

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ABSTRACT

The effects of Electromagnetism on potable water and waste water has been proven in practice but not scientifically proven to the extent that it is accepted by Engineers and Engineering Consultants. The operating principle of magnetic filtration or separation is based on the interaction of electromagnetic fields with the materials under test. Technical water system (TWS) system configuration has been analysed to determine the system characteristics. Three field trials and some laboratory experiments have been reported in this report. Finite element software has been used for the analysis of magnetic field distribution of the TWS system and also for magnetic separation modelling. There is a need to do some more experiments for more convincing and conclusive outcome.

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INTRODUCTION

1.1 Introduction

Pure water is very important for our society. According to medical and health sciences, there is virtually no function or reaction inside human body that can take place without the presence of water. Approximately 70% of our body weight is water and water makes up over 80% of our brain and 90% of our blood. Since with all activities inside human body water is involved with, there is now evidence to indicate that insufficient hydration of the body can, in itself, lead to or exacerbate specific health conditions and illnesses. The other important benefits obtained from water:

- Water helps the body absorb and assimilate nutrients into the blood stream and internal organs.
- Proper hydration helps the body resist the formation of kidney stones, urinary infections, and constipation. Water also accelerates the excretion of toxins and wastes from the body.
- Sufficient consumption of clean water has been shown to cut the risk of certain cancers like colon, breast, bladder and kidney.
- Drinking water before meals helps with weight loss and weight control since it aids digestion and reduce cravings.
- Water lubricates joints and muscles, reduces inflammation, aids in the recovery of injuries and decreases the risk of certain types of physical injuries such as sprains and pulls.
- Water boosts mental performance. As little as 2% dehydration can lead to significant short-term memory loss.

Clean water and as well as clean air are very important for a good life and health. Air should be free from smoke, dust, odours and pollens. Water should be free from metals such as lead, arsenic, mercury etc., should not be mixed with chemicals and microbes.

1.2 Water Cycle

The water cycle is also known as the hydrologic cycle. There is the same amount of water on the Earth now as there was when the Earth began. The water cycle is how the earth's water recycles itself.

The cycle includes precipitation, evaporation, condensation, and transpiration. Earth's water keeps changing from liquid water to vapour and then back again. This cycle happens because of the sun's heat and gravity. Figure 1.1 shows a frictional representation of water cycle.

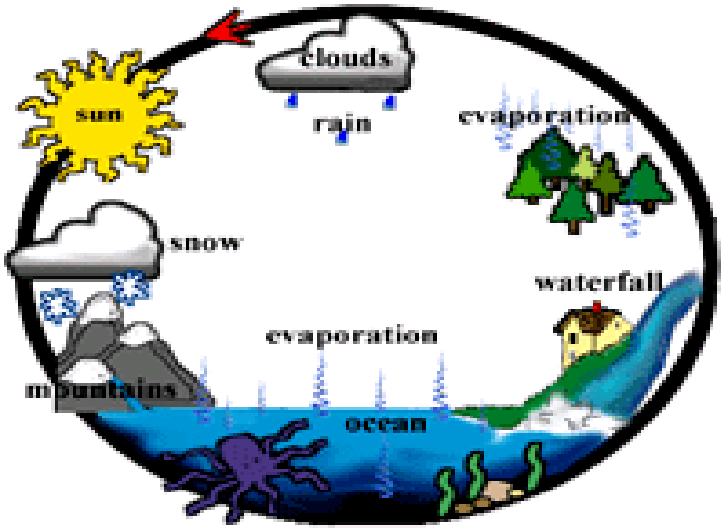


Figure 1.1: Water Cycle

- Water molecules from lakes, rivers, streams, reservoirs, and the ocean get heated up by the sun and turn into vapour that rises into the air [evaporation].
- Plants are heated up by the sun, too, and send water molecules into the air through their leaves [transpiration].
- These water molecules form into clouds.
- When the air and the water cool, they form drops of water that fall to the earth as rain. If they are frozen, they become snow or sleet [condensation]. The vapour has changed into a liquid.
- Once the water reaches the ground, it can flow across the land until it reaches rivers, lakes, streams, or the ocean. This is surface water. It

can also sink into the ground and flow with gravity through gaps in rock, gravel, and sand until it reaches these bodies of water, too. This is groundwater.

- The cycle begins continues.

1.3 Water Sources

There are different sources of water. A few of them are described.

1.2.1 Surface water

Surface water is the easiest water to understand because we see it every day. It is any water that travels or is stored on top of the ground. This would be the water that is in rivers, lakes, streams, reservoirs, even the oceans--even though we can't drink saltwater.

Snow can become surface and groundwater. An example of this is when it snows a few times on a mountain; the snow might not melt in between snows. When it warms up in the spring, there could be too much water for the earth to absorb. This causes the melted snow water to run down the mountains as surface water until it reaches a body of water.

Sometimes surface water sinks into the ground and becomes ground water. Runoff is the water that runs in gutters, off roofs, and out of mall parking lots when it rains. This is surface water, too. Runoff is a problem because it carries bad things like car oil, road salt, and trash into the water supply.

Surface water is treated before it becomes drinking water. This is done because things like leaves, fish, animal droppings, and boat fuel can easily get into lakes, streams, and rivers. Some companies try to use groundwater more than surface water because it is cleaner.

1.2.2 Ground water

Ground water is a little harder to understand than surface water. Any water that is underground is groundwater. Half of the people in the United States use ground water for drinking water.

In the water cycle, some of the precipitation sinks into the ground and goes into watersheds, aquifers and springs. The amount of water that seeps into the ground depends on how steep the land is and what is under ground. For example: places that have lots of sand underground will allow more water to sink in than ones that have lots of rock.

When the water seeps down, it will reach a layer of ground that already has water in it. That is the saturated zone. The highest point in the saturated zone is called the water table. The water table can raise and lower depending on seasons and rainfall.

Groundwater flows through layers of sand, clay, rock, and gravel. This cleans the water. Because groundwater stays underground, things that fall into surface water can't fall into it. This means that groundwater stays cleaner than water on the surface. It has its problems, too. When farmers use fertilizers and insecticides, rain will wash them into the soil where they get into aquifers [groundwater]. Gas stations have big, underground tanks where they keep the gas. If these leak, the gas sinks into the groundwater, too. Groundwater doesn't need as much treatment as surface water, but it usually gets some because of these problems.

From above discussion it is seen that clean water and as well as air are very important for a good life and health. Air should be free from smoke, dust, odours and pollens. Water should be free from metals such as lead, arsenic, mercury etc and should not be mixed with chemicals and microbes.

1.3 Water Problems

Water can be mixed with many contaminants. Some of them are not good for the society. In this section a few problems are described.

1.3.1 Hard Water

Hard water is a problem in over 85% of the world according to the US Geological Survey. Water is considered “hard’ when it has a high concentration of dissolved minerals, specifically calcium and magnesium. Water is a good solvent and these minerals dissolve in it as it moves through soil and rock and are carried along, eventually ending up in our water supply.

Hard water interferes with almost every cleaning task from laundering and dishwashing to bathing and personal care. The amount of hardness minerals in water affects the amount of soap and detergent necessary for cleaning. Clothes laundered in hard water may feel harsh and scratchy. Dishes and glasses may be spotted when dry. Hard water may cause a film on glass shower doors, shower walls, bathtubs, sinks, faucets, etc. Skin washed with hard water can become itchy and dry. Water flow may be reduced by deposits in pipes and shower heads. Faucets and other fixtures can have permanent deposits on them and the chrome finish can be destroyed.

Hard water also contributes to inefficient and costly operation of water-using appliances. Heated hard water forms a scale of calcium and magnesium minerals that can contribute to the inefficient operation or failure of water-using appliances. Pipes can become clogged with scale that reduces water flow and ultimately requires pipe replacement.

Hard water has no known adverse health effects. On the contrary, hard water, particularly very hard water, can be a small contributor to the daily need of calcium and magnesium. There has been research that shows that drinking hard water can decrease the risk of heart attacks. The decrease was very small, and it is still under investigation.

1.3.2 Temporary Hardness

Temporary hardness is hardness that can be removed by boiling or by the addition of lime (calcium hydroxide). It is caused by a combination of calcium ions and bicarbonate ions in the water. Boiling, which promotes the formation of carbonate from the bicarbonate, will precipitate calcium carbonate out of solution, leaving water that is less hard on cooling.

It should be noted that the above explanation is an oversimplification of the process that is occurring. The following equilibrium reaction actually happens when calcium carbonate ($CaCO_3$) is dissolved in water:

$$CaCO_3 \text{ (solid)} + H_2O \text{ (liquid)} + CO_2 \text{ (gas)} \leftrightarrow Ca^{2+} \text{ (aqueous)} + 2\ HCO_3\text{- (aqueous)}$$

Upon heating, less CO_2 is able to dissolve into the water. Since there is not enough CO_2 around, the reaction cannot proceed from left to right, and therefore the $CaCO_3$

will not "dissolve" as readily. Instead, the reaction is forced to go from right to left (i.e. products to reactants) to reestablish equilibrium, and solid $CaCO_3$ is formed. Heating water will remove hardness as long as the solid $CaCO_3$ that precipitates out is removed. After cooling, if enough time passes the water will pick up CO_2 from the air and the reaction will again proceed from left to right, allowing the $CaCO_3$ to "redissolve" in the water.

1.3.3 Permanent Hardness

Permanent hardness is hardness (mineral content) that cannot be removed by boiling. It is usually caused by the presence of calcium and magnesium sulfates and/or chlorides in the water, which become more soluble as the temperature rises. Despite the name this can be removed using a water softener, or ion exchange column.

1.4 Literature Survey

A lot of research articles on magnetic separation have been reported in technical literature. Only a few of them has been described here. The literature can basically be divided into two categories. In the first category the authors have studied the effect of magnetic field on water. In the 2nd category the water is mixed with some seeding materials and the magnetic field combined with some filtering arrangement has been studied.

1.4.1 Literature Survey using only magnetic field

(1) K. J. Kronenberg, "**Experimental evidence for effect of Magnetic Fields on Moving water",** IEEE Transactions on Magnetics, Vol. 21, No. 5, September 1985, pp. 2059-2061.

K. J. Kronenberg in the above paper stated that the world-wide controversy regarding the effects of magnetic fields on water results in part from the fact that surprisingly little is known about the physical structure of liquid water. Many of the extra-ordinary properties of "ordinary" water are explained the tendency of the water molecules to form complexes $(H_2O)_n$ with 20 < n < 200. Hydrogen bonds hold neighbouring

H_2O molecules together, forming clusters which cause the abnormal freezing habits of the water. Internal vibratory motion accounts for the uniquely high specific heat of the liquid water.

Reported observations of effects of magnetic fields on water have proliferated with the improvements of available permanent magnets, particularly countries where chemical capabilities for water conditioning are less developed and therefore physical water conditioning is widely use. It has been shown theoretically that the interaction between magnetic fields and the hydrogen bonds between the water molecules are by orders of magnitude too weak for direct, significant effects.

It is the intent of this work to offer a tangible scientific concept whereby the influence of well controllable magnetic fields and a sensitive observation of crystallization modes may contribute to a more complete model of the structure of liquid water, a by-product, and some valuable and environmentally advantageous methods of water conditioning may emerge from these studies.

Waters with various mineral contents were forced to flow through a number of magnetic fields of permanent magnets. Systematic variations of the number of the fields, their sequences, field strength, and gradients, and of the water flow velocity were applied. The water had moved through a number of magnetic fields. The former scarcity of crystallization nuclei in the water had been turned into an abundance of nucleation centres in the water. The reduction of the number of the substrate-bound crystals has been used as a quantitative measure of the magnetic effect.

In general, magnetically treated water makes most chemical additions more effective. This is most noticeable for detergents (steamcleaners), fertilizers, feed stuffs, and softening agents. The wetting capability is improved for most powdery materials and surfaces. This shortens drying time when the water leaves a thinner film after running off surfaces. More subjective observations, such as diminished taste and smell from chlorine and sulfitic contaminations can be explained as a result of the secondary crystallization of these substances on the $CaCO_3$-seed crystals.

(2): I. Otsuka and S. Ozeki, **"Does Magnetic Treatment of water change its properties?",** The Journal of physical Chemistry Letters, B, vol. 110, pp. 1509-1512, 2006.

Ichira otsuka and Sumio Ozeki in the above paper have examined some properties and functions of water treated under magnetic field. They have tried to show that the degree of "magnetization" of water can be quantitatively and easily evaluated by contact angle along with other sensitive methods. They observed whether pure water is "magnetized" by magnetic-field-treated water (MT water). Using a CCD camera system both MT and non-MT (NMT) water contact angle was measured at the same time for both sides of several drops. And the contact angle was plotted against time. The existence of O_2 may be a dominant factor for magnetization of water. It is noteworthy to point out that the addition of electrolytes (10 mM) such as NaCl, KCl, and $CaCl_2$ to the distilled water caused no MT effects as long as there was no O_2, which is different from most reports that ionic species brought about MT effects to pure water, because the Lorentz force or current during MT would be presumed. The appearance of the shoulder suggests that the forbidden transition in the Raman combination modes should be forgiven by symmetry changes of O2-containing water with the MT. No change in properties of pure water distilled from ultra pure water in vacuum was observed by magnetic treatment. Measuring the electrolytic potential after the contact angle recovered the initial value ($\Delta\Theta = 0$); no electrolytic potential shift was observed. However, when the same magnetic treatment was carried out after the distilled water was exposed to O_2, water properties such as vibration modes and electrolytic potential were changed.

They have concluded that only when water dissolves O_2, not ionic species, is the water magnetized by changing the magnetic flux over the water. So, there is a "magnetic-field affecting water" (MFA water), although the phenomena are still puzzling from the viewpoint of modern science. Since water structure changes dynamically, a structure formed by MT and thus "magnetization", if any, should be propagated or stand independent of thermal fluctuation. Such a process seems to be very difficult, even in O_2-containing water. The dispersion force between two bodies should depend on the magnetic susceptibility of a medium, a magnetic field may affect the interactions between hydrogen bonded clusters in the paramagnetic medium.

(3): W. Maeda, S. Yamada and M. Iwahara, **"Development of a Magnetic Separator for Biomaterials Labelled by the Magnetic Beads",** Proceedings of Asia Pacific Symnposium on Applied Electromagnetics, Sydney, Australia, July 20-21, 2006.

The authors in the above paper have introduced and developed a novel magnetic separator for biomaterials labelled by the magnetic beads which enables continuous separation with high-throughput compared to the conventional one. The magnetic separator consists of three rectangular coils, two circular coils, and a separation chamber, which is located between circular coils. The experimental configuration for performance test of the separator consists of the separator, bead flow in the chamber is controlled by the tube pump and the current to the coil supplied by the power source. Using an image processing software number of beads was counted. The most of the beads flew out from the outlet "Positive selection" once the current is applied to the coils. The maximum separation rate is obtained at 178 μ1/m of the flow rate. In this research, the new high – throughput magnetic separator has been proposed. The future tasks are to improve the separation rate, and practical experiments using biomaterials.

(4): M. Krzemieniewski, M. Teodorowicz, M. Debowski and J. Pesta, **"Effect of a constant magnetic field on water quality and rearing of European sheatfish Silurus glanis L. Larvae",** Aquaculture Research, Vol. 35, pp. 568-573, 2004.

In the above paper the authors hav aimed to determining the influence of a constant magnetic field on the water properties in a closed system and on the condition and rearing of European sheatfish. The experiment was carried out in two different breeding systems first was placed in three basins supplied with water flowing through the magnetizer system and the second group was kept in three basins supplied with the same water but without the magnetizer system with a closed water circuit. Fish in each tank were fed same amount of trout and dead fishes were counted and removed from the basins everyday. Water samples were taken every day from the sedimentation tank for physicochemical analysis of pH, alkalinity, acidity, conductivity, hardness, chloride, ammonium and organic compounds (COD). Also the mortality of the fish larvae was determined. The average fish weight was determined at the beginning and at the end of the experiment.

There were no significant changes of the water composition under a constant magnetic field in system with the European sheatfish larvae. A correlation between the mortality, the larval weight increase and the technology of water preparation in the system was observed. There was a mean mass increase in the larvae in the constant magnetic field (CMF) group was 0.26 g per fish and 0.58 g per fish in the control group. There were no significant changes observed in water phosphate, ammonium, COD or chloride concentrations. Changes reported concern molecular structure modification, polarization and changes in electric charge. It has further been shown that CMF influences water properties such as surface tension, density, viscosity, light extinction and wettability of solid matter. Most investigations on magnetic field effects concerned the influence on water properties

(5): S. Ozeki and I. Otsuka, "**Transient oxygen Clathrate – like Hydrate and water Networks Induced by Magnetic Fields",** The Journal of physical Chemistry Letters, B, vol. 110, pp. 20067-20072, 2006.

Sumio Ozeki and Ichiro Otsuka in the above paper have tried to obtain the spectroscopic evidence indicating the existence of a quasi-stable structure in the magnetic field-affecting water (MFA water), an oxygen clathrate-like hydrate, and developed water networks. Experiment for MFA water has been carried out at 298 K after checking the contact angle. MFA water was prepared by MT under various atmospheres of water distilled from ultrapure water in vacuum. The contact angle of both MT and NMT waters was measured at the same time for both sides of several drops with a CCD camera system. From the results it shows that the difference absorption intensities of the doublet peak increased with increase in O_2 concentration in water, magnetic field intensity of MT, and contact angle decrease $|\Delta\theta|$, demonstrating that the contact angle decrease or hydration enhancement due to MT should arise from some IR active structure induced by MT of O_2 dissolving water. The magnetic water treatment will be promising technique because a magnetic filed having a strong power of material transmission is an ecologically clean and soft energy and a compact device for MFA water could be constructed easily using permanent magnets.

1.4.2 Literature Survey in combination of Magnetic field and some other arrangement

(6): J. A. Oberteuffer, "**Magnetic Separation: A Review of Principles, Devices and Applications**", IEEE Transactions on Magnetics, Vol. 10, No. 2, June 1974, pp. 223-238.

In this article John A. Oberteuffer has reviewed principles, devices and applications of magnetic separation. Magnetic separation is an old technique for the removal of tramp iron and for the concentration of iron ores. Conventional magnetic separation devices are widely used for the removal of tramp iron from a variety of feed materials and for the beneficiation of ferrous ores. These devices for separation of strongly magnetic materials employ a variety of mechanical designs. The developed high gradient magnetic separation devices extend the useful application of magnetic separation to very weekly magnetic materials of small particle size. Potential applications of these new devices in pollution control, chemical processing are indicated. The principle of operation of magnetic separation devices is the interaction between magnetic forces and competing gravitational, hydrodynamic and interparticle forces within the magnetic separator. Without resort to a detailed analysis of the separation process, an understanding of the characteristics of magnetic separators is possible by consideration of a simple force-balance method.

(7): David R. Kelland, "**High Gradient Magnetic Separation Applied to Mineral Beneficiation",** IEEE Transactions on Magnetics, Vol. 9, No. 3, September 1973, pp. 307-310.

In this article the author has claimed that the High gradient magnetic separator can be applied to many areas. A magnetic separator featuring high magnetic field values, high field gradients, and large flow capacity has been applied to problems in mineral beneficiation [A]. With the magnetic separator oxidized and semitaconite ores was separated. Oxidized taconites and semitaconites are made up principally of goethite [FeO(OH)], hematite (Fe_20_3), and martite (chemically Fe_20_3, but pseudomorphic after magnetite). An important feature of all these taconite ores is the distribution of their component minerals in very small particles which are intermixed with gangue

material such as late and chert (microcrystalline quartz, up to 5-10 μm in size). Concentration of the iron bearing minerals in this structure requires grinding until they are liberated from the gangue. After grinding, a separation of the iron minerals must be made to raise the grade (% Fe) up to an acceptable level for steel making. The advancements in available magnetic-field strength were made possible by using larger coils and currents, improved magnetic circuits, and smaller circuit gaps. Higher field gradients in the working volume of separators have resulted from their use of sharp pointed elements, grooved plates and spheres of various diameters. The static separator consists of a canister through which the ore slurry flows, filled with a filamentary ferromagnetic matrix which has a solid volume of about 5% of the canister volume. Typical matrix materials used are steel and stainless steel wool and expanded metal. The 95% open volume allows a high flow rate. A magnetic field is created in this volume when magnetic materials are to be trapped from the slurry and is reduced to zero for cleaning the matrix.

(8): C. De Latour, "**Magnetic Separation in Water Pollution Control**", IEEE Transactions on Magnetics, Vol. 9, No. 3, September 1973, pp. 314-316.

Christopher De Latour has described magnetic separation as applied to waterborne contaminants is successful in reducing the solids content of a water sample and in removing the dissolved orthophosphate from aqueous slurry. The contaminants are chemically associated with a magnetic seeding material, and subsequent removal of this seed sweeps the pollutants from the system. The advantage of this form over conventional techniques is the high speed and large handling capacity of a magnetic filtering device. He has concluded by observing "Every water clarification task is unique, so no purification process is universally acceptable. However, for suspended solids removal and orthophosphate removal, magnetic separation offers an alternative treatment process. It is an alternative, however, that is quite attractive because of the high processing rates, the compactness of the filtering machinery and the simplicity of the backwashing of the magnetic filter".

(9): C. De Latour and H. Kolm, "**Magnetic Separation in Water Pollution Control – II**", IEEE Transactions on Magnetics, Vol. 11, No. 5, September 1975, pp. 1570-1572.

In this article the authors stated that the Magnetic separation in water purification uses a magnetically susceptible seeding material as a substrate for pollutants removal. The chemical bond between the seed and the pollutant is normally achieved by the action of a chemical coagulant. There are cases, however, in which an additive is not necessary, as in the removal of algal cells from sea water. Under the proper chemical conditions, a coagulant cation such as Fe(III) or Al(III) will yield an insoluble precipitate that will form rapidly throughout the solution. This insoluble species coats the solids of the system and is responsible for the bonding that occurs among the particulates. Since the magnetically susceptible seed material is now part of the coagulum that is formed, the subsequent magnetic separation procedure will remove all of the suspended matter as well as the absorbed precipitate. This removal is rapid and efficient in the magnetic filtration device. The capability of the magnetic separation process to remove the insoluble precipitates and coagulated solids from solution has been examined in detail and reported in the article.

(10): R. R. Oder, "**High Gradient Magnetic Separation – Theory and Applications**", IEEE Transactions on Magnetics, Vol. 12, No. 5, September 1976, pp. 428-435.

R. R. Oder has discussed key technical and economical achievements which have extended the range of application of magnetic separation methods into the commercial processing of micron size feebly magnetic materials. Commercial application of magnetic methods in the cleaning of kaolin clay has been reviewed and a discussion of magnetic separation principles has been given with emphasis on identification and utilization of important process parameters. Possible future developments in magnetic processing of municipal and industrial wastewaters and of applications of magnetic methods to the preparation of clean fuels from coal are discussed in the paper.

(11): S. C. Trindade and H. H. Kolm, "**Magnetic Desulfurization of Coal**", IEEE Transactions on Magnetics, Vol. 9, No. 3, September 1973, pp. 310-313.

In the past cleaning of coals using magnetic field was done by passing coal particles usually pretreated or containing additives to enhance the magnetic susceptibility of the components to be separated. The paper above is probably the first systematic attempt at using high gradient magnetic separation techniques in coal slurries. The rationale for magnetic desulfurization of coal resides in the paramagnetism of pyrites and their liberation from the coal substance. Usually most of the separations carried out in the process industries make use of the difference in the value of some physical property between the materials to be separated. Density difference between coal components are the basis of most separation processes. The density of coal without minerals ranges between 1.3 and 1.6 gm/cm^3. Common coal minerals have the following densities, in gm/cm^3: kaolinite – 2.6, muscovite – 3.0, pyrite – 5.1 and quartz – 2.65.

In magnetic separation the relevant property is the magnetic susceptibility. The magnetic force (the translational one) along a given direction on a small anisotropic body (particle) of a non-ferromagnetic material immersed in a magnetic field is given by

$$F = \chi V H \frac{dH}{dx} \qquad [1.1]$$

F is the force acting on the particle along a given direction

χ the volume susceptibility of the particle

V is the volume of the small body (particle)

H is the total magnetic field acting on the particle along the given direction.

$\frac{dH}{dx}$ is the gradient of the magnetic field along the given direction.

So the basic principle of magnetic separation is then the development of a high amount of magnetic field as well as a high gradient of magnetic field along the same direction. Depending upon the geometry and the design of the separator, and the nature of medium carrying the particles to be separated, there could be forces of different natures acting on the particles; some of them add to the magnetic force, whereas some oppose the separation. Typical nonmagnetic forces are the particle weight, buoyancy, drag by the fluid carrying the particles etc. From the experimental

results the authors have concluded that the most important independent variables in magnetic separation are: particle size distribution, slurry velocity, magnetic field intensity and packing characteristics.

(12): T. Hartikainen, J. P. Nikkanen and R. Mikkonen, "**Magnetic Separation of Industrial Waste Waters as an Environmental Application of Superconductivity**", IEEE Transactions on Applied Superconductivity, Vol. 15, No. 2, June 2005, pp. 2336-2339.

In this paper the authors have reported the design and construction of a superconducting isodynamic open gradient magnetic separator. They are tested with different slurries to determine the optimum separation conditions. Open gradient magnetic separation enables continuous operation of the separator without the need of matrix-elements. The separator consists of liquid helium cryostat and an interchangeable pair of NbTi and Nb3Sn coils. The separator has been used to purify waste water of synthetic and genuine steel mill. Synthetic waste water contained dissolved Cr while the genuine steel mill waste water contained Cr, Fe, Ni and Mo both in particle and in ionic form. Chemical treatment was needed to make the dissolved metals susceptible for magnetic field; this was achieved with the help of an adsorbent and ferromagnetic magnetite. Two types of industrial waste waters were reported. It was found that heavy metals in dissolved i.e. ionic form could be separated, if they were first absorbed to chemically made magnetite-silicate network. Successful separation depends on experimentally optimized parameters, such as size and magnetic susceptibility of particles to be separated, applied magnetic force density and flow velocity through separation zone. The force needed for separation is proportional to the product of magnetic flux density, B, and its gradient.

(13): N. Karapinar, "**Magnetic Separation of ferrihydrite from wastewater by magnetic seeding and high-gradient magnetic separation**", International Journal of Mineral Processing, Vol. 71, 2003, pp. 45-54.

In this paper it has been reported that ferrihydrite, a member of iron oxides family, has been used an adsorbent for the removal of heavy metal ions from industrial wastewater. The success of the operation depends mainly on the efficient removal of

ferrihydride from the aqueous phase. Hence, the emphasis of the study was given on the separation of ferrihydride magnetic separator to overcome solid/liquid separation difficulties of ferrihydride. The paper has clarified the seeding of ferrihydrite with magnetite mineral and its effects on the operation parameters in High Gradient magnetic Separator. Magnetic seeding technique was used to make magnetic separation available for the removal of ferrihydrite and the magnetite mineral was chosen as a seeding material. The method clearly involves the attachment of ferrihydrite to a magnetic seed material and subsequent magnetic separation of ferrihydrite-magnetite coagulates. In seeding process, finely divided magnetite particles were entrapped in ferrihydrite precipitate evolving by increasing pH of solution. In relation to hydrolysis properties of FE(III) ion, there is a pH range where the seeding performance is optimal. Iron/magnetite ratio had a marked effect on the separation of seeded precipitate by HGMS. This ratio determines the operation parameters such as magnetic field strength and flow rate on which the cost and performance of HGMS depend.

(14): Y. Kakihara, T. Fukunishi, S. Takeda, S. Nishijima and A. Nakahira, "**Superconducting high gradient magnetic separation for purification of wastewater from paper factory**", IEEE Transactions on Applied Supercondcutivity, Vol. 14, No. 2, June 2004, pp. 1565-1567.

The authors have attempted the purification of wastewater coming out of paper factory by superconducting high gradient magnetic separation both in laboratory scale and pilot-plant scale. Magnetite and some kinds of iron hydroxide particles were used as scavenging materials for suspended substances and organic dye molecules included in wastewater. Optimum dosage of the scavenger was examined in the paper. Figure 1.2 shows the schematic representation of the scheme developed by the authors. The system consists of a simple structured reaction tank, a separation tank and a magnetic separation tank. By applying suitable amount magnetite, iron (II) sulfate (or aluminum sulfate) and NaOH were added to paper mill drainage, it was observed that magnetic flocks containing magnetite formed in the reaction tank. It was also observed that with ferrous sulfate it was hard to solve the problem of coloring due to oxidation of iron.

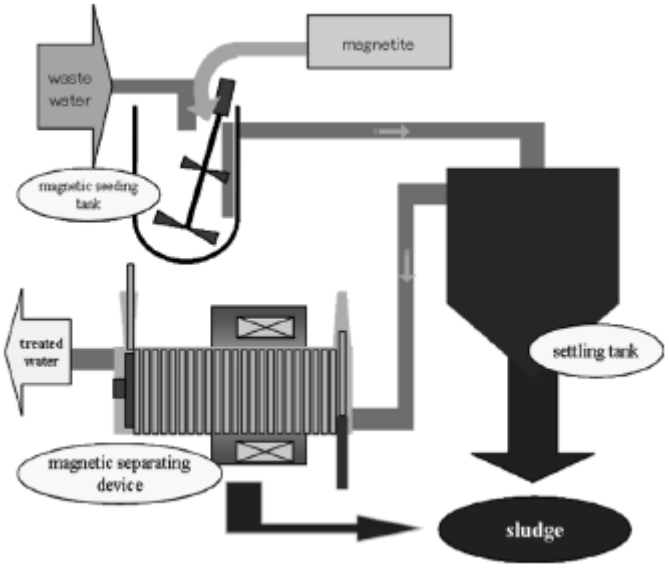


Figure 1.2: Superconducting magnetic separation for wastewater purification

(15): O. Larue and E. Vorobiev, "**Floc size estimation in iron induced electrocoagulation and coagulation using sedimentation data**", International Journal of Mineral Processing, Vol. 71, 2003, pp. 1-15.

Floc size and density significantly influence the performance of liquid/solid separation processes. The large and dense flocks are preferable as they are more easily dewatered. Chemical dosing with metal ions (iron or aluminum) is often used in primary treatments to remove colloids from wastewater but new technologies as electrocoagulation are susceptible to produce flocks of higher size and density. The estimation of average floc diameter using sedimentation and optical data were reported in the above paper. The study was applied to a kaolin suspension destabilized by chemical dosing with iron salts ($FeCl_3$ or $FeSO_4$) or electrocoagulation (EC) with iron electrodes. Optimum pH and coagulant concentration were defined by turbidity measures on destabilized suspensions. The suspensions were subsequently settled in a vertical column.

(16): C. H. Setchell, "**Magnetic Separations in Biotechnology – a Review**", Journal Chemical. Tech. Biotechnology, Vol. 35B, pp. 175-182, 1985.

There is a board range of potential applications of magnetic separation in both small and large scale biotechnology. It is considered that the separation technology is one of the most complex and important areas of industrial biotechnology. The lack of cost effective technique is a major drawback to the biological production of medium and low value product. Conventional magnetic separation methods have been viewed as standard techniques for a long time, but until recently their application to biotechnology has been restricted and of limited use. The new methods of generating high magnetic field gradients and use of efficient and superconducting magnets have aroused fresh technical interests. The high gradient magnetic separation technology uses magnetic field as high as 8 T and can separate even paramagnetic or very fine particles from a rapidly flowing liquid such as water. The development of HGMS has greatly improved the capabilities of magnetic separation technology. The principle of operation of HGMS in its simplest form, a ferromagnetic matrix is packed in a tube which is placed in an external field. The result is the production of high field gradients across a large surface area of matrix on which the magnetic particles can be stored. If an aqueous suspension of magnetite is passed through the tube, the magnetite is retained whilst the water passes through. When the matrix is loaded, the field is turned off and the particles collected from the water are released. The efficiency of separation is related to various operating parameters, including matrix packing density, matrix strand size, flow velocity and field intensity. In all cases the smaller the particle size the greater the magnetic field required to produce a force strong enough to facilitate rapid separation.

(17): L. Petrakis and R. F. Ahner, "**Use of High Gradient Magnetic Separation Techniques for the Removal of Oil and Solids from Water Effluents**", IEEE Transactions on Magnetics, Vol. 12, No. 5, September 1976, pp. 486-488.

High Gradient Magnetic Separation technique and necessary instrumentation in water treatment problems has been described in the above paper. Water effluents from both a refinery and a chemical sewer have been used with flocculants to reduce total suspended solids and oil content. The preliminary experimental results have clearly

indicated that HGMS holds much promise as a technique for removal of solids and other contaminants from water streams. However, the same results clearly indicate that one must be careful about generalizing the results to other water treatment problems, for one must consider what stream one is dealing with and then design a set of conditions that optimize the removal. The parameters that one can manipulate include flow-rates, field gradients, field strengths, packing materials and density of canisters that can be used. Nevertheless, the technique appears of sufficient potential that it seems to merit further serious investigations.

(18): J. A. Oberteuffer, "**Engineering Development of High Gradient Magnetic Separators**", IEEE Transactions on Magnetics, Vol. 12, No. 5, September 1976, pp. 444-449.

High gradient magnetic separation is a technology that is proving applicable to the solution of a wide range of problems in both mineral processing and water treatment. The commercial development of high gradient magnetic separation began in 1969. Applications of HGMS technology to mineral processing and water treatment have been in use since then. The above paper has reported the design of a high performance high gradient magnetic separator. High gradient magnetic separation doesn't require the use of costly reagents like floatation. In direct filtration applications the use of flocculants is not required as they are for sedimentation. The strong magnetic forces produced on the edge of the fine filaments in high gradient magnetic separators permit the separation of fine, even weakly magnetized particles often at very high flow rates. The ability to separate micron-size particles is an important advantage of high gradient magnetic separators over gravity separation methods, floatation or mechanical filters all of which become rather ineffective for small particle sizes.

(19): H. H. Kolm, "**Research Needs in Magnetic Separation**", IEEE Transactions on Magnetics, Vol. 12, No. 5, September 1976, pp. 450-454.

High gradient magnetic separation is a new technique which provides a practical means for separating weakly paramagnetic materials down to colloidal particle size on a large scale and at flow rates one hundred times faster than conventional filtration. It is based on the use of matrices of finely divided filamentary ferromagnetic material

containing 95% void space, such as steel wool, subjected to strong magnetic fields generated by sophisticated magnets of a type not previously used for magnetic separation. The technique is of importance to the entire chemical and mineral industry, and in the treatment of water and sewage, but its application in other areas has been delayed by lack of interdisciplinary communication. What is needed at present is a better understanding of the mechanism of HGMS to permit a more scientific approach to future applications, and more inducement to the firms which are currently developing the next generation of hardware. Other approaches to magnetic separation also merit more serious attention; particularly those based open gradient rather than matrix structures. New magnet technology developed in conjunction with HGMS and the advent of superconductivity make available field strengths, gradients and volumes at least an order of magnitudes above those offered by the prior art. Such magnetic fields have potential value beyond their use in magnetic separation in as much as they are likely to affect the kinetics of many chemical reactions, very probably also those involved in the combustion process itself. The research needs in magnetic separation technology has been discussed in this paper.

(20): E. C. Hise, "**Development of high gradient and open gradient magnetic separation**", IEEE Transactions on Magnetics, Vol. 12, No. 5, September 1976, pp. 450-454.

In the above paper the development of high gradient and open gradient magnetic separator has been reported and experimental results have been presented.

(21): Y. Yanagisawa, T. Hasuda and J. Iwasaki, "**Fine Treatment of Industrial Sludges by High Gradient Magnetic Separation**", IEEE Transactions on Magnetics, Vol. 17, No. 6, November 1981, pp. 3317-3319.

In the above paper the authors have reported high gradient magnetic separation for the treatment of industrial waste sludges. These sludges were made up of chemical reagents of a-Fe_2O_3, $Cr(OH)_3$ and SiO_2, which are weakly magnetic with the particle size less than about 20 μm. In this paper the change of magnetic capture through one cycle of separation was defined as a "magnetic capture process". This process

includes initial magnetic capture, build-up and breakthrough phenomena. Separation tests of paramagnetic or weakly magnetic α-Fe_2O_3 from a diamagnetic SiO2 were successful with the separation efficiency of more than 90 percent. A complete particle trajectory model has been developed and reported in the paper.

(22): R. R. Birss and M. R. Parker, "**Magnetic Separation of Diamagnetic Particles**", IEEE Transactions on Magnetics, Vol. 15, No. 6, September 1979, pp. 1523-1525.

A new aspect of magnetic separation, the capture of diamagnetic particles in high gradient magnetic filters has been reported in the above paper. It is not generally realized that, in such systems, diamagnetic as well as paramagnetic particles may be captured and that the former undertake capture trajectories causing them to be held at the surfaces of fibers in angular sectors repulsive to paramagnetic particles.

(23): D. Lewis and T. D. Wellington, "**Some Old and New Concepts in Magnetic Separation**", IEEE Transactions on Magnetics, Vol. 12, No. 5, September 1976, pp. 480-482.

Magnetic fields, or regions of a magnetic field have been termed isodynamic, katadynamic or anadynamic. Force constant in magnitude throughout an isodynamic field region has proved useful in concentrating particles according to slight differences in magnetic susceptibilities. In the katadynamic field region the highest gradients of magnetic intensity, and consequently the greatest magnetic force can be applied to a particle. The anadynamic magnetic field region, in which the force on a particle decreases in magnitude in the direction in which field intensity increases, functions in creating a magnetic barrier at which particles of low paramagnetic or diamagnetic susceptibility can be separated.

(24): A. S. Bahaj, D.C. Ellwood and J.H.P. Watson, "**Extraction of Heavy Metals Using Microorganisms and High Gradient Magnetic Separation**", IEEE Transactions on Magnetics, Vol. 27, No. 6, November 1991, pp. 5371-5374.

Many microorganisms have an affinity to ingest or precipitate ion onto their surfaces. In the case of magnetic ionic species, magnetic separation methods could be applied to remove ion-loaded organisms from the surroundings. In the above paper a wide range of metal ions were studied and the results showed that the microorganisms developed an appreciable magnetic moments which lends their removal by magnetic separation. In most cases, starting metal concentration of the order 10 ppm were reduced to 1 ppb level. This process can be applied in the mineral processing industry in addition to the treatment of effluents from the nuclear industry, in the recovery of precious metals and other industrial plants.

(25): J. Kopp, "**Superconducting Magnetic Separation**", IEEE Transactions on Magnetics, Vol. 24, No. 2, March 1988, pp. 745-748.

The initially high hopes of a speedy replacement of conventional magnetic separators by superconducting ones have not been realized. The reasons for this are complex, ranging from the conservative nature of the mineral processing industry to insufficient cryogenic reliability and poor magnet design. In the above paper the major systems delivered to industry has been described and some possible future developments have been outlined.

(25): Z. Li and J.H.P. Watson, "**Vortex Magnetic Separation**", IEEE Transactions on Magnetics, Vol. 30, No. 6, November 1994, pp. 4662-4664.

The fundamental aspects of Vortex magnetic separation has been discussed in this reference The factors such as applied magnetic field Ho, slurry velocity Vo, and matrix design, which are significant parameters in HGMS play important roles in VMS and lead to under certain conditions, high selectivity and high output.

(26): A.S. Bahaj, P.A.B. James and F.D. Moeschler, "**High Gradient Magnetic Separation of Motile and Non-Motile Magnetotactic Bacteria**", IEEE Transactions on Magnetics, Vol. 32, No. 5, September 1996, pp. 5106-5108.

Motile magnetotactic bacteria are normally separated from a solution by applying a low intensity (mT) orientating magnetic field. This constraints the bacteria to swim in

the required direction. High Gradient Magnetic Separation is well established method for the extraction of magnetic particles from solutions. The above reference has reported on the separation properties of both motile and non-motile magnetotactic bacteria using both techniques. A comparison of HGMS separation with low field orientational magnetic separation is made and the conditions under which HGMS becomes beneficial have been considered.

(27): O. P. Perez, Y. Umetsu and H. Sasaki, "**Precipitation and densification of magnetic iron compounds from aqueous solutions at room temperature**", Hydrometallurgy, Elsevier Science, Vol. 50, pp 223-242, 1998.

The feasibility of magnetite generation at ambient temperatures by a controlled aerial oxidation of starting ferrous solution has been demonstrated in ref#[16]. Moreover, the stability of the iron compounds is closely related to the established ratio of dissolved O_2/initial Fe^{2+} that would regulate the oxidant conditions of the aqueous environment. Lower precipitation pH and insufficient availability of dissolved oxygen retarded magnetite generation, favoring the stability of the voluminous intermediate green-rust II. It has been suggested that in an open-to-atmosphere precipitation system it will not be feasible to generate magnetite from very diluted concentrations of ferrous ion and under practical conditions; lower initial Fe^{2+} concentrations promoted a fast and complete oxidation of ferrous species and precipitation of amorphous ferric compounds.

(28): D. R. Kelland, "**Magnetic Separation of Nanoparticles**", IEEE Transactions on Magnetics, Vol. 34, No. 4, July 1998, pp. 2123-2125.

Magnetic particles in the nanometer size range can be captured by sufficiently large magnetic forces in competition with thermal diffusion. In the above reference the results of two types of magnetic separation, matrix and continuous, to particles in the nanometer size range have been reported. Rather than capture particles on a matrix, it is advantageous for some applications to employ a continuous method of separation. The results of the axial continuous separations showed the effectiveness of the repulsive mode of separation. It is possible to design multiple outlet separator for

specific applications by varying the number of channels, the size of the channels, the length of the separator and the shape of the magnetic wire.

(29): D. Feng, C. Aldrich and H. Tan, "**Removal of heavy metal ions by carrier magnetic separation of adsorptive particulates**", Hydrometallurgy, Elsevier Science, Vol. 56, pp 359-368, 2000.

Mining and metallurgical operations handle large volumes of process water, which are invariably contaminated with fines, chemicals, metal ions, oils and other materials. Aqueous streams containing heavy metals are frequently encountered in industrial effluents and sources of Cu, Pb, Zn and Cd are very common in the electroplating facilities, electrolytic refining plants and acid mine waters, among others. For many years, the conventional approach to the removal of heavy metals consisted of the precipitation settling of the metal hydroxide, followed by thickening of filtration of the sludge. This method suffers from several drawbacks, such as incomplete precipitation, chemical instability of the precipitates and formation of large volumes of sludge that can be difficult to filter. In the above reference the authors have studied the removal of Pb, Cu and Cd ions using magnetic filtration.

(30): H. Kumakura, T. Ohara, H. Kitaguchi, K. Togano, H. Wada, H. Mukai, K. Ohmatsu, H. Takei and H. Okada, "**Development of Bi-2223 Magnetic Separation System**", IEEE Transactions on Applied Superconductivity, Vol. 11, No. 1, March 2001, pp. 2519-2522.

The construction of a prototype of conduction cooled Bi-2223 magnet for magnetic separation system has been reported in this paper. The magnet has 200 mm room temperature bore and generated fields higher than 1 T in 11 liter room temperature space. The temperature of the magnet increased during energizing and de-energizing the magnet, however the temperature started to decrease as soon as the field became constant. The magnetic separation of α-hematite containing aquatic slurry has been tried. Almost 100% of hematite particles were successfully separated from the slurry.

(31): T. Deng, M. Prentiss and G. M. Whitesides, "**Fabrication of magnetic microfiltration systems using soft lithography**", Applied Physics Letter, Vol. 80, No. 3, pp 461-46, 21 January 2002.

In the above reference the authors have described a magnetic microfiltration system that has array of nickel posts as filtering elements. The reported magnetic filtration device is compatible with fluidic micro systems. Using magnetic filters integrated into microfluidic systems reduces the size of these systems substantially related to conventional magnetic filtration system; these integrated Microsystems also required only small quantities of sample.

(32): A. Chiba, H. Okada, T. Tada, H. Kudo, H. Nakagawa, K. Mitsuhashi, T. Ohara and H. Wada, "**Removal of Arsenic From Geothermal Water by High Gradient Magnetic Separation**", IEEE Transactions on Applied Superconductivity, Vol. 12, No. 1, March 2002, pp. 952-954.

The above reference has reported an on-site experimentation of high gradient magnetic separation for arsenic removal from geothermal water using a high-Tc superconducting magnet. To enhance the magnetic properties of the arsenic-containing particles in geothermal water, three different pretreatment methods were used: (i) the ferrite formation method; (ii) the ferric hydroxide coprecipitate method; and (iii) the modified ferric hydroxide coprecipitate method. The conditions of the HGMS were a 1.7 T applied magnetic field and 100^{o}C water at a flow rate of 10 L/min. Percentages of the arsenic-removal rates were strongly dependent on the pretreatment methods, because of a very small magnetization of the arsenic. Arsenic-removal rates of 40%, 80% and 90% were obtained by pretreatments I, ii and III respectively. Although the environmental standard for arsenic if 0.01 mg/L, corresponding to a 99% removal rate, could not be achieved in the reported experiment.

(33): H. Okada, T. Tada, A. Chiba, K. Mitshuhashi, T. Ohara and H. Wada, "**High Gradient Magnetic Separation for Weakly Magnetized Fine Particles**", IEEE Transactions on Applied Superconductivity, Vol. 12, No. 1, March 2002, pp. 967-970.

In the above reference it has been reported that High Gradient Magnetic Separation were able to effectively separate weakly magnetized particles such as hematite (Fe_2O_3) and iron hydroxide ($Fe(OH)_3$), fine particles suspended in water. Fe_2O_3 and $Fe(OH)_3$ have relatively small relative susceptibilities near 10^{-3} and average particle diameter near 1 μm.

(34): C.M.Rey, W.C. Hoffman, Jr., K. Cantrell, Y.M. Eyssa, S.W. VanSciver, D. Richards and J. Boehm, "**Design and Fabrication of an HTS Reciprocating Magnetic Separator**", IEEE Transactions on Applied Superconductivity, Vol. 12, No. 1, March 2002, pp. 971-974.

The conceptual design and fabrication details of a conduction-cooled High Temperature Superconducting (HTS) Reciprocating Magnetic Separator have been reported above Reciprocating magnetic separators are used in the purification of kaolin clay. The HTS coil is 0.3 m in length and has a 0.25 m inner diameter. The central operating magnetic field is a nominal 3.0 T with a design operating current of 126 A. In terms of combined size and magnetic field strength, this is one of the largest HTS magnets ever fabricated, possessing a stored energy > 0.1 MJ. The HTS magnet is conduction cooledvia one single-stage G-M cryocooler with a nominal operating temperature of 30 K. The HTS conduction uses a stainless steel reinforced Bi-2223 material.

(35): S. Nishijima, Y. Izumi, S. Takeda, H. Suemoto, A. Nakahira and S. Horie, "**Recycling of Abrasives from Wasted Slurry by Superconducting Magnetic Separation**", IEEE Transactions on Applied Superconductivity, Vol. 13, No. 2, June 2003, pp. 1596-1599.

In this paper a fundamental study was performed on the application of superconducting magnetic separation technique to recycle wasted slurry from the solar battery factory. It was shown the applicability of this technique to treat the wasted slurry of abrasives. The conclusions drawn from the study are:

(i) the wasted slurry contains not only nonmagnetic abrasives but also SiC abrasives. SiC abrasives can easily be recovered by magnetic separation.

(ii) The iron fragments can be easily recovered by magnetic separation.

(iii) SiC abrasives can be divided from silicon fragments using centrifugation after magnetic separation, which can lead the way for recycling the SiC abrasive wasted from solar battery factory.

(36): C. Hoffmann, M. Franzreb and W.H. Holl, "**A Novel High-Gradient Magnetic Separator (HGMS) Design for Biotech Applications**", IEEE Transactions on Applied Superconductivity, Vol. 12, No. 1, March 2002, pp. 963-966.

A novel high-gradient magnetic separator (HGMS) has been reported in the above paper to met the strong requirements of biotech process to grant high product yield, efficient cleanability and low operating costs. The novel design using a rotary permanent magnet leads to an "on-off" characteristic of the field in the separation zone. This combines the permanent magnet's advantage of low running costs with solenoid's advantage to flush the filter in place. The utilization of NdFeB magnets into the yoke allows high magnetic inductions leading to efficient and fast separation of magnetic supports used in biotech processes. The bioprocess requirement of complete particle recovery and efficient matrix cleaning after separation was achieved by the integration of an ultrasonic device.

(37): R. Gerber, "**Some aspects of the present status of HGMS**", IEEE Transactions on Magnetics, Vol. 18, No. 3, May 1982, pp. 812-816.

Usually the name HGMS (High Gradient Magnetic Separation) used for magnetic separation is derived from the fact that high gradients of the magnetic field, H, are the fundamental to this process. This is quite misleading as the magnetic traction force is not only dependent on the gradient of the magnetic field but also on the magnitude of the field, H, itself. To produce a high value of magnetic field intensity usually superconducting magnets are used. With high temperature superconductors it is possible to develop a magnetic separator with high processing rate. It is rather difficult to forecast the development of HGMS on a purely scientific level. However, the HGMS is a highly interdisciplinary technique and thus its progress can be expected to occur at the interface between applied magnetism and other disciplines. As the sizes of particles undergoing separation treatments become smaller, the surface

forces gain in prominence and must be taken adequately into account. Consequently, a more intimate involvement of colloidal ad surface chemistry with HGMS process is desirable and likely in the future. This in association with statistical mechanics, may lead to the development of ultra high gradient magnetic separation which would handle suspensions with particles of 500 $\mathring{A}$ or less in size.

(38): M.R. Parker, "**Evaluation of magnetic filter performance**", IEEE Transactions on Magnetics, Vol. 18, No. 3, May 1982, pp. 822-826.
In this paper the author has reported that in high gradient magnetic separation two mainstream lines of basic investigation have evolved. The first one has involved theoretical and experimental research on the basic mechanisms of particle build-up on individual fibers. The second deals with the overall performance of filters comprising random matrices in high magnetic fields and in particular with the phenomenon of breakthrough. The author has attempted to correlate information from these two major lines of effort. The trajectory of particle and particle build-up process is very important to understand the performance of magnetic filter.

(39): A.S.Bahaj, J.H.P. Watson and D.C.Ellwood, "**Determination of magnetic susceptibility of loaded micro-organisms in bio-magnetic separation**", IEEE Transactions on Magnetics, Vol. 25, No. 5, September 1989, pp. 3809-3811.

Bio-magnetic separators capture microbial cells on ferromagnetic wires under the influence of an externally magnetic field. These microorganisms and microbial products are highly efficient bio-accumulators of soluble and particulate forms of metals especially from dilute external concentrations. If paramagnetic ions are used, the resultant time dependent "coat" of a microorganisms make it magnetic. The strength of the magnetic susceptibility is related to the accumulated magnetic ions absorbed on the microorganism cell surfaces. The technique of biosorption is important from the point of view of industrial benefits, in the recovery of precious metals and the removal of radio-nuclides/heavy metal ions from effluents. It is of importance to magnetically characterize the microorganisms in terms of their susceptibilities because of any variation of, say, growth conditions of the microorganisms will correspond to an increase in their magnetic moment. Hence

susceptibility studies provide a clear tool in determining the rate the magnetic moment increases with time so that the necessary parameters for a practical design of the bio-magnetic separation process can be achieved.

(40): A.S. Bahaj, P.A.B. James and I.W. Croudace, "**Metal uptake and separation using magnetotactic bacteria**", IEEE Transactions on Magnetics, Vol. 30, No. 6, November 1994, pp. 4707-4709.

Usually magnetotactic bacteria align themselves with the earth's magnetic field enabling them to navigate towards their ideal environment in sediments of ponds, streams or river in which they live. By applying a low, focusing magnetic field, metal loaded magnetotactic bacteria can be forced to swim in a required direction. The above paper has discussed use of magnetotactic bacteria in low magnetic field "orientation separation". This encompasses the efficiency of various sizes of orientation separators and the effect of different metals on bacterial motility. The proposal reported in the paper is very attractive, but there are several problems which are difficult to overcome. Several common metals, notably copper and zinc inhibit bacterial motility even when present at 1 ppm concentrations.

(41): H. K. Collan, M.A. Kokkala and O.E. Toikka, "**Application of the theory of magnetic filtration in determining the optimum filter configuration**", IEEE Transactions on Magnetics, Vol. 18, No. 3, May 1982, pp. 827-832.

Although a rough idea about the applicability of magnetic filtration can be achieved when knowing the size and the magnetic properties of the particles, reliable estimates always required experiments, from which the characteristics properties of the filter can be derived. The filtration performance for a small size filter are not the same to that of a full size filter. Another important factor needing careful consideration is the fact that the properties, for instance the solid concentration, of the waste water may vary considerably in short time intervals during the on-site experiments. The quality of the treated water will change accordingly and cause large variation in the raw data. Based on the raw data only of a simple on-site experiment it is thus not easy to determine the best filter matrix configuration or the optimal filter size.

(42): M. R. Parker, "**Magnetic filtration by a current-carrying wire matrix**", IEEE Transactions on Magnetics, Vol. 17, No. 6, November 1981, pp. 2816-2818.

Magnetic field created by a current-carrying conductor can be used to capture magnetic particle. In the above paper the author has investigated the mechanisms of magnetic particle capture by current-carrying conductor. Mathematical equation describing particle trajectories in the vicinity of cylindrical conductors in terms of an amperian magnetic velocity are derived. The schematic representation of current-carrying wire matrix is shown in figure 1.3. It has been shown in the paper that it is possible to construct practical filters from current carrying wire matrices. These would be low gradient devices and would operate on slurries or suspensions containing particles of high susceptibility. Nevertheless these are inherently low-cost devices and could be made of any desired length, since the flow resistance is negligible and since so consideration need to be given to the question of efficient flux return of an external magnet. It has also been shown in the paper that high pulsed electrical currents in wire matrices could aid significantly the flocculation and sedimentation of colloidal magnetic suspensions.

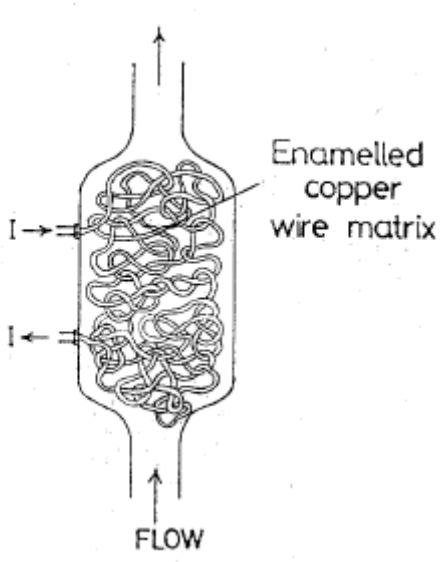


Figure 1.3: Random current-carrying wire matrix [42]

(43): O. P. Perez, Y. Umetsu and H. Sasaki, "**Precipitation and densification of magnetic iron compounds from aqueous solutions at room temperature**", International journal on Hydrometallurgy, Elsevier, Vol. 50, pp. 223-242, 1998.

To generate a precipitate containing target elements, the technical proposal should consider a high efficiency of ions removal, suitable physical characteristics to make easier the solid-liquid separation and an appropriate chemical stability for solid disposal without any direct or potential damage to the ecosystems.

(44): C.M. Rey, W.C.Hoffman, Jr. K. Cantrell, Y. M. Eyssa, S. W. VanSciver, D. Richards and J. Boehm, "**Design and fabrication of an HTS reciprocating magnetic separator**", IEEE Transactions on Applied Superconductivity, Vol. 12, No. 1, March 2002, pp. 963-966.
The design of a magnetic separator based on HTS coils of length 0.3 m and an inner diameter of 0.25 m is reported. The HTS conductor uses a stainless steel reinforced Bi-2223 material. The central operating magnetic flux density is 3.0 T with a design current of 126 A. The reciprocating magnetic separators are used in the purification of kaolin clay.

(45): R. R. Oder, "**Magnetic separation of lunar soils**", IEEE Transactions on Magnetics, Vol. 27, No. 6, November 1991, pp. 5367-5370.

The above paper has reported measurement results of the distribution of lithic, mineral and fused soil components magnetically separated from the minus 1 mm size fractions of five lunar soils.

(46): J.Y. Hwang, G. Kellerud, M. Takayasu, F.J. Friedlaender and P.C. Wankat, "**Selective seeding for magnetic separation**", IEEE Transactions on Magnetics, Vol. 18, No. 6, November 1982, pp. 1689-1691.

In magnetic separation direct application of magnetic field is not very successful. The above paper has investigated the potential of an indirect method, that of selective seeding. Selective seeding utilizes surface chemistry to bond a desired mineral or minerals to ferromagnetic seeds. The experiments reported in the paper demonstrate the viability of the selective seeding method. In the mixture of $Al(OH)_3$ – SiO_2, $Al(OH)_3$ was selectively flocculated with the introduced Fe_3O_4 (magnetite) seeds and then removed by magnetic separation. Fe_3O_4, the carrier, was recovered for reuse.

(47): M. Takayasu, R. Gerber and F. J. Friedlaender, "**Magnetic separation of submicron particles**", IEEE Transactions on Magnetics, Vol. 19, No. 5, September 1983, pp. 2112-2114.

The authors have studied the application of high gradient magnetic separator to capture sub-micron sized particles. The relevance of the critical particle size to the phenomena of dynamic and static capture has been discussed for various materials ranging from ferromagnetic to diamagnetic. The steady state solution of the diffusion equation was used to discuss the high gradient magnetic separation of submicron particles. The buildup of submicron particles consists of two regions: one is formed by a continuous distribution of the particle concentration and the other region is established by the "saturation" of the collected particle distribution (i.e., some upper limit of the particle concentration is reached). In the former region the particles are captured dynamically as a cloud. On the other hand, in the latter region the particles form a static buildup surrounded by the dynamic buildup.

(48): J.N.M. Agricola, J.L.Top and A.F.Fort, "**Magnetic separation of weakly magnetic copper minerals**", IEEE Transactions on Magnetics, Vol. 21, No. 5, September 1985, pp. 2065-2068.

Using high gradient magnetic separator bornite and chalcopyrite can both be easily separated from a concentrate. The obtained recoveries indicate that for smaller particles the magnetic field should be higher. The recoveries of bornite and chalcopyrite in the tailings and ore are lower. This is due to the intergrowth of these minerals with gauge and other minerals. These results reported in the paper indicate that bornite and chalcopyrite can be separated from a low grade ore provided all mineral particles are free. Care has to be taken to avoid mechanical trapping and clogging of nonmagnetic minerals. The clogging of the bigger particles can be reduced by using a less dense steelwool matrix. The mechanical trapping can be reduced by using higher slurry and flushing flow velocities, but then the magnetic background field would have to be increased as well.

(49): J.H.P. Watson and A.S. Bahaj, "**Vortex capture in high gradient magnetic separators at moderate Reynolds number"**, IEEE Transactions on Magnetics, Vol. 25, No. 5, September 1989, pp. 3803-3805.

1.5 Objective of our research

In this research we have studied the different techniques used fro purifying water, emphasizing the use of magnetic filtration. The initial objective was to investigate the system used by Technical Water Systems to clean waste water and explain the operation scientifically.

The objective of this project will be to find out whether this method should become the benchmark to be used by all people who treat water. In practice the machinery needed to process the water by this method is about 50% cheaper for capital and 75% cheaper for operating cost than conventional methods at present. The rationale for the project is to find a new innovative, cheaper and better alternative to the waste problems that are facing all of New Zealand.

1.7 Organization of the thesis

This thesis is organized into eight chapters. After the general introduction in chapter 1, chapter 2 describes the conventional methods used of water purification. The principles of water purification using magnetic field is described in chapter 3. Chapter 4 describes the overview of Technical water systems (TWS) and some of the application of TWS system. The finite element model formulation for the characterization of all the orientation of the magnetic circle configuration is described in chapter 5. Some of the experiments conducted are described in chapter 6. Chapter 7 describes the sensors and the sensor networks used in water quality monitoring. Finally the work is concluded in chapter 8.

CHAPTER 2
CONVENTIONAL METHOD OF WATER PURIFICATION

2.1 Introduction

In this chapter the conventional methods used for water purification are described. Water purification is the process of removing contaminants from a raw water source, the goal is to produce water for a specific purpose with a treatment profile designed to limit the inclusion of specific materials most water is purified for human consumption drinking water. Water purification may also be designed for a variety of other purposes and water purified to meet the requirements of medical, pharmacology, chemical and industrial applications. There are different methods to clean or purify water.

2.2 Conventional Method

The methods of purifying water following the conventional way are described.

2.2.1 Screens and settling

There is always possibility of water gets contaminated with many dirt particles, the major contaminants in the environment are living organisms, soil and dead vegetation. This can be a big problem if there are frequent floods in that area. It is possible to clean water significantly simply by filtration, screens the water moves through, as well as by settling. There is a relationship of cleanliness of water with the speed of the water as which it moves through. If water moves very quickly, dirt also gets carried away with water. When the water slows down, the effects of gravity on the higher density contaminants become predominant and the heavy dirt particles just drop out. Due to this reason the reservoir behind dams are filled out with incoming water first.

2.2.2 Activated charcoal / carbon

Dirty water can be purified using activated charcoal or carbon and it relies on a principle called adsorption. The carbon used in this process is specially manufactured to have a large surface area. Usually activated charcoal consists of lots of loosely packed carbon filaments, so that 1 g of material has a surface area of hundreds of

square meter. When water with contaminants flows through the matrix of carbon filaments, there is a high probability that the contaminants, lead, mercury, chemicals, etc., come in contact with the surface of the carbon. The intermolecular forces between the surface and these contaminants are stronger than the force on the contaminants by the water molecules moving, so the contaminants tend to stick to the surface of the carbon. After a lot of use, enough of the surface is covered by contaminants that the filter ceases to be effective. Indeed, in some circumstances excessive use, with degradation of the filter material, can lead to the filter releasing some of the contaminants trapped earlier.

2.2.3 Distillation

If solution of water mixed with various contaminants is heated up, the various components of the solution will boil at different temperatures. Volatile organics boil off at lower temperatures and then water boils off. Solute materials that would be solid up to the boiling point of water are left behind. Cellular contaminants like bacteria are likely killed in the boiling process. So by capturing only the material boiled off near 100 ^{o}C, it is possible to obtain pure water. In practice, the purification is good but not absolute. The temperature throughout the solution is not entirely uniform, and, in addition to boiling off individual molecules of water, some water vapour can boil off with trapped contaminants. Also, due to the temperature distribution one is still boiling off the “volatiles” when the water starts boiling off, and simple system usually lack the ability to exhaust the volatiles to air. Thus, these systems often put the distilled water through an activated charcoal filter to trap any volatiles, and further are set to stop before fulling boiling all the water, to keep the heaviest elements trapped. This method has the benefit that it is relatively cheap to implement in poor areas with lots of solar power. Essentially all that is needed is a clear oven heated by the sun, a panel above for the water to condense on and then run down into a clean water trap.

2.2.4 Chemicals

Certain chemicals are often added to water as disinfectants. Chlorine is common in pools and in smaller quantities in tap water, due to its anti-bacterial effects. Iodine pills provide a similar portable function.

2.2.5 Ion exchange

Ion exchange is widely used in laboratories for providing purified water on demand. Laboratory deionizers invariably incorporate mixed-bed cartridges of ion exchange resins that are either returned to a regeneration station for recharging when they become exhausted, or else discarded. ELGA pioneered the concept of collective regeneration of ion exchange resins, and its regeneration stations are some of the largest in the world.

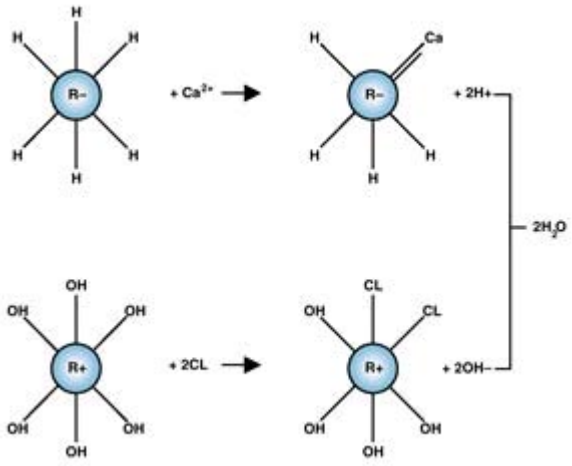


Figure 2.1: Anions and cations in the feedwater are removed by the ion exchange resins and are replaced by hydrogen and hydroxyl ions from the resin. The hydrogen and hydroxyl ions combine to form water molecules.

Ion exchange functions by exchanging hydrogen ions for cationic contaminants and hydroxyl ions for anionic contaminants in the feedwater. The ion exchange resin beds are made up of tiny spherically shaped beads through which the feedwater passes. After a period of time, cations and anions will have replaced most of the active hydrogen and hydroxyl sites in the resins and the cartridges will need to be replaced or regenerated.

Benefits of ion exchange

Ion exchange has many advantages over distillation for the production of purified water. First of all, it is an on-demand process; the water is available when it is needed.

Secondly, when using high purity resin materials, effectively all the ionic material will be removed from the water to give a maximum resistivity of 18.2 MΩ-cm (at 25ºC). Tiny fragments of the ion exchange resin materials can be washed out of the cartridge by the water passing through it. Therefore, ion exchange should be used in conjunction with filters if particle-free water is required. As bacteria will grow rapidly in stagnant water, the cartridges may become contaminated if they are not regularly used. The problem is alleviated by frequent recirculation of the water to inhibit bacterial build up and by regular replacement or regeneration of the resins, since regenerant chemicals are powerful disinfectants.

Ion exchange will only remove polar organic compounds from the water and dissolved organics can foul the ion exchange beads, decreasing their capacity. Where organically and inorganically pure water is needed, the combination of reverse osmosis followed by ion exchange is particularly effective.

There have been many attempts to overcome some of the limitations of ion exchange and distillation. In some systems distillation has preceded ion exchange - the cartridges last much longer, but the problem of bacteria remains. In some others, ion exchange has preceded distillation - but then the problems of storage and not having water on demand remain.

2.2.6 Electrode ionization

Electrode ionization (EDI) is a purification process that is electrically driven and features a combination of ion exchange resin and ion-selective membranes. EDI, which is normally coupled with reverse osmosis, provides a useful alternative to other purification methods. It provides laboratory reagent water at high volumes without the need for deionization cartridges. This approach avoids the decrease in product water quality associated with cartridges as they become exhausted as well as the associated cartridge replacement costs.

EDI has evolved from electrodialysis (ED). The principle of ED is that water is purified in a cell containing two types of ion selective membranes - cation-permeable and anion-permeable - placed between a pair of electrodes. When a direct electric potential is applied across the cell, the cations in the water are drawn towards the

negatively charged cathode and the anions are drawn towards the positively charged anode. The cations can pass through the cation-permeable membrane, but not through the anionic one. Likewise, the anions can pass through the anion-permeable membrane, but not through the cationic one. The net result is the movement of ions between chambers and the water in one section can become deionized while that in another section becomes concentrated.

In practice, ED can only be used economically to produce water of relatively high conductivity (200 µS/cm or more) because of the prohibitively high electrical voltages required to drive ions through water of increasingly high purity.

This problem is overcome in EDI technology by filling the spaces between the membranes with ion exchange resins. The resins provide a conductive flow path for the migration of ions, enabling deionization to be virtually complete and resulting in the production of high-purity water. A further benefit of EDI is that the continuous electrolysis of water occurring in the cell produces hydrogen and hydroxyl ions. These ions maintain the resins in a highly regenerated state, thereby avoiding the need for chemical reactivation. The resins used in EDI systems can either be separate chambers of anion or cation beads, layers of each type within a single chamber or an intimate mixture of cation and anion beads.

Some EDI systems incorporate mixed resin beds in a plurality of narrow cells. This is particularly effective in large-scale plants for pharmaceutical and other applications. Veolia Water Systems, ELGA's parent company, is the leading supplier of a wide range of CDI technologies which address these larger scale applications.

ELGA's ADEPT (Advanced Deionization by Electrical Purification Technology) process utilizes separate beds of cation and anion resins as well as a bed of intimately mixed resins. The separate beds of cation and anion resins are housed in wide cells that provide a flow path for the ions in transit. This offers advantages in the flexibility of design and mechanical simplicity on a laboratory scale. The relatively high volume of resin in the cells provides a buffer against changes in feedwater quality. The quality of water produced is then further enhanced by a mixed resin bed.

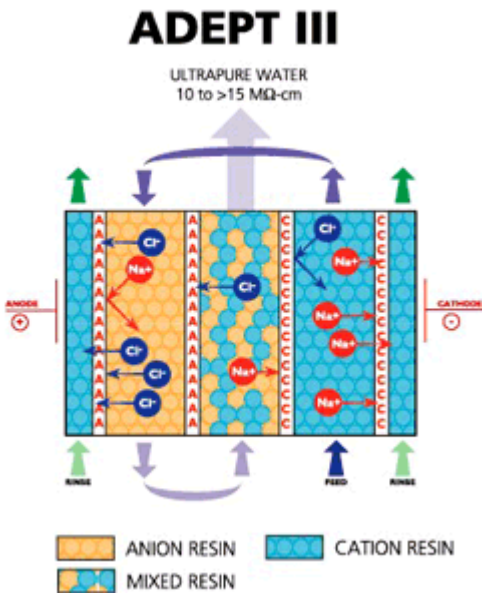


Figure 2.2: Diagram of

The multiple-pass process in which feedwater pre-purified by reverse osmosis flows through a cation exchange bed, an anion exchange bed and a bed of mixed resin is analogous to many large scale high purity water purification systems.

Typically, the product water has a resistivity of 10-18 MΩ-cm (at 25°C) and a total organic carbon content below 20 ppb. Bacterial levels are minimized because the chemical and electrical conditions within the system inhibit the growth of micro-organisms.

EDI very effectively complements reverse osmosis. RO is a pressure-driven process in which the water is stripped of its contaminants as it passes through the membrane. It does not however remove all the ionic species and cannot remove dissolved species such as carbon dioxide. EDI can remove carbon dioxide as well as other weakly ionizable species, such as silica, by ionizing them and moving them through the membrane.

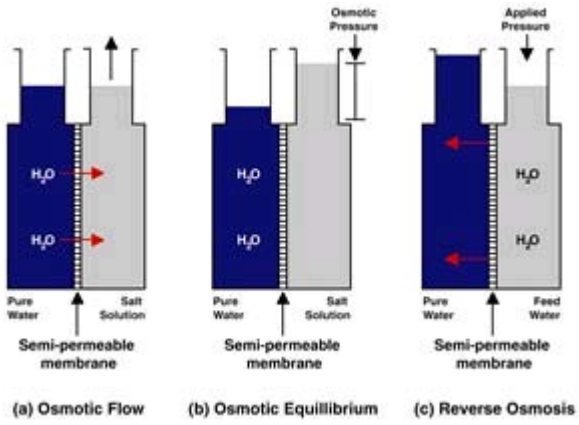


Figure 2.3:

2.2.7 Solar radiation

Bacteria can also be killed by UV radiation. UV is high energy protons that can disrupts most chemical bonds, leading to malfunction in the cells and subsequent death.

2.2.8 Reverse osmosis

Reverse osmosis (RO) is a process that overcomes many of the shortcomings of distillation and ion exchange. To explain reverse osmosis let us first look at osmosis. This is a natural process, which occurs whenever a dilute solution is separated from a concentrated solution by a semi-permeable membrane. Water, driven by a force caused by the concentration difference - the osmotic pressure - passes through the membrane into the concentrated solution. The flow of water continues until the concentrated solution is diluted and back pressure prevents any further flow through the membrane (osmotic equilibrium).

If a pressure greater than the osmotic pressure is applied to the higher concentration side of the membrane, the normal direction of osmotic flow is reversed, pure water passes through the membrane from the concentrated solution and is thus separated from its contaminants. This is the basic principle of reverse osmosis (sometimes call hyper-filtration).

In practice, feedwater is pumped into a pressure vessel containing a spiral or set of hollow fibers of semi-permeable membranes. The purified water passes through the

membrane to form the 'permeate'. The contaminants accumulate in the residual water, called the 'concentrate', which is bled continuously to drain. The latest generation of polyamide thin film composite reverse osmosis membranes which have replaced early cellulosic membranes, remove 95-98% of inorganic ions, together with virtually all the large non-ionic contaminants and organic molecules with a molecular weight greater than 100. Dissolved gases are not removed. Thin-film composite membranes are used in all ELGA's laboratory reverse osmosis equipment.

Due to this exceptional purifying efficiency, reverse osmosis is a very cost-effective technology for a water purification system. However, it is limited by the relatively slow rate of production and is, therefore, normally used to fill a reservoir prior to use or further purification. Reverse osmosis tends to protect the system from bacteria and pyrogens. It is often combined with ion exchange to considerably improve product water quality.

2.2 Waste Water Project – PNCC – A case Study

Every city council in New Zealand have got some arrangement on treating water, either for drinking, waste, sewage etc. I came across about the waste water project of Palmerston North City council. The web page is http://www.pncc.govt.nz/Council/Projects/WasteWater.htm. Most of the materials for this section has been taken from their web page. The aim of this section is to provide an overview of the methods used by the council and the amount of finance required for this job.

The PN City Council is currently implementing a $11.8M wastewater treatment plant upgrade project to meet new discharge consent standards. Stage One was opened on 23 September 2004.

In June 2003 the Council gained a 25 year consent for discharging treated wastewater to the Manawatu River in the vicinity of the Totara Road Treatment Plant. The present treatment of wastewater is to a **high standard and meets current consent conditions**. However, further treatment improvements are being made to meet future requirements as follows:

1. To meet the higher environmental standards set in the consent to the timeframe required.
An Ultra Violet irradiation plant to disinfect the wastewater by November 2004
A phosphorus removal facility to reduce the dissolved phosphorus discharged to the river by November 2007.

2. Additional features that are part of the project as a result of consultation with the community and iwi.
A wetland pond and land passage,
A new outfall structure.

3. Capacity upgrade of the existing facility to cope with the additional loadings from growth of the city.

The project is being implemented in two stages:

Stage One to be completed by November 2004 at a cost of **$4.5M** includes:
Ultra Violet Irradiation plant to disinfect the wastewater
A new outfall structure
A wetland pond and land passage

Stage Two to be completed by November 2007 at a cost of **$7.3M** includes:
Phosphorus removal facility,
Sludge process improvements,
Capacity improvements.

The Palmerston North City Council manages the project with technical and design services provided by the PNCC City Enterprises Unit and Montgomery Watson Harza Ltd (MWH).

2.2.1 Wetland pond

This pond is now in operation. There has been an initial planting of flaxes with other wet water plants to be added later on in the year.

This pond will provide useful storage capacity when the gate to the river needs to be closed due to high river levels. The wastewater enters the pond by trickling over a rock filter.

The Council will monitor the effectiveness of this in reducing ammonia levels.

Figure 2.4: Waster water treatment plant project by PN City Council

Figure 2.5: Wetland pond

2.2.2 Outfall structure

Six pipes spread the discharge to the river through a 50 m length of rock embankment. This provides improved aesthetics and better mixing with the river than the previous single point discharge.

This structure is now operational with minor tidying up work still to be done.

Tararua Roading Ltd constructed the outfall.

Figure 2.6: Outfall structure

2.2.3 UV Facility - Building & Channel

The Ultra Violet radiation facility consists of a concrete channel in which banks of UV light tubes are mounted. As the flow passes these tubes the wastewater is disinfected. Adjacent to UV channel is a building that houses the control equipment and emergency generator. This facility is due to become fully operational from November 2004.

Wedeco New Zealand Ltd has supplied the UV equipment. The civil works contract is let to Mainzeal Property and Construction Ltd.

Figure 2.6: UV Control Building

Figure 2.7: UV Channel

2.3 WasteWater Quality Standards

Table 2.1 summarizes and compares EPA drinking water standards, USP pharmaceutical water standards, and suggested standards for laboratory animal drinking water. The asterisk * indicates that the limit is the same as the EPA Primary Standard MCL. Other symbols and abbreviations are defined at the end of the table

2.4 WasteWater Treatment Processes

Below is an outline of the wastewater treatment process. Each step of the process has a number which refers to the wastewater schematic.

2.4.1 Screening

As the wastewater enters the treatment plant three coarse screens collect debris such as rags, plastics, and larger solids. The screenings go to the landfill. The flow is then pumped up to the pre-aeration tank for grit removal.

2.4.2 Pre-aeration Grit Removal

Air is pumped into the pre-aeration tank where grit falls out of suspension into a collection hopper. After dewatering, grit from the pre-aeration tank is buried in the landfill.

Table 2.1: Water Quality Standards (mg/l unless other units given).

Contaminant	EPA Standards (as of 10/96)		USP 23 (as of 11/96)		Animal Drinking Water
Primary MCL (1)	MCLG (2)	Secondary MCL (3)		Purified Water	WFI
Organic Contaminants	0.4	0.4	*	*	*
Adipate (diethylhexyl)	0.002	zero	*	*	*
Alachor	0.007	0.007	*	*	*
Aldicarb	0.007	0.007	*	*	*
Aldicarb sulfone	0.007	0.007	*	*	*
Aldicarb sulfoxide	0.003	0.003	*	*	*
Atrazine	0.005	zero	*	*	*
Benzene	0.0002	zero	*	*	*
Benzo(a)pyrene (PAH)	0.04	0.04	*	*	*
Carbofuran	0.005	zero	*	*	*
Carbon Tetrachloride	0.002	zero	*	*	*
Chlordane	0.07	0.07	*	*	*
2,4-D	0.0002	zero	*	*	*
Dibromochloropropane (DBCP)	0.075	0.075	*	*	*
p-Dichlorobenzene	0.6	0.6	*	*	*
o-, m-Dichlorobenzene	0.005	zero	*	*	*
1,2-Dichloroethane	0.007	0.007	*	*	*
1,1-Dichloroethyene	0.07	0.07	*	*	*
cis-1,2-Dichloroethylene	0.1	0.1	*	*	*
trans-1,2-Dichloroethylene	0.005	zero	*	*	*
1,2-Dichloropropane	0.006	zero	*	*	*
Di(2-ethylhexyl)phthalate (PAE)	0.007	0.007	*	*	*
Dinoseb	0.02	0.02	*	*	*
Diquat	0.1	0.1	*	*	*
Endothall	0.002	0.002	*	*	*
Endrin	0.7	0.7	*	*	*
Ethylbenzene	0.00005	zero	*	*	*
Ethylene dibromide	0.7	0.7	*	*	*
Glyphosate	0.0004	zero	*	*	*
Heptachlor	0.0002	zero	*	*	*
Heptachlor epoxide	0.001	zero	*	*	*
Hexachlorobenzene	0.05	0.05	*	*	*
Hexachlorocyclopentadiene	0.0002	0.0002	*	*	*
Lindane	0.04	0.04	*	*	*
Methoxychlor	0.1	0.1	*	*	*
Monochlorobenzene	0.2	0.2	*	*	*
Oxamyl (Vydate)	0.001	zero	*	*	*
Pentachlorophenol	0.5	0.5	*	*	*
Picloram	0.0005	zero	*	*	*
Polychlorinated biphenyls (PCBs)	0.004	0.004	*	*	*
Simazine	0.1	0.1	*	*	*
Styrene	0.005	zero	*	*	*
Tetrachloroethylene	1.0	1.0	*	*	*
Toluene	0.003	zero	*	*	*
Toxaphene	0.05	0.05	*	*	*
2,4,5-TP Silvex	0.07	0.07	*	*	*
Trichlorobenzene (1,2,4-)	0.2	0.2	*	*	*
1,1,1-Trichloroethane	0.005	0.003	*	*	*
1,1,2-Trichloroethane	0.005	zero	*	*	*
Trichloroethylene	0.002	zero	*	*	*
Vinyl chloride	10	10	*	*	*
Xylenes	0.10	zero	*	*	*
Total trihalomethanes			0.05	0.05	*
Total Organic Carbon (TOC)					

Contaminant				Animal Drinking Water		
Primary MCL (1)	MCLG (2)	Secondary MCL (3)		Purified Water		WFI
Inorganic Contaminants	0.006	0.006	1.0	*	*	*
Antimony	0.05	-	2.0	*	*	*
Arsenic	7 MFL	7 MFL	0.05	*	*	*
Asbestos	2	2	to 0.2	*	*	*
Barium	0.004	0.004	250	*	*	*
Beryllium	0.005	0.005	0.3	*	*	*
Cadmium	0.1	0.1	0.05	*	*	*
Chromium	1.3	1.3	6.5-	*	*	*
Copper	0.2	0.2	8.5	*	*	*
Cyanide	4.0	4	0.1	*	*	*
Fluoride	0.015	zero	250	*	*	*
Lead	0.002	0.002	500	*	*	*
Mercury	0.1	0.1	5.0	*	*	*
Nickel	10.0	10.0		*	*	*
Nitrate (as N)	1.0	1.0		*	*	*
Nitrite (as N)	0.05	0.05		*	*	*
Selenium	0.002	0.0005		*	*	*
Thallium				(4)	(4)	6.5-8.5 (brass)
Aluminum				5.7-7.0	5.7-7.0	2.5-8.5 (ss/plastic)
Chloride				(4)	(4)	
Iron				(4)	(4)	
Manganese				(4)	(4)	
pH				(4)	(4)	
Silver				(4)	(4)	
Sulfates				4.7-5.8 µS/cm (depending on pH)	4.7-5.8 µS/cm (depending on pH)	
Total dissolved solids (TDS)						
Zinc						
Ammonia						
Calcium						
Heavy Metals						
Conductivity						
Radionuclides	15 pCi/L	++		*	*	*
Gross alpha particle activity	4	++		*	*	*
Beta particle and photon activity	mrem/yr	++		*	*	*
Radium 226 and 228 (total)	5 pCi/L					
Microbiological Contaminants	<1/100 mL	zero		*	*	*
Coliforms (total)	TT	zero		100 cfu/mL**	10 cfu/100 mL**	TT
Giardia lamblia	TT	NA			. 0.25 EU/mL	100 cfu/mL **
Heterotrophic Plate Count	TT	zero				1 cfu/mL**
Legionella	0.5-1.0 NTU	NA				*
Pseudomonas sp.	TT	zero				TT
Pyrogens						
Turbidity						
Viruses						

Figure 2.9: Pre-aeration Grit Removal

2.4.3 Sedimentation

Three 40 metre long sedimentation tanks allow heavy solids to settle to the bottom and fats, oils and greases to rise to the top. Bottom scrapers collect the solids into hoppers from which the solids are pumped to sludge digestors. Water sprays move the surface material to skimmers. This material is also fed to the sludge digestors. It takes the flow approximately an hour to pass through this tank. About 90% of solid matter is removed at this point. The flow then passes to the aerated lagoons.

Figure 2.10: Sedimentation tank

2.4.4 Aerated lagoons

Two aerated lagoons are used to breakdown organic material remaining after the primary sedimentation treatment. Air is pumped into the lagoons by large paddle

aerators to provide oxygen to help microbiological organisms grow and consume the organic material. It takes the wastewater about 4 days to pass through these lagoons before going through the UV channel for disinfection and discharge to the river.

Figure 2.11: Aerated lagoons

2.4.5 Phosphorus Removal

A new facility will be constructed by November 2007 between the aerated lagoon and the UV disinfection channel to reduce the dissolved phosphorus in the wastewater. This will be achieved by adding the chemical alum to the wastewater to make dissolved phosphorus settle out as a sludge. This removal facility will be used during times of low river flow when high phosphorus levels can cause algal growth in the river.

2.4.6 UV Disinfection

An Ultra Violet irradiation facility that disinfects wastewater will become operational by November 2004. Banks of ultra violet lamps mounted in the wastewater channels emit light of a wavelength that kills 99.9% of bacteria as the wastewater flows past.

Figure 2.12: Ultra Violet irradiation facility

2.4.7 Wetland Pond and Land Passage

The discharge to the river is diverted through a Wetland Pond and Land Passage. This facility has a dual role. It meets some cultural concerns of iwi by allowing the wastewater to pass through mother earth before entering the river. The pond also has an operational function of being able to store wastewater when the gates to the river are closed because of high river levels. In addition the flow into the pond trickles over a long rock filter, which is designed to reduce the level of ammonia in the discharge.

Figure 2.13: Wetland pond

2.4.8 Outfall Structure

The treated wastewater is discharged to the river through an outfall structure that distributes the flow along 50m of rock embankment. This provides a better and more aesthetic interface with the river than the previous point discharge structure. It also helps better mixing.

Figure 2.14: Outfall structure

2.4.9 Sludge Digesters

Sludge is held in digesters for around 20 days at 35 ^{o}C to allow anaerobic breakdown to produce a more stable and more easily dewatered material. Gas from the breakdown is used for heating at the plant with excess gas being flared. Digested sludge is discharged into sludge lagoons where it is kept for about 5 years. The sludge is then safe for use at the landfill.

Figure 2.15: Sludge digester

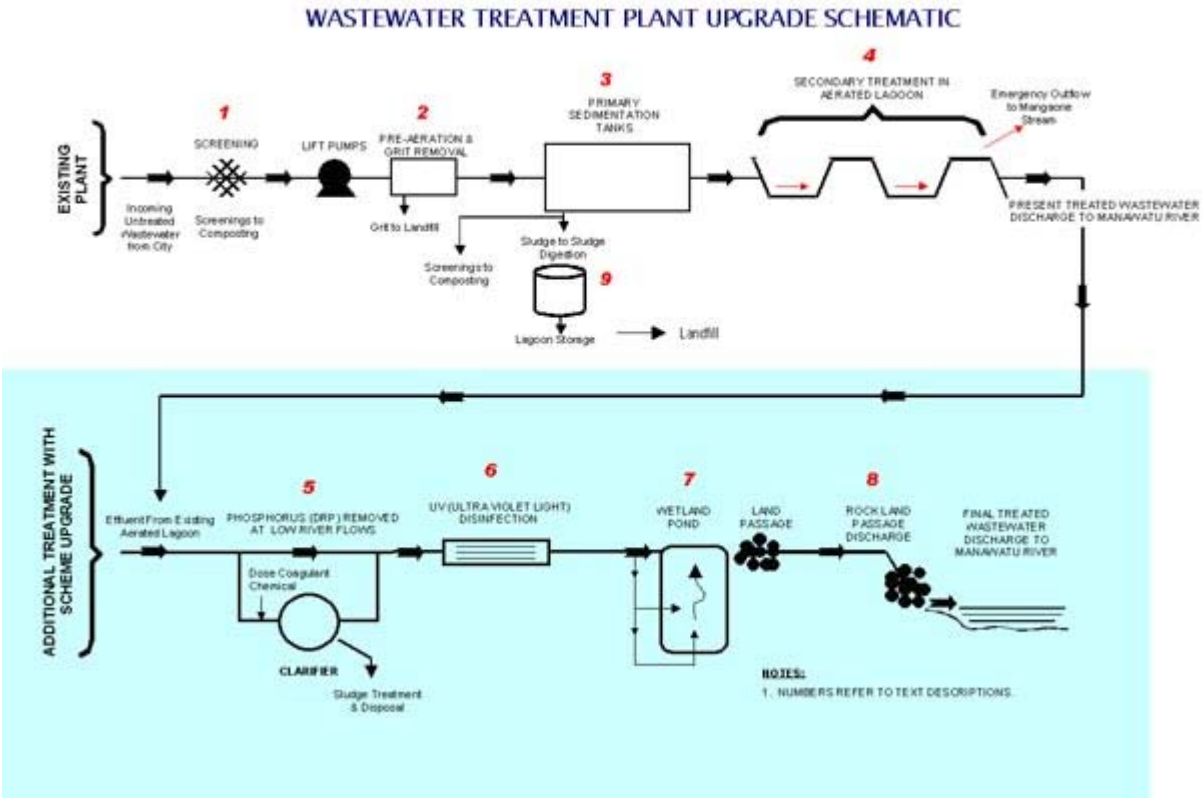


Figure 2.16: Waste water treatment schematic diagram of PNCC

2.5 Conclusions

In this chapter the conventional methods of water purification have been described. I has been seen the conventional method is quite complicated, needs considerable space and time, and quite expensive. So there is a real need of developing new methods for water purification. We will investigate how magnetic fields can be used to purify water.

CHAPTER 3

PRICIPLE OF MAGNETIC SEPARATION OR FILTRATION

3.1 Introduction

Magnetic separation or filtration means filter out undesired elements from given system using magnetic field. For example filter out contaminants mixed in water to purify water.

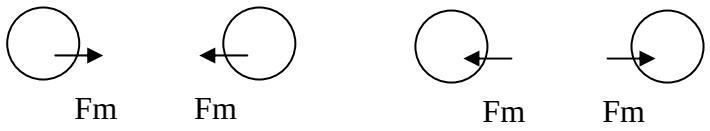
One method which is very commonly used now-a-days in USA, Japan, Europe and many other countries, is to treat water by using magnetic filtration. The magnetic filtration method usually makes use of supported surface complex adsorbent such as natural magnetite (FeO, Fe2O3) in a fixed bed mode. Due to its ferromagnetic property, magnetite can be used not only as an adsorbent for removing toxic metals from water solution, but also as a magnetically energizable element for attracting and retaining paramagnetic nanoparticles, thus removing from water solution. Ferrite is a generic term for a class of magnetic iron oxide compounds. Ferrite posses the property of spontaneous magnetization and are crystalline materials soluble only in strong acid. Iron atoms in iron ferrite (FeO, Fe2O3) can be replaced by many other metals ions without seriously altering its spinal structure. The use of iron ferrite and magnetite in wastewater treatment has a number of advantages over conventional flocculent precipitation techniques for metal ion removal. Ferrite solids are crystalline materials, unlike hydroscopic metal hydroxide sludge, and can be more readily filtered; and their ferromagnetic character permits use of magnetic separation of the solids from solution. A wide variety of metal ion impurities can be effectively removed in one treatment step, and their removal is not seriously affected by high salt concentrations. The ferrite does not require expensive chemicals and since iron is usually a constituent of waste solutions, its oxidation states can be adjusted by chemical or electrolytic means to form waste.

3.2 Forces Operating Principle of Magnetic Filtration

The forces are dependent on both the nature of the feed to be separated as well as the character of the separation device. A simple theory of magnetic separation which accounts for the general relationship between these parameters will be explained in

this section. It will also be shown how the magnetic force in a separator may be maximized by matching the magnetic field gradient to the particle size.

The magnetic force – attractive or repulsive (figure 3.1) – along a given direction on a small particle of a non-ferromagnetic material immersed in a magnetic field is given by



(a) Unlike polarity (b) Like polarity

Figure 3.1: Magnetic force on two magnetized particles

$\overline{F}_m = The\ Magnetic\ traction\ \ force\ acting\ on\ a\ small\ \ particle$

$$\overline{F}_m = \mathrm{X} * V_p * M_p * grad(H) \qquad [3.1]$$

X – Volume susceptibility of the particle

V – Volume of small body

$$grad(H) = \frac{\partial H}{\partial x} a_x + \frac{\partial H}{\partial y} a_y + \frac{\partial H}{\partial z} a_z \qquad [3.2]$$

$$M_p = X_v * H$$
$$X_v = Volume\ susceptibility \qquad [3.3]$$

$$X \approx X_p - X_m$$
$$The\ diffrence\ between\ susceptibility\ of\ \ the\ particle \qquad [3.4]$$

It is clear that magnetic force (equation 3.1) depends on the both magnetic field H and the gradient of the field over the particle volume. In equation 3.3 M_p represents the average dipole moment of the particle. The units of M are amperes per meter. Magnetization vector is related to the magnetic field B in the material in the simple manner given by equation 3.5.

$$M = \frac{X_m}{1 + X_m} B \qquad [3.5]$$

Where X_m a dimensionless parameter, is known as the magnetic susceptibility. The quantity X_m is a measure of the ability of the material to become magnetized and differs from one magnetic material to another.

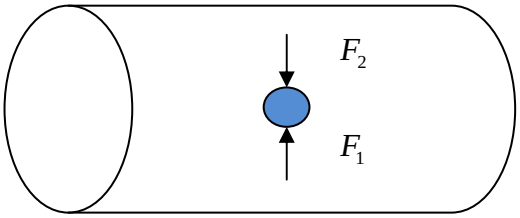


Figure 3.2: Representing the buoyant force and the weight

$$F_1 = Upward\ \ force = V * \rho * g$$
$$\rho = Density\ of\ \ air\ or\ water \qquad [3.6]$$

$$F_2 = Downward\ \ force(weight) = mg \qquad [3.7]$$

This upward force is called the buoyant force, and all fluids apply such a force to objects that are immersed in them. The buoyant force exists because fluid pressure is larger at greater depths.

No matter what is the shape of the object the buoyant force pushes it upward in accord to Archimedes' principle. Archimedes' principle state that any fluid applies a buoyant force to an object that is partially or completely immersed in a fluid the magnitude of the buoyant force equals the weight of the fluid that objects displaces. Due to the gravity weight of the particle italic is acting on the particle (equation 3.7).

$$\underbrace{F_B}_{\text{Magnitude of buoyant force}} = \underbrace{W_{Fluid}}_{\text{Weight of displaced fluid}} \qquad [3.8]$$

In an ideal fluid there is no viscosity to hinder the fluid layers as they slide past one another within a pipe of uniform cross section. Every layer of an ideal fluid moves with the same velocity. When viscosity is present the fluid layers have different velocities. The fluid at the center of the pipe has the greatest velocity and the fluid layer next to the wall surface does not move at all because it is held tightly by intermolecular forces. The magnitude of the tangential force F required to move a fluid layer is given in equation 3.9.

$$\bar{u}_{ext} = \frac{\bar{F}}{6\pi\eta r}$$
$$u_{ext} = external\ velocity$$
$$r\ is\ the\ particle\ radius \qquad [3.9]$$
$$\eta\ is\ the\ dynamic\ vis\cos ity$$

Flow velocity of the particles can be represented by equation 3.10.

$$v = \frac{2*r^2 * g(d_1 - d_2)}{9*c} \quad [3.10]$$

r = the radius of a sphere in cm

d_1 = the density of the sphere in g/cm3

d_1 = the density of the fluid in g/cm3

g = the local gravitational acceleration in cm/S2

c = the Viscosity of the fluid in Poise

v = the terminal velocity in cm/S

3.2.1 Vortex

A vortex can be any circular or rotary flow that possesses vorticity. Vorticity is a mathematical concept used in fluid dynamics. It can be related to the amount of "circulation" or "rotation" in a fluid. In fluid dynamics, vorticity is the circulation per unit area at a point in the flow field. It is a vector quantity, whose direction is along the axis of the swirl. A **vortex** is a spinning, often turbulent, flow (or any spiral motion) with closed streamlines. The shape of media or mass swirling rapidly around a centre forms a vortex. In TWS system water flows in an open circular motion.

There are two types of vortex

1. Free (irrotational) vortex

The tangential velocity is given by equation 3.11:

$$v_\theta = \frac{\Gamma}{2\pi r}, \quad [3.11]$$

Γ *is the circulation and* r *– is the radial distance from the centre of vortex*

2. Forced (rotational) vortex

The tangential velocity is given by equation 3.12:

$$v_\theta = \omega r, \quad [3.12]$$

ω *is the angular velocity and* r *– is the radial distence from the centre of vortex*

3.3 MATLAB model

This section will explore MATLAB model for analyse the all the equations explained above. Model is presented in figure 3.2.

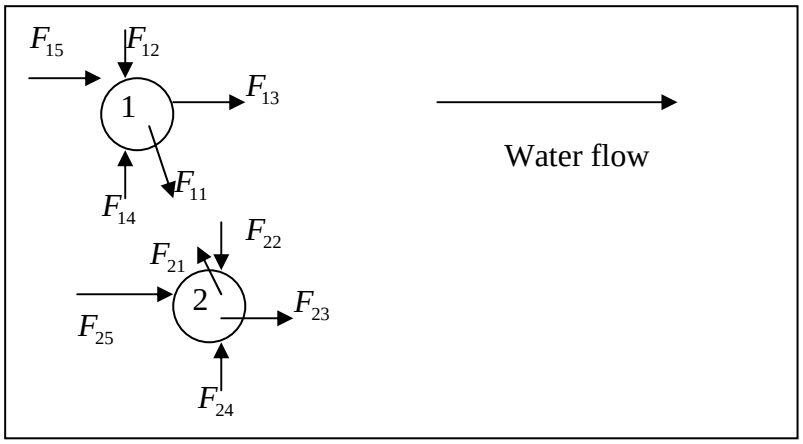


Figure 3.2: model for two magnetized particles and all the other forces acting on them

F_{11}, F_{21} = Magnetic forces [3.13]

F_{12}, F_{22} = weight acting on each particle [3.14]

F_{13}, F_{23} = forces due to the water flow [3.15]

F_{14}, F_{24} = buoyant force [3.16]

F_{15}, F_{25} = forces acting on the particles due to the viscosity of the water [3.17]

F_{16}, F_{26} = forces acting on the particles due to the vortex path of the TWS system [3.18]

As shown in the equations 3.13 to 3.18 and from figure 3.2 these are all the forces acting on two separate particles flow through a system. Only for MATLAB modelling only two particles have taken in to the consideration. As shown in the figure 3.3 we could see that after sometime two particles combine together and form a one complete particle. If more particles taken into consideration all the magnetized particles will form a one complete particle. And due the extra weight it will go down to the bottom of the container. MATLAB program is attached in the appendix.

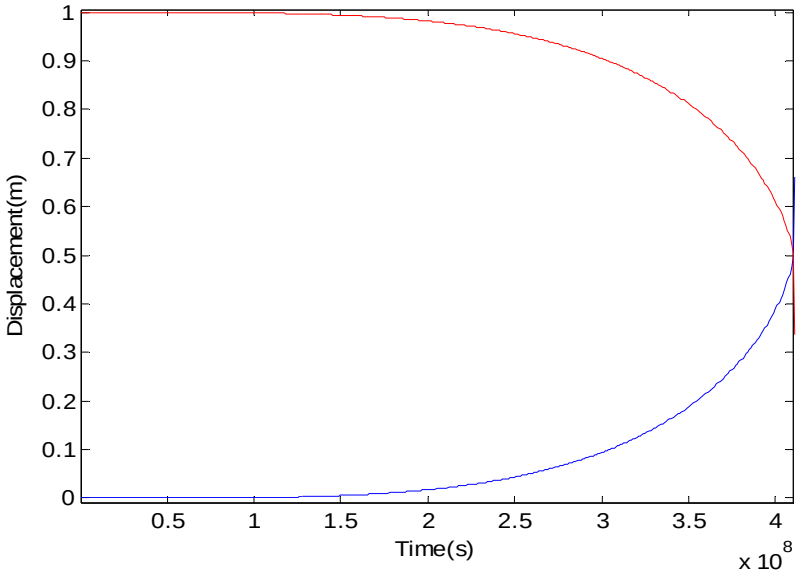


Figure 3.3: MATLAB output of the model

CHAPTER 4
TECHINICAL WATER SYSTEMS and FIELD WORKS

4.1 Introduction

This work is a TIF (Technology Industry Fellowship) project with the company being the Technical Water Systems (TWS). The company Technical Water Systems located at 36/1 Tawa Street, Mt. Maunganui is involved with the magnetic treatment of water for last few years. The original concept of Electromagnetism as a treatment for water was invented by Grant Birchall in 1998. Main products and services are Water Treatment Systems that clean up potable and waste water non-chemically. Grant is a substantial shareholder and works in the company. The ownership of the TWS is shown in table 4.1.

Table 4.1: Company Ownership

Shareholder	Nationality	Percentage of Ownership
Grant Birchall	NZ	28%
Murray Falloon	NZ	28%
Joseph Goddard	NZ	14%
Christopher Gambitsis	NZ	12 ½%
Joan Ferrari	USA	12 ½%
Others	NZ	5%

The system consists of three main components: as shown in figure 4.1. The descriptions of three components are provided, taking materials from the company web page [www.techwater.co.nz]. The author doesn't take any responsibility of the accuracy of the statement.

4.1.1 Scud – it is basically a filtration device used to clarify water of all suspended solids such as mud, silica etc. The scud is step one in the water treatment process used by Technical water Systems. It is an alternative to sand and other filtration method. Usually water is passed through scud before it enters the magnetic circle. The scud usually contains fine stainless steel wool to form a matrix to filter out big particles to be separated. The size of stainless steel wool can be changed to varying degree for different types of treatment. The solids trapped in the scud are removed by a backwash system.

4.1.2 Magnetic circle – The second step of water filtration process used by the Technical Water Systems is the magnetic circle. It is an electromagnetic unit which is used to reduce unwanted elements in water such as iron, sodium, manganese, hardness and carbon dioxide etc. The magnetic circle generates magnetic field and the water is forced to pass through the magnetic field. The filed strength of the generated magnetic field can be changed to any value and it depends on the requirement. It can be made in varying sizes depending on the application. For better performance the water should be re-circulated a few times through the magnetic the whole system and then settled in tanks or pond to achieve optimum flocculation. A picture of the scud and magnetic circle is shown in figure 4.2 and 4.3.

4.1.3 Zuuka – The zuuka is basically an ultra violet disinfection unit. This is a closed unit unlike the open unit used in many places. The purpose is to kill bacteria, viruses, coliform and micro-organisms mixed in water. The water coming out of magnetic circle is passed through zuuka for disinfection. A picture of ZUUKA is shown in figure 4.4.

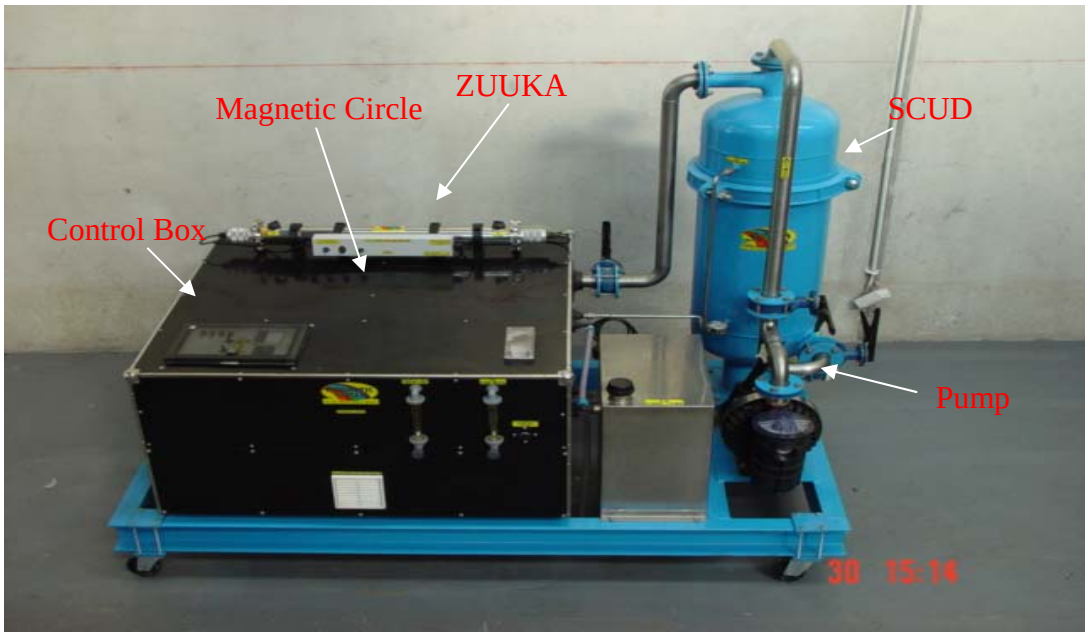


Figure 4.1: TWS complete System

Figure 4.2: Picture of a magnetic circle unit

Figure 4.3: Picture of large size magnetic Circle

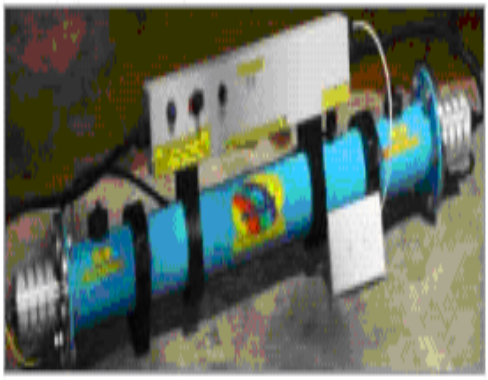


Figure 4.4: ZUUKA system

Depending on the situation the Technical Water Systems can use one more Scud of different filtration level after the magnetic circle. The pictures of micron scud and micron filter are shown in figures 4.5 and 4.6 respectively.

So far the Technical water Systems have installed quite a few units in different places and are getting good results. A picture of their installed system is shown in figure 4.7.

Figure 4.5: Micron SCUD

Figure 4.6: 5 Micron filter

Figure 4.7: Pictorial representation of a complete unit developed by Technical water Systems

4.2 Project Trials

The samples of different water bottles were given to Massey University from Technical Water Systems as shown in figure 4.8.

Figure 4.8: Different water samples supplied from TWS

At the start of my project some sample bottles were given to Massey University by Technical water system to analyse. After measuring the weight content in each sample

then H1 NMR readings were taken to check the presence of organic material in each sample. As shown in table 4.2 and figures 4.9 to 4.12 respectively.

Table 4.2: Weight content in each sample

Sample	Weight (mg)	Standard unit (g/m3)
1 – Makatana Raw	5	500
6 – Makatana Raw 2	4	400
2 – Makatana Mag Circle tank	4	400
3 – (IPL Mixed Water UV)	13	1300
4 – (Edgecumbe raw)	7	700
10 – (Edgecumbe M/C Treated)	5	500
5 – (McCain D119 Raw)	18	1800
7 – (McCains Treated)	3	300
8 – (Tauranga Tapwater)	1	100
9 – (TWS ++ - - Potable)	1	100

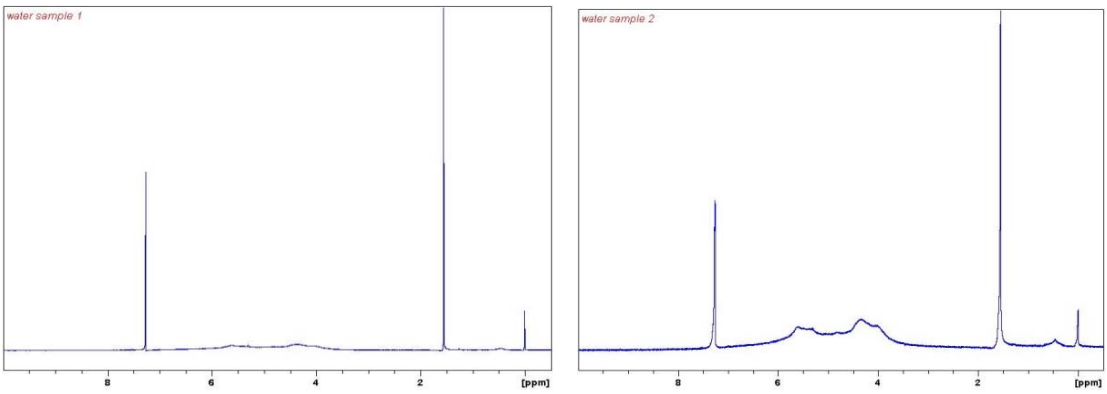


Figure 4.9:H1 NMR reading of water sample 1 and water sample 2

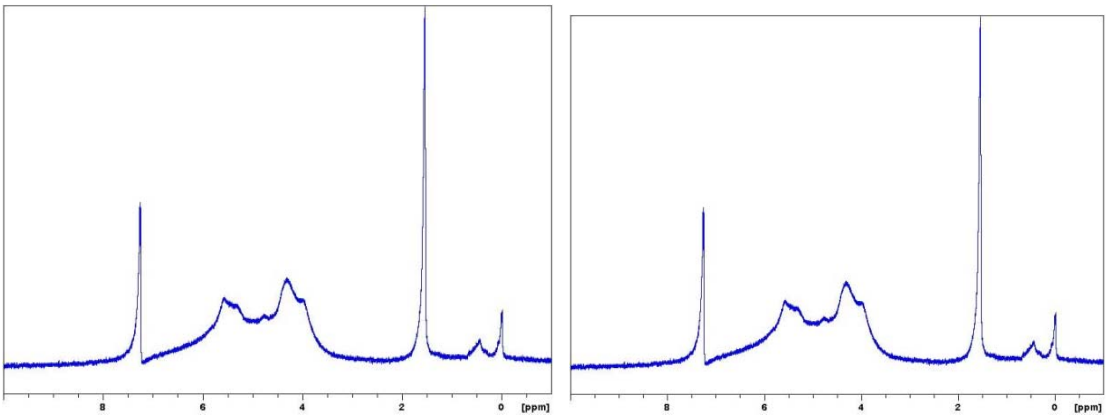


Figure 4.10: H1 NMR reading of water sample 3 and water sample 4

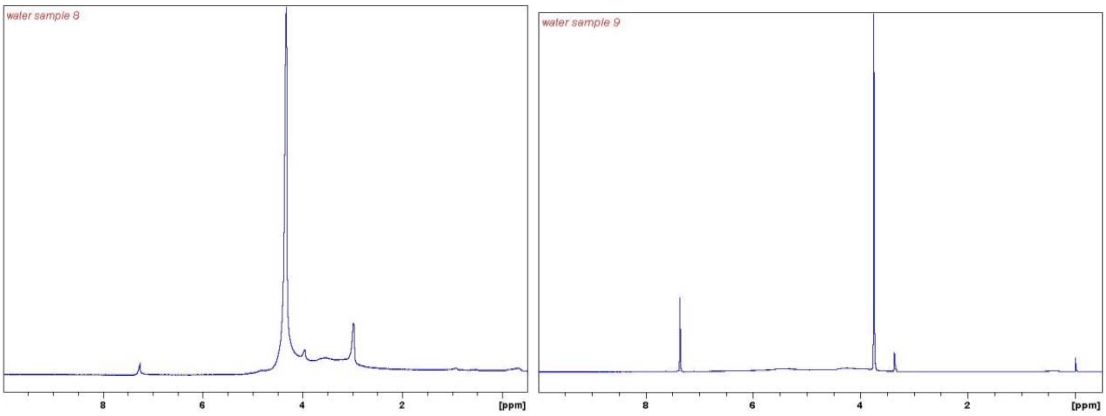


Figure 4.11: H1 NMR reading of water sample 8 and water sample 9

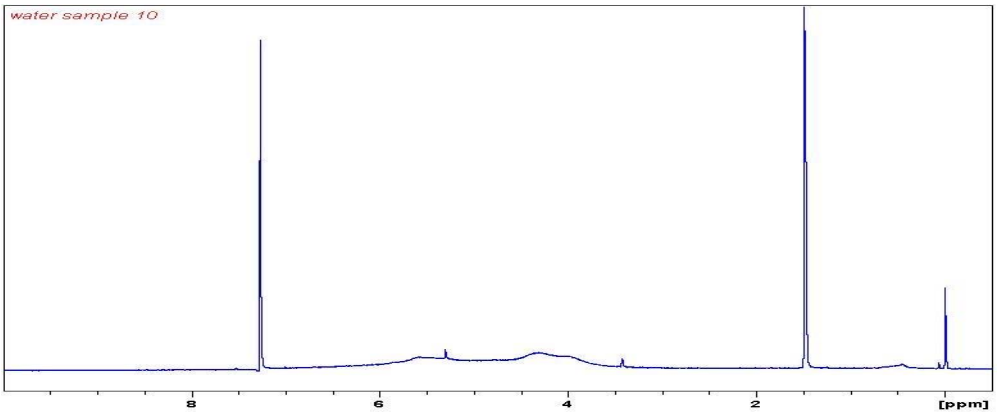


Figure 4.12: H1 NMR reading of water sample 10

Nuclear Magnetic Resonance (NMR) is a technique that allows one to non–invasively analyse the physical and chemical properties of materials by probing the nuclear dipole moments within the material. Nuclei of certain atoms have an intrinsic spin with angular momentum (L) that gives rise to a magnetic dipole moment (μ) and can be considered to be like a small spinning magnet. The relationship between the spin angular momentum and the magnetic moment is given as

$$\tilde{\mu} = \gamma \tilde{L} \qquad [4.1]$$

Where γ is called the gyromagnetic ratio and is nuleus – dependent. For protons $\gamma = 2.675 \times 10^{8} s^{-1} T^{-1}$.

From the above NMR figures (figures 4.9 to 4.12) we could see that from the peaks that there are some organic materials are present in all the samples. It was not possible test the samples at the university to know he contents. So all the samples were tested to check the Calcium, Magnesium, Sulphate and Iron content in each sample also total hardness and the pH had been tested. Table (4.3) shows all the values.

Table 4.3: Contents of water samples – test results.

Sample	**Ca** (g/m3 Ca)	**Mg** (g/m3 Mg)	**Fe** (g/m3)	**TH** (g/m3 CaCO3)	**PH**	**Sulphate** (g/m3 SO4)
1- Matakana raw	3.3	0.54	0.036	8	8.69	0.63
6 – Matakana Raw 2	3	0.51	0.039	10	7.8	0.24
2- Matakana Mag Circle tank 3	2.9	0.44	0.032	7	8.06	0.45
5 – McCain D119 Raw	17.3	24.8	2.62	150	6.62	0.23
7 – McCains Treated	4.6	3	0.334	24	8.2	606
4 – Edgecumbe raw	11.6	11.8	3.33	77	7.529	<0.02
10 – Edgecumbe M/C Treated	14.4	8.1	0.014	70	8.58	<0.02
8 – Tauranga Tapwater	2.8	0.56	<0.005	8	7.27	1.8
9 – TWS ++ - - Potable	5.3	0.56	0.11	14	7.16	2.17
3 – IPL Mixed Water UV	1.7	0.32	0.027	4	8.38	0.09

From table 4.3 it is seen that the water samples content different contaminants, the percentage content of different materials from one water sample to another one vary quite significantly. While the sample 1. Makatana raw and 6 Makatana6 are compared to sample 2 Makatana Magnetic Circle tank, it is seen there is no much difference. The contents of two raw samples vary quite significantly from one another. So it can be concluded that the effect of magnetic circle on raw water is not there at all. On the other hand if we compare sample 5 McCain Raw with sample 7 McCain Treated, it is seen that the amount of calcium, magnesium, iron as well as total hardness has reduced considerably. The reason of which expect the iron part is difficult to explain.

For iron part it can be explained in the following way. While iron is passed through the magnetic circle, the iron particles if not strongly bonded with water molecules can be separated and precipitate at the tank. It is difficult to explain how the sulphate content of treated sample becomes so large, 606 g/s3 compared to only gm/m3.
For the sample 4 and 10, Edgecumbe raw and treated, there is some difference in Fe content, otherwise there is no much change.
So there are no consistent results available from the TWS system. It is important to obtain very consistent results to explain the operation of the system from scientific principles. In the next section results obtained from some field trials are described.

4.3 FIELD TRIALS

4.3.1 Wanganui Council Water Softening Trial

The problem of Wanganui water in that it is too hard. The purpose of the trial is to see whether the TWS system can help in dealing with the problem. So the problem can be defined as remove the calcium and magnesium minerals that cause the hardness in the drinking water supply.

Hard water is water that has a high mineral content (water with a low mineral content is known as soft water). This content usually consists of high levels of metal ions, mainly calcium (Ca) and magnesium (Mg) in the form of carbonates, but may include several other metals as well as bicarbonates and sulphates.

Total water 'hardness' (including both Ca^{++} and Mg^{++} ions) is reported as ppm (or mg/L) of $CaCO_3$. Water hardness usually measures the total concentration of Ca and Mg, the two most prevalent divalent metal ions, although in some geographical locations iron, aluminium, and manganese may also be present at elevated levels. Calcium usually enters the water from either $CaCO_3$, as limestone or chalk or from mineral deposits of $CaSO_4$. The predominant source of magnesium is dolomite, $CaMg(CO_3)_2$.

Temporary hardness

Temporary hardness is hardness that can be removed by boiling or by the addition of lime (calcium hydroxide). It is caused by a combination of calcium ions and

bicarbonate ions in the water. Boiling, which promotes the formation of carbonate from the bicarbonate, will precipitate calcium carbonate out of solution, leaving water that is less hard on cooling.

It should be noted that the above explanation is an oversimplification of the process that is occurring. The following equilibrium reaction actually happens when calcium carbonate ($CaCO_3$) is "dissolved" in water:

$CaCO_3$ (solid) + H_2O (liquid) + CO_2 (gas) ↔ Ca^{2+} (aqueous) + 2 HCO_3- (aqueous)

Upon heating, less CO_2 is able to dissolve into the water. Since there is not enough CO_2 around, the reaction cannot proceed from left to right, and therefore the $CaCO_3$ will not "dissolve" as readily. Instead, the reaction is forced to go from right to left (i.e. products to reactants) to reestablish equilibrium, and solid $CaCO_3$ is formed. Heating water will remove hardness as long as the solid $CaCO_3$ that precipitates out is removed. After cooling, if enough time passes the water will pick up CO_2 from the air and the reaction will again proceed from left to right, allowing the $CaCO_3$ to "redissolve" in the water.

Permanent hardness

Permanent hardness is hardness (mineral content) that cannot be removed by boiling. It is usually caused by the presence of calcium and magnesium sulfates and/or chlorides in the water, which become more soluble as the temperature rises. Despite the name this can be removed using a water softener, or ion exchange column.

Treatment

The most common method to treat hard water is through ion exchange water softening. Ion exchange water softening is a process in which the hardness ions, magnesium and calcium, are exchanged with either sodium or occasionally, potassium ions. This is accomplished by directing the flow of hard water over a bed of plastic resin beads. Each bead has a slight electric charge, which holds the sodium on the bead. As the water flows over the beads, the hardness minerals (ions) are attracted to the beads. When the hardness minerals attach themselves to the beads, the sodium ions are displaced. Hence, the hardness ions are replaced by the sodium ions. At some point the plastic resin beads will be covered with hardness ions and will no longer be able to remove hardness from the water. In order to remove the hardness ions from the beads, brine or salt (sodium chloride) solution is added to the resin bed. This solution

contains a high concentration of sodium ions, which remove the hardness ions from the beads. Next the solution and the hardness ions are flushed out of the resin bed with fresh water, and once again the beads can remove hardness from the water. This process is called regeneration.

Table 4.4: Hardness of water

Water type	Hardness (ppm)
Soft water	Less than 17
Slightly hard	17 to 60
Hard	120 to 170
Very Hard	170 and higher

The SCUD Stainless steel micron screens as well as media such as sand and carbon are utilised. But in this application resin beads are used in the scud. And resin beads are charged with brine.

An ion exchange resin is an insoluble matrix (or support structure) normally in the form of small (1-2 mm diameter) beads, usually white or yellowish, fabricated from an organic polymer substrate on the surface of which are sites with easily trapped and released ions in a process called ion exchange. There are multiple different types of ion exchange resin which are fabricated to selectively prefer one or several different types of ions.

Figure 4.13: Resin Beads

This resin is used extensively for water softening during water purification. They were developed as a more flexible alternative to the use of natural or artificial zeolites.

Most ion exchange resins are based on cross linked polystyrene. The required active groups can be introduced after polymeration, or substituted monomers can be used. The cross linking is usually achieved by adding a small proportion of divinyl benzene to styrene. Non-cross linked polymers are used only rarely because of their tendency to change dimensions in dependence on the ions bonded. However, crosslinking

somewhat decreases the capacity of the resin and prolong the time for reaching the equilibrium for the ions in solution and in the resin.

Block diagram of the complete system is shown below.

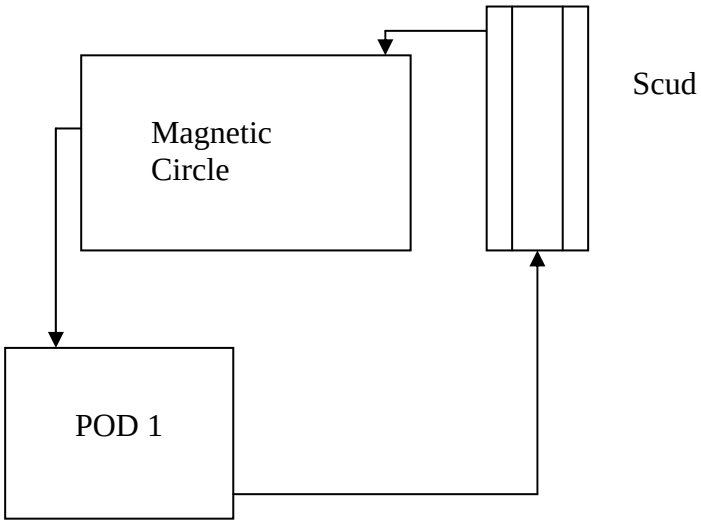


Figure 4.14: Block diagram of system under test

First pod 1 is filled with raw water form bore then several tests were done.
Tests follow:

1. Control **(A)**
2. Magnetic Circle --and Resin Beads charged **(B)**
3. Magnetic Circle ++ and Resin Beads charged **(C)**
4. Magnetic Circle ++-- and Resin Beads charged **(D)**
5. Magnetic Circle --++ and resin beads charged **(E)**
6. Resin Beads exhausted**(F)**
7. Magnetic Circle -- and resin beads exhausted **(G)**
8. Magnetic Circle ++ and resin beads exhausted **(H)**
9. Magnetic Circle --++ and resin beads exhausted **(I)**
10. Magnetic Circle ++-- and resin beads exhausted **(J)**
11. Magnetic Circle --and No Resin Beads **(K)**
12. Magnetic Circle ++ and No Resin Beads **(L)**

Several water samples were taken on each test. For an example for test -1

I. Take sample direct from bore **(Samples 1 - B1.01)**
II. Pump water direct from bore via Magnetic Circle (turned on) with scud connected into pod 1 **(Samples 2 - B1.02)**
III. Circulate pod 1 via magnetic circle (turned on) with scud connected for 1 hour **(Samples 3 - B1.03)**
IV. Leave water in pod for 24 hours **(Samples 4 - B1.04)**
V. Circulate via magnetic circle (turned off) for 5 minutes **(Samples 5 - B1.05)**
VI. Empty pod

Table 4.5: Wanganui testing procedure

Water Softening Trials	**Control (A)**	**Magnetic Circle -- and resin beads charged (B)**	**Magnetic Circle ++ and resin beads charged (C)**	**Magnetic Circle ++-- and resin beads charged (D)**
Raw	Take sample direct from bore **(A1.01)**	Take sample direct from bore **(B1.01)**	Take sample direct from bore **(C1.01)**	Take sample direct from bore **(D1.01)**
	Pump water direct from bore to Fill pod 1	Pump water direct from bore via Magnetic Circle (turned on) with scud connected into pod 1	Pump water direct from bore via Magnetic Circle (turned on) with scud connected into pod 1	Pump water direct from bore via Magnetic Circle (turned on) with scud connected into pod 1
Single pass exposure to air	Take sample from pod 1 **(A1.02)**	Take sample from pod 1 **(B1.02)**	Take sample from pod 1 **(C1.02)**	Take sample from pod 1 **(D1.02)**
	Circulate pod 1 via mag circle (turned off) with scud disconnected for 1 hour	Circulate pod 1 via mag circle (turned on) with scud connected for 1 hour	Circulate pod 1 via mag circle (turned on) with scud connected for 1 hour	Circulate pod 1 via mag circle (turned on) with scud connected for 1 hour
Multiple Pass 1 hour	Take sample from pod 1 **(A1.03)**	Take sample from pod 1 **(B1.03)**	Take sample from pod 1 **(C1.03)**	Take sample from pod 1 **(D1.03)**
	Pump water into pod 1 Start Magnetic Circle-- and Resin Beads procedure			
	Leave water in pod for 24 hours	Leave water in pod for 24 hours	Leave water in pod for 24 hours	Leave water in pod for 24 hours
Multiple Pass 1 hour After 24 hours rest	Take sample from pod 1 **(A1.04)**	Take sample from pod 1 **(B1.04)**	Take sample from pod 1 **(C1.04)**	Take sample from pod 1 **(D1.04)**
	Circulate via mag circle (turned off) with scud disconnected for 5 minutes	Circulate via mag circle (turned off) for 5 minutes	Circulate via mag circle (turned off) for 5 minutes	Circulate via mag circle (turned off) for 5 minutes
Backwash equivalent test	Take sample from pod 1 **(A1.05)**	Take sample from pod 1 **(B1.05)**	Take sample from pod 1 **(C1.05)**	Take sample from pod 1 **(D1.05)**
Test End	Empty pod 1	Empty pod 1	Empty pod 1	Empty pod 1
Water Softening	**Magnetic Circle**		**Resin Beads Exhausted**	**Magnetic Circle**

Trials	-- ++ and resin beads charged (E)		(F)	-- and resin beads exhausted (G)
Raw	Take sample direct from bore **(E1.01)**		Take sample direct from bore **(F1.01)**	Take sample direct from bore **(G1.01)**
	Pump water direct from bore via Magnetic Circle (turned on) with scud connected into pod 1		Pump water direct from bore via Magnetic Circle (turned off) with scud connected into pod 1	Pump water direct from bore via Magnetic Circle (turned on) with scud connected into pod 1
Single pass exposure to air	Take sample from pod 1 **(E1.02)**		Take sample from pod 1 **(F1.02)**	Take sample from pod 1 **(G1.02)**
	Circulate pod 1 via mag circle (turned on) with scud connected for 1 hour		Circulate pod 1 via mag circle (turned off) with scud connected for 1 hour	Circulate pod 1 via mag circle (turned on) with scud connected for 1 hour
Multiple Pass 1 hour	Take sample from pod 1 **(E1.03)**		Take sample from pod 1 **(F1.03)**	Take sample from pod 1 **(G1.03)**
			Pump water into pod 1 Start Magnetic Circle -- and Resin Beads procedure	
	Leave water in pod for 24 hours		Leave water in pod for 24 hours	Leave water in pod for 24 hours
Multiple Pass 1 hour After 24 hours rest	Take sample from pod 1 **(E1.04)**		Take sample from pod 1 **(F1.05)**	Take sample from pod 1 **(G1.04)**
	Circulate via mag circle (turned off) for 5 minutes		Circulate via mag circle (turned off) for 5 minutes	Circulate via mag circle (turned off) for 5 minutes
Backwash equivalent test	Take sample from pod 1 **(E1.05)**		Take sample from pod 1 **(F1.05)**	Take sample from pod 1 **(G1.05)**
Test End	Empty pod 1		Empty pod 1	Empty pod 1

Water softening Trials	Magnetic Circle ++ and Resin Beads exhausted (H)	Magnetic Circle --++ and Resin Beads exhausted (I)	Magnetic Circle ++ --and Resin Beads exhausted (J)	Magnetic Circle -- and No Resin Beads (K)
Raw	Take sample direct from bore **(H1.01)**	Take sample direct from bore**(I1.01)**	Take sample direct from bore **(J1.01)**	Take sample direct from bore **(K1.01)**
	Pump water direct from bore via Magnetic Circle (turned on) with scud connected into pod 1	Pump water direct from bore via Magnetic Circle (turned on) with scud connected into pod 1	Pump water direct from bore via Magnetic Circle (turned on) with scud connected into pod 1	Circulate pod 1 via mag circle (turned on) with scud connected(**no resin beads)** for 1 hour
Single pass exposure to air	Take sample from pod 1 **(H1.02)**	Take sample from pod 1 **(I1.02)**	Take sample from pod 1 **(J1.02)**	Take sample from pod 1 **(K1.02)**
	Circulate pod 1 via mag circle (turned on) with scud connected for 1 hour	Circulate pod 1 via mag circle (turned on) with scud connected for 1 hour	Circulate pod 1 via mag circle (turned on) with scud connected for 1 hour	Leave water in pod for 24 hours
Multiple Pass 1 hour	Take sample from pod 1 **(H1.03)**	Take sample from pod 1 **(I1.03)**	Take sample from pod 1 **(J1.03)**	Take sample from pod 1 **(K1.03)**
	Leave water in pod for 24 hours	Leave water in pod for 24 hours	Leave water in pod for 24 hours	
Multiple Pass 1 hour After 24 hours rest	Take sample from pod 1 **(H1.04)**	Take sample from pod 1 **(I1.04)**	Take sample from pod 1 **(J1.04)**	
	Circulate via mag circle (turned off) for 5 minutes	Circulate via mag circle (turned off) for 5 minutes	Circulate via mag circle (turned off) for 5 minutes	
Backwash equivalent test	Take sample from pod 1 **(H1.05)**	Take sample from pod 1 **(I1.05)**	Take sample from pod 1 **(J1.05)**	
Test End	Empty pod 1	Empty pod 1	Empty pod 1	

Magnetic Circle ++ and No Resin Beads (L)
Take sample direct from bore **(L1.01)**
Circulate pod 1 via mag circle (turned on) with scud connected(**no resin beads)** for 1 hour
Take sample from pod 1 **(L1.02)**
Leave water in pod for 24 hours
Take sample from pod 1 **(L1.03)**

Table 4.6: Wanganui trial Results

Sample ID	Total Hardness (mg/L as CaCO3)	(Na) Content (mg/L)	Free (CO2) (mg CO2/L)	pH	Alkalinity (mg/L as CaCO3)
A1.01	172	16	6	7.7	151
A1.04	<1	101			
B1.05	<1	99			
C1.02	80	60			
C1.03	<1	97			
C1.04	<1	96			
C1.05	<1	96			
D1.02	85	56			
D1.03	11	93			
D1.04	14	92			
D1.05	10	92			
E1.02	106	46			
E1.03	21	85			
E1.04	21	85			
E1.05	32	79			
F1.02	131	34			
G1.02	130	35			
G1.03	43	76			
G1.04	44	76			
G1.05	51	72			
H1.02	130	34			
H1.03	71	63			
H1.04	68	63			
H1.05	65	63			
I1.02	53	71			
I1.03	84	56			
I1.04	81	55			
I1.05	80	56			
J1.02	138	31			
J1.03	86	54			
J1.04	85	54			
J1.05	80	56			
K1.02	170	16	5	7.8	149
K1.03	170	16	5	7.8	151
L1.02	170	16	6	7.7	152
L1.03	170	16	6	7.7	152

Total hardness and the Sodium content have been tested in the lab. Some selected samples carbon dioxide content also measured.

From the results we can see that initially when resin beads are charged Hardness of the water drop 172 to < 1.

Five minutes later hardness of the water dropped from 172 (mg/L as CaCO3) to average of 106 (mg/L as CaCO3).

Then after 1hour later alter due to the ion exchange hardness of the water dropped from 172 (mg/L as CaCO3) to average of 52 (mg/L as CaCO3). After 24 hours leaving the water in the pod hardness of the water is 52 (mg/L as CaCO3) (I have ignored A, B and C for this calculation). And there is not much difference between leaving the water for 24 hours.

And the sodium content of the water increases to 16 mg/L to 101 mg/L at the initial stage.

After five minutes sodium levels increased from 16 mg/L to average of 45 mg/L. Because there is less time to react with resin beads. According to the drinking water standards sodium level in water should be less than 100 mg/L. because excess sodium cause hurt diseases.

It is seen from table 4.6 that total hardness of water gradually goes down. As an at the start resin beads are washed brine water and after while resin beads get depleted. So due that resin beads need to be washed regularly to have a control system.

And after one hours sodium level increases form 16 mg/L to average of 65 mg/L. In the last 2 tests hardness of the water and the sodium content of the water wasn't changed. Results and the procedure follow. Last tests were done with out any resin beads in the scud. So from the table we could see that total hardness hasn't changed and sodium content also remain same. It is concluded that in this process there is very little effect from the magnetic circle and it's only an ion exchange process.

4.3.2 Rangitikei District Council (Ratana) Water trial

Figure 4.15: Actual experiment set up at Rangitikei (Ratana) District council

The problem of Ratana is also that water is too hard. The purpose of the trial is to see whether the TWS system can help in dealing with the problem. So the problem can be defined as remove the calcium and magnesium minerals that cause the hardness in the drinking water supply. And the iron content in Ratana water is really high. Figure 4.15 represents the actual testing system. In ratana trial extra filter had been used for filter out all the extra particles.

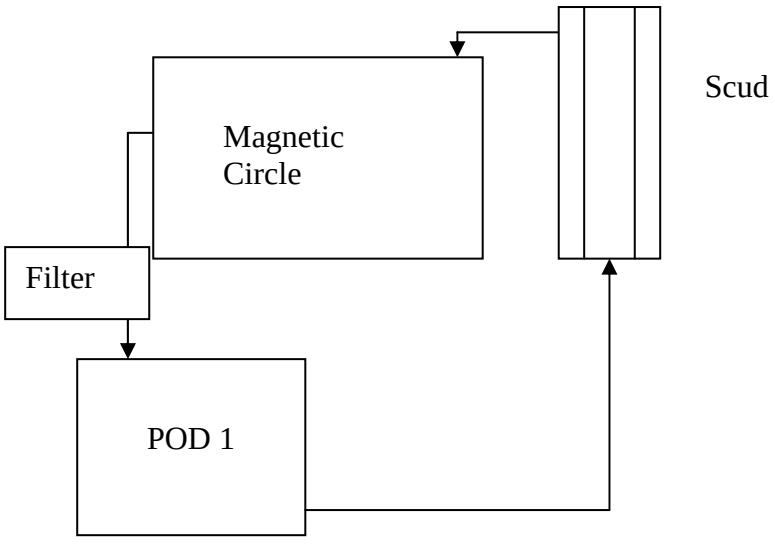


Figure 4.16: System under test at Ratana trial

Table 4.7 contains results obtained during Ratana trial. Some of the information (total hardness and turbidity values) had not been sent to us by the company. It is seen from the table 4.7 that at first test (RA-01) when the magnetic circle is turned off and no filters are connected total dissolve solids. In Ratana water is about 850 g m^{-3} and the

iron content is about 2.49 g m^{-3}. In the second test (RA-02) iron level had gone down significantly but the TDS had gone 100 g m^{-3}. It must have been due to by back washing the resin beads with brine water (Na content). And in the fifth test (RA-05) once the magnetic circle was turned on TDS levels had gone up significantly (by 1200 g m^{-3}). And Iron levels are kept low but at the ninth test (RA-09) iron level had gone up significantly (3.9g m^{-3}). And the last test (RA-18) once the magnetic circle was turned off TDS level (by 2100 g m^{-3}) and the iron level (by 3.5 g m^{-3}) had gone up quite a bit. It is concluded that it is really had to explain this process by analysing table 4.7. Some more tests needed to be done.

Table 4.7: Ratana trial Results

Sample Bottle Label	Magnetic Circle Polarity	Total Hardness (g m^{-3})	TDS Approx (g m^{-3})	Total Iron (g m^{-3})	Total Manganese (g m^{-3})	Turbidity (NTU)	pH (Ratana)	pH (testing)	Extra Filter Type	Scud Media	Air Pumped	pH Adjustment
RA-01	OFF		850	2.49	1.88		7.3	7.6	N/A	N/A	N/A	N/A
RA-02	OFF		954	0.46	0.54		7.4	7.5	Pleated	Resin Beads	NO	N/A
RA-03	OFF		893	0.49	0.53		7.3	7.5	Carbon	Resin Beads	NO	N/A
RA-04	OFF		935	0.47	0.6		8.0	8.0	Carbon	Resin Beads	NO	Soda Ash
RA-05	- -		2080	0.48	0.42		7.6	7.6	Pleated	Resin Beads	NO	N/A
RA-06	++		1150	0.49	0.41		7.6	7.5	Pleated	Resin Beads	NO	N/A
RA-07	+ -		978	0.45	0.46		7.5	7.4	Pleated	Resin Beads	NO	N/A
RA-08	- +		960	0.54	0.36		7.4	7.3	Pleated	Resin Beads	NO	N/A
RA-09	- +		960	4.66	0.54		4.9	5	Pleated	Resin Beads	NO	Citric Acid
RA-10	++		1120	2.4	0.32		7.8	7.7	Sediment	Resin Beads	YES	N/A
RA-11	- -		997	1.32	0.5		7.6	7.8	Sediment	Resin Beads	YES	N/A
RA-12	++		997	1	0.29		7.8	7.8	Sediment	Resin Beads	YES	N/A
RA-13	+ -		1050	0.69	0.48		8.0	8	Sediment	Resin Beads	YES	N/A
RA-14	- +		993	0.23	0.43		7.9	7.8	Sediment	Resin Beads	YES	N/A
RA-15	OFF		992	1.93	0.33		N/A	7.4	N/A	N/A	N/A	N/A
RA-16	OFF		887	0.98	0.31		N/A	7.6	N/A	N/A	N/A	N/A
RA-17	OFF		386	1.34	0.43		N/A	7.2	N/A	Resin Beads	N/A	N/A
RA-18	OFF		>3000	>6.0	2.29		N/A	7.4	N/A	Resin Beads	N/A	N/A

4.5.3 CEDENCO Project

A complete system of TWS, installed at Cedenco premises, Gisborne to treat the waste water.

Cedenco Foods is a food ingredient processing and marketing company with factory operations in Gisborne, New Zealand. Whilst remaining independent of any food retail manufacturer the Cedenco Group is now 100% owned by USA food processor SK Foods.

Cedenco produces and exports vegetable and fruit powders; aseptic paste, purees and dice; UHT purees; frozen purees; and Individually Quick Frozen (IQF) products to customers in countries including Australia, Japan, Asia, the Middle East, North America and Europe. These products include sweetcorn, pumpkin, tomato, peas, onions, celery,

apples, pears, kiwifruit, broccoli, capsicum and carrots. Certified by Bio-Gro New Zealand as an organic producer, Cedenco produces organic products specific to individual customer requirements.

Gisborne and Echuca both have a mild, sunny climate and fertile soils which enable the supply of a wide range of process-grade fruit and vegetable crops.

Cedenco Foods in Gisborne, New Zealand, operates four key processes producing:

- Powder - sweetcorn, pumpkin and tomato
- Aseptic Paste - tomato, apple, onion and kiwifruit
- UHT Puree - sweet corn, pumpkin, celery, green peas, carrots, onion and broccoli
- Frozen Puree - sweetcorn and pumpkin
- IQF - Individually Quick Frozen (IQF) sweetcorn, peas, celery, onion, capsicums and broccoli ingredients

Problem

Waste that has been produced by tomato, sweet corn, onion and pumpkin etc filled in to a clarifier. And this contains so much waste that shouldn’t be exposed to normal/drinking water. There is a guidelines by City council for the waste disposal which they are unable to maintain. Technical water Systems is trying to solve

Cedenco's problem with the developed system. A system has been installed and is under trial.

According to Technical Water Systems, the system is working and is giving excellent results. TWS wanted us to visit the plant and the system to have a look and experience. So Aprof Subhas Mukopadhyay and I visited cedenco waste water treatment plant with a few objectives such as:

1. To visit the Cedenco plant and to have a look of the installed system,
2. to see the operation of magnetic circle and the complete TWS system,
3. to collect some samples from every input point and output point.

Main system consists of two magnetic circles and two types of scuds (filters). Even though the installation is almost complete, the complete system is not in operation. Only one magnetic circle was connected to the main clarifier. The use of magnetic circle is shown with the help of block diagram 1. The waste water is passed through the magnetic circle taken at some depth of the clarifier and discharged at top. It was not possible to collect all the samples that we wanted. Samples had been collected from the top of the clarifier and the sludge point at 3.

Figures 4.17 to 4.23 show different pictures taken there.

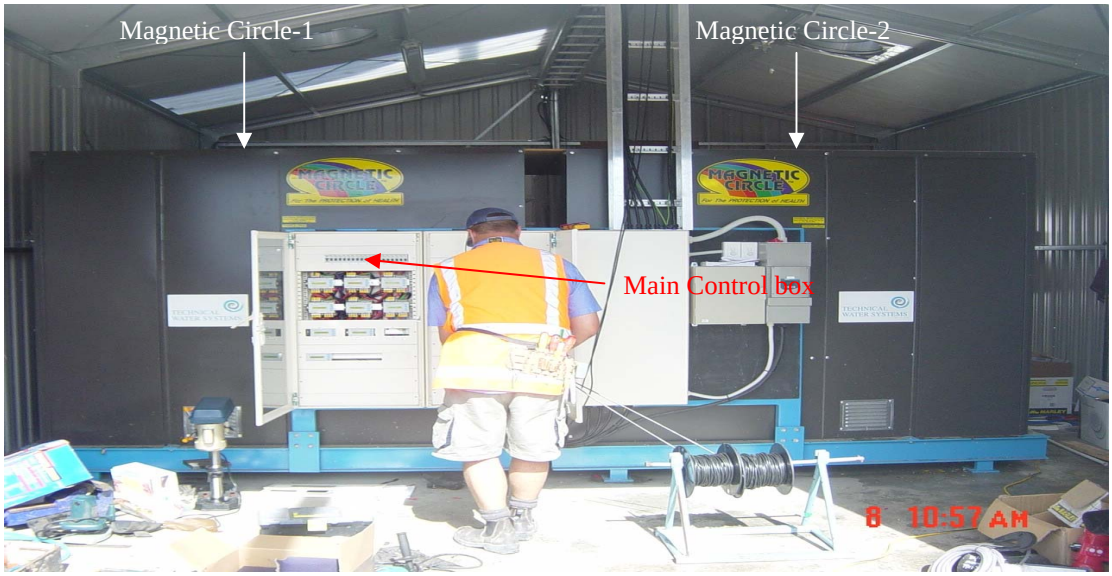


Figure 4.17: CEDENCO Main System

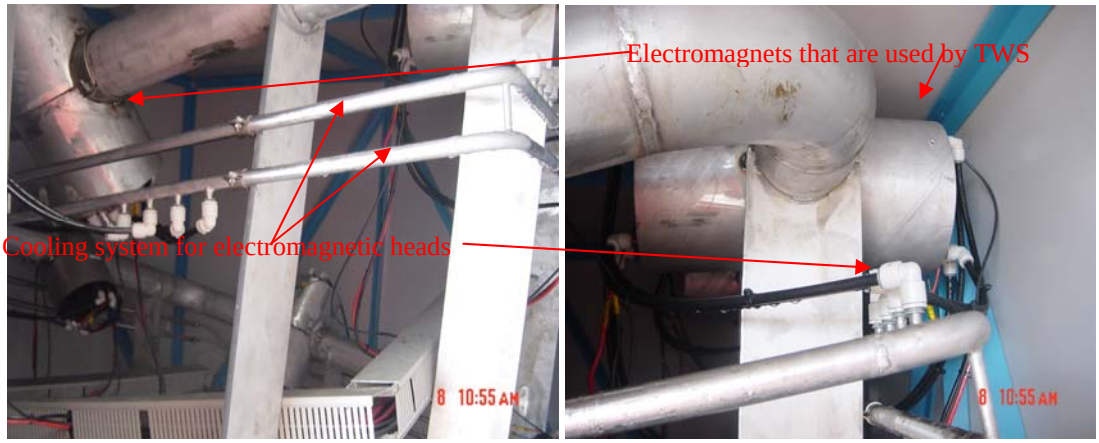


Figure 4.18: one of the magnetic circles for the generation of magnetic field used by Technical Water Systems and the cooling system

Figure 4.19: Sweet corn and tomato stock

Figure 4.20: main clarifier

Figure 4.21: Top view of the main clarifier

Figure 4.22: 2nd TWS system for cleaning only tomato waste water

Figure 4.23: tomato water tank some of the water gone through the Magnetic treatment

Description of the samples

Two samples had been collected from at point – 1. At the moment of collection magnetic circle wasn't working so we have decided to collect one sample **(SAMPLE-1)** at 11.30am and one **(SAMPLE-2)** at 12.00pm. Another sample was collected at point – 3**(SAMPLE-3)** which is bottom of the clarifier. And another treatment plant was working on cleaning only tomato water. So another two samples had been collected at input **(SAMPLE-4)** to the magnetic circle and output **(SAMPLE-5)** of the magnetic circle. All the samples have passed to testing laboratory to test for the total Fe, Ca, Mg and sulphate on the supernatant, and the oil and grease on the supernatant plus solids.

Results

The results obtained from Central Environmental Laboratory are given below.

Table 4.8: CEDENCO Test results

Sample	PH	Calcium (g/m3)	Iron (g/m3)	Magnesium (g/m3)	Sulphate (g/m3 SO4)	Fats, Oils and Greases (g/m3)
SAMPLE-1	6.36	14.6	0.817	5.02	19.8	
SAMPLE-2	7.59	14.4	1.24	5.06	19	
SAMPLE-3	3.63	18.7	15.5	8.6	21.9	3800
SAMPLE-4	6.44	10.8	5.76	1.26	6	
SAMPLE-5	3.99	11	5.86	1.27	5.19	

We see from the results we can see that sample-2 has higher iron content than sample-1. This may be due to fact that magnetic circle wasn't working so the iron content in the clarifier had gone up slightly. And the magnesium, calcium and sulphate content remained all most same all the time as the magnetic field has very little effect. Since the sample-3 has been collected from the bottom of the clarifier so all the wastes (heavy particles) have gone down to the bottom so sample-3 has a very high concentration of calcium, Iron, magnesium and sulphate. Sample – 4 and sample – 5 have almost same amount of everything because even though tomato (sample – 4) goes through the magnetic circle once afterwards it get mixed with normal water. PH value of Sample – 1 has gone up from 6.36 to 7.59 (Sample – 2) after half and hour. Ph value of bottom of the clarifier was 3.63. So it was more acidic at the bottom. Sample – 5 is more acidic than sample – 4. Overall sample – 3 had a very high Fats, Oils and Greases concentration.

4.6 Conclusion and Suggestion

In order to have control system resin beads in Wanganui and Ratana trial systems need to be backwashed using following method.

Hardness of the water – **x ppm**

Allowable – **y ppm**

Get rid of – **(x - y) ppm**

M - Litre water to be treated

Amount to get rid of - $\{\frac{(x-y)}{10^6}\}\times M$ (Mg^{+2}/Ca^{+2})

Brian water - $\{\frac{(x-y)}{10^6}\}\times M\times 2$

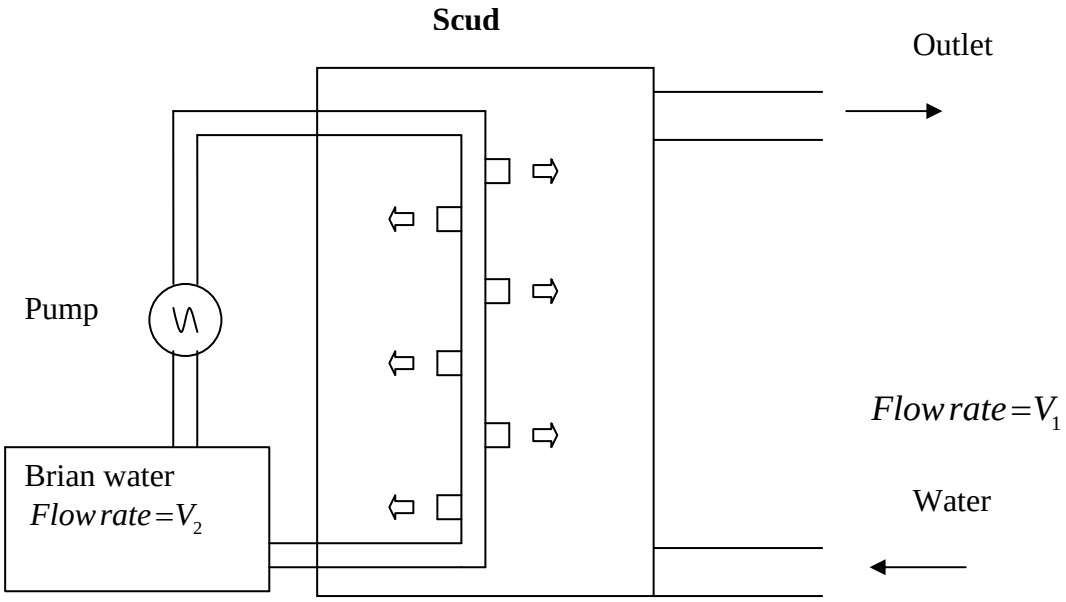


Figure 4.24: Suggested System

$$\frac{V_1}{V_2} = \frac{M}{\frac{(x-y)}{10^6} \times M}$$

$$V_2 = \frac{(x-y)}{10^6} \times V_1$$

From the above results we observe that the current magnetic circle has a very little effect on Calcium, Magnesium and Sulphate. It has some effect on iron but with the modification of the existing design it will be possible to filter out waste. It is known that fluids in a high speed, properly formed vortex can be separated by type where type may be atomic weight or viscosity or simply suspended versus dissolved particulates. So due to the vortex effect all the waste separated from the water and goes in to the bottom of the clarifier. So I would suggest of using some sort of seeding material to separate all the particles from Cedenco waste. There is a plenty of opportunity to apply a properly designed magnetic separation system to achieve the desired result.

CHAPTER 5

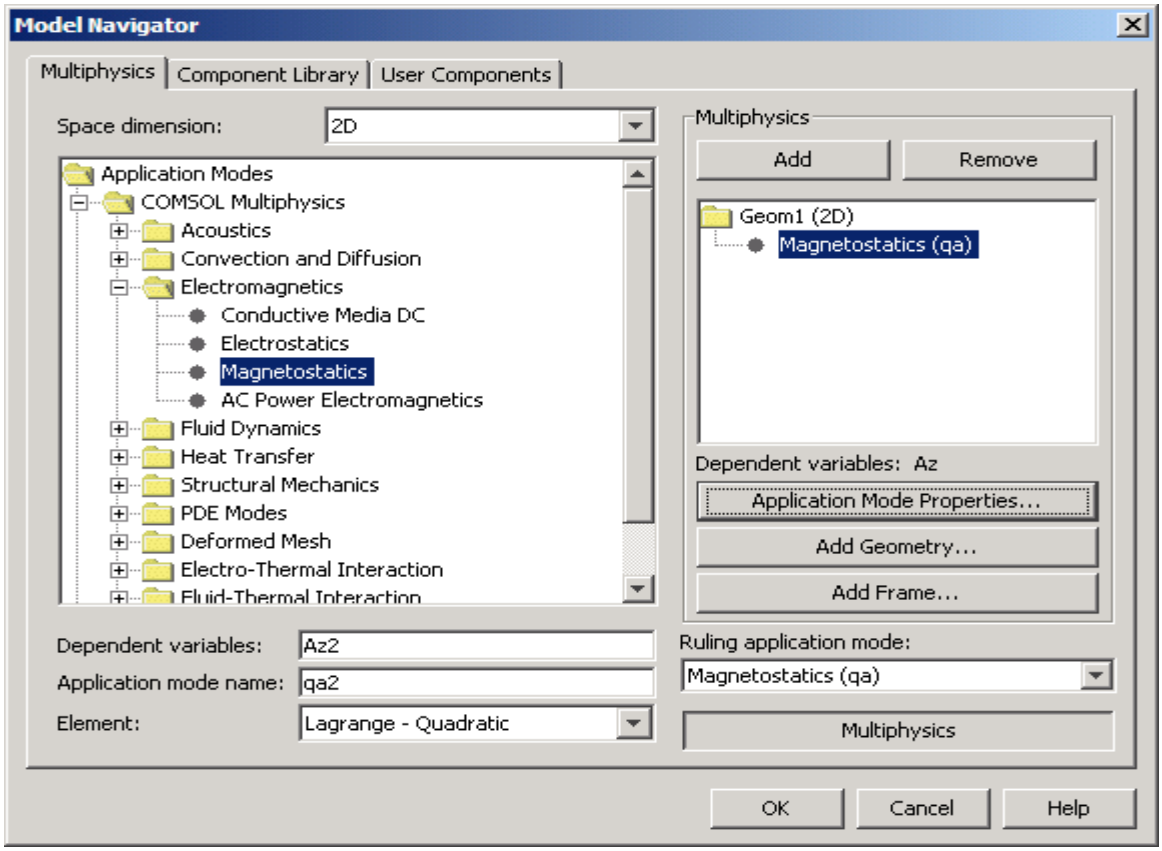
DESIGN IMPROVEMENT OF CURRENT SYSTEM

5.1 Introduction

In order to fully understand the operation of the TWS system it is essential to know the magnetic field distribution of the magnetic circle. Finite element analysis has been used to analyse it.

5.2 Finite Element Modelling of Magnetic Circle

The finite element software FEMLAB by COMSOL is used to model and analyze the field distribution of the TWS system. FEMLAB (COMSOL 3.3) solves all kind of scientific and engineering problems based on partial differential equations (PDEs).



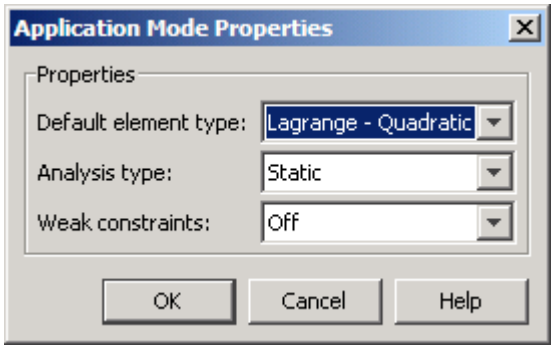


Figure 5.1: FEMLAB (COMSOL) model navigator for 2D modelling

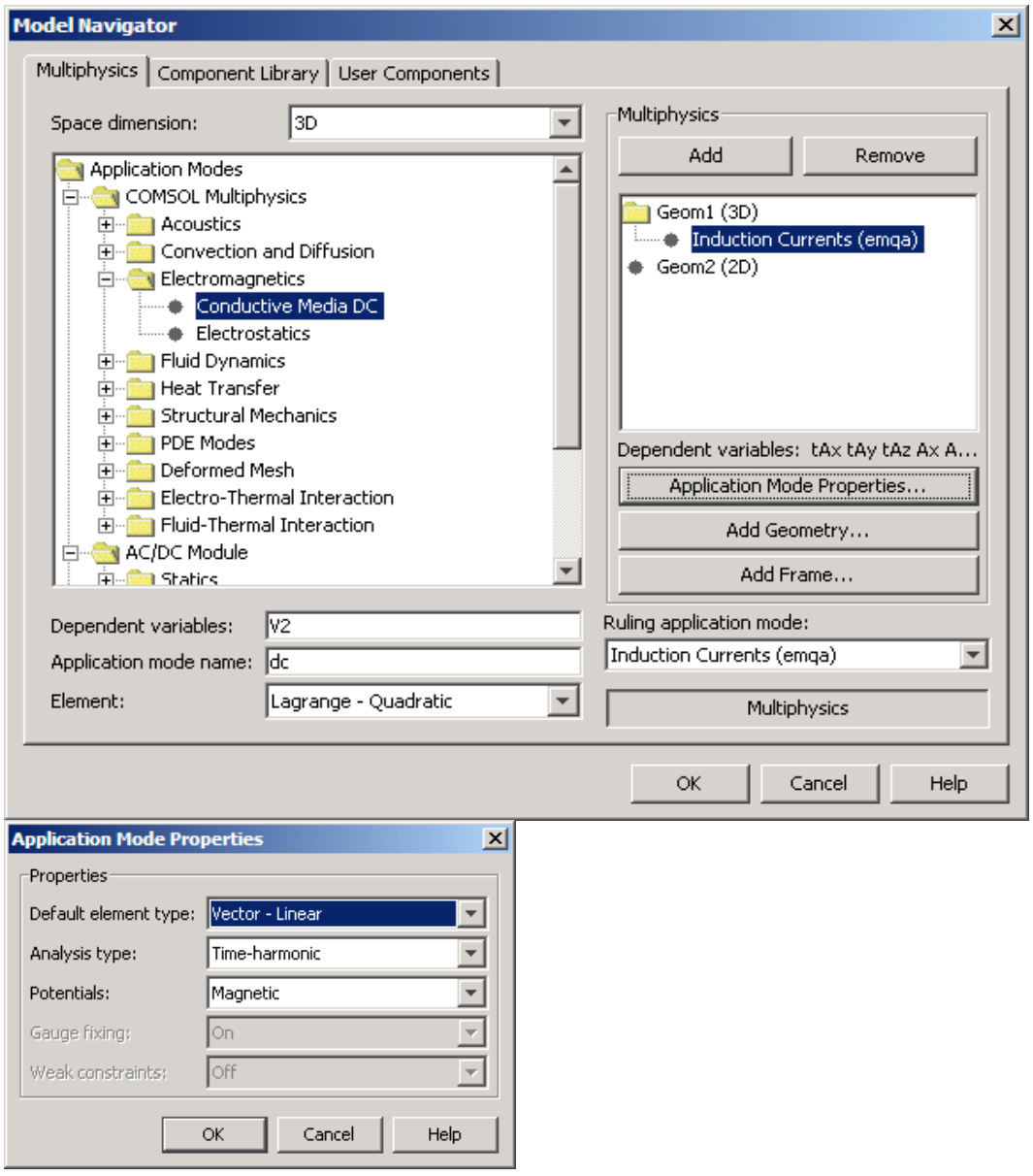


Figure 5.2: FEMLAB (COMSOL) model navigator for 3D modelling

In the model navigator “Multiphysics” is chosen since electric and/or magnetic fields are used to model the magnetic circle. Electromagnetics Module in 2-D mode magnetostatics (qa) and the in 3-D mode conductive media DC (emqa) is selected as shown in figure 5.1 and figure 5.2.

One of the effects of Maxwell’s equation is that there is no synchronization between the changes of t he electromagnetic field and changes in time of currents and charges. Due to the finite aped of propagation of electromagnetic waves the changes of the fields are always not in line with respect to the changes of the sources. Magnetostatic approximation involves ignoring this effect, and obtaining electromagnetic fields by considering stationary current at every instant.

Hence Maxwell’s equations can be written as:

$$\nabla \times H = J = \sigma(E + v \times B) + J^e \qquad [5.1]$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad [5.2]$$

$$\nabla \bullet B = 0 \qquad [5.3]$$

$$\nabla \bullet D = \rho \qquad [5.4]$$

$$\nabla \bullet J = 0 \qquad [5.5]$$

Table 3.1: Symbols used in the derivation

Symbol	
H	Magnetic Field Strength
J^e	Externally applied current density
σ	Electrical Conductivity
E	Electrical Filed intensity
V	Velocity of the conductor
B	Magnetic Flux density
ρ	Volume charge density
D	Electric flux density

It is important that the cureent and the electromagnetic field vary slowly in a quasi – static approximation.

Using the definitions of the potentials,

$$B = \nabla \times A \qquad [5.6]$$

$$E = -\nabla V - \frac{\partial B}{\partial t} \qquad [5.7]$$

And the relationship between magnetic field, magnetic filed strength and Magnetization (M)

$$B = \mu_0 (H + M) \qquad [5.8]$$

Ampere's law can be rewritten as

$$\sigma \frac{\partial A}{\partial t} + \nabla \times (\mu_0^{-1} \nabla \times A - M) - \sigma v \times (\nabla \times A) + \sigma \nabla V - J^e \qquad [5.9]$$

Where A = magnetic vector potential and μ_0 is the magnetic permeability of free space

Taking the divergence of the equation above gives the equation of continuity

$$-\nabla \cdot (\sigma \frac{\partial A}{\partial t} - \sigma v \times (\nabla \times A) + \sigma \nabla V - J^e) = 0 \qquad [5.10]$$

In the "Application Mode Properties" dialog box the default element type is given as A- vector and V – Linear. Equations 5.9 and 5.10 give a system of equation for A and V.

A time harmonic analysis is chosen as the "Analysis Type" and both electric and magnetic fields are chosen as the potentials. "Gauge Fixing" is turned on. Gauge transformation involves a variable transformation of the potentials. The electric and magnetic fields are not uniquely defined through the electric and magnetic potentials (equations 5.6 and 5.7).

Introducing two new potentials

$$\tilde{A} = A + \nabla \Psi$$
$$\tilde{V} = V - \frac{\partial \Psi}{\partial t} \qquad [5.11]$$

When substituted into equations 5.6 and 5.7 they give the same electric and magnetic fields,

$$E = -\frac{\partial A}{\partial t} - \nabla V = -\frac{\partial (\tilde{A} - \nabla \Psi)}{\partial t} - \nabla (\tilde{V} + \frac{\partial \Psi}{\partial t}) = -\frac{\partial \tilde{A}}{\partial t} - \nabla \tilde{V} \qquad [5.12]$$

$$B = \nabla \times A = \nabla \times (\tilde{A} - \nabla \Psi) = \nabla \times \tilde{A} \qquad [5.13]$$

A particular gauge is chosen to obtain a unique solution. This means that constraints are put on Ψ. A constraint can also be put $\nabla . A$ and $\nabla \times A$ are given a vector field can be uniquely defined up to a constant. Coulomb gauge ($\nabla . A$) is used.

It has been noted the amount of magnetic flux density required for the experiment to have an appreciable effect is higher than 3 T.

The magnetic circle used by Technical water Systems is shown in figure 5.3.

Figure 5.3: The magnetic circle for the generation of magnetic field used by Technical Water Systems

The magnetic field distribution of the above magnetic circle has been analyzed with the help of finite element analysis. The three dimension representation of the magnetic circle is shown in figure 5.4.

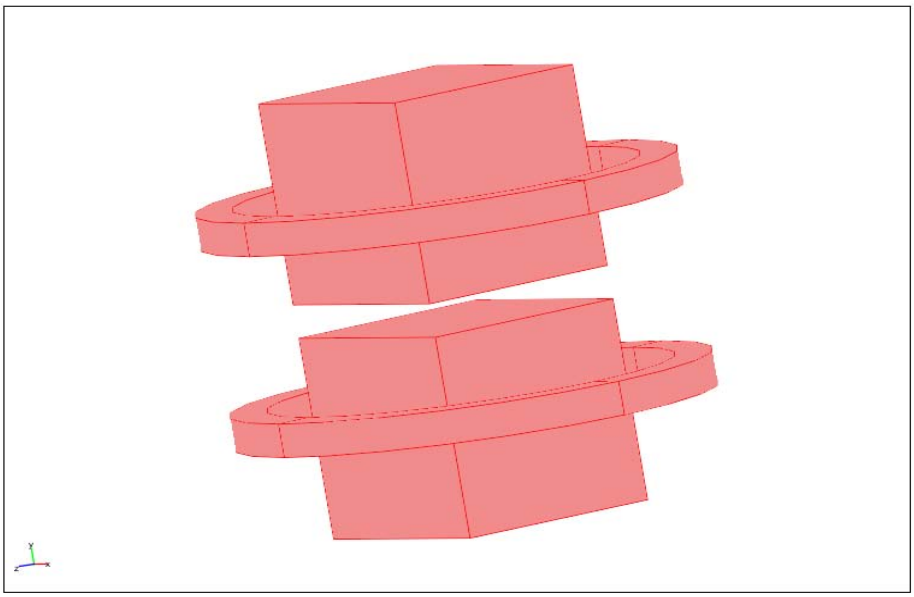


Figure 5.4: The 3-D representation of the magnetic circle

The two dimensional model of the magnetic circle has been solved. The magnetic field distribution foe the current direction of Top (+ -) and Bottom (+ -) for an exciting current of 25 A is shown in figure 5.5.

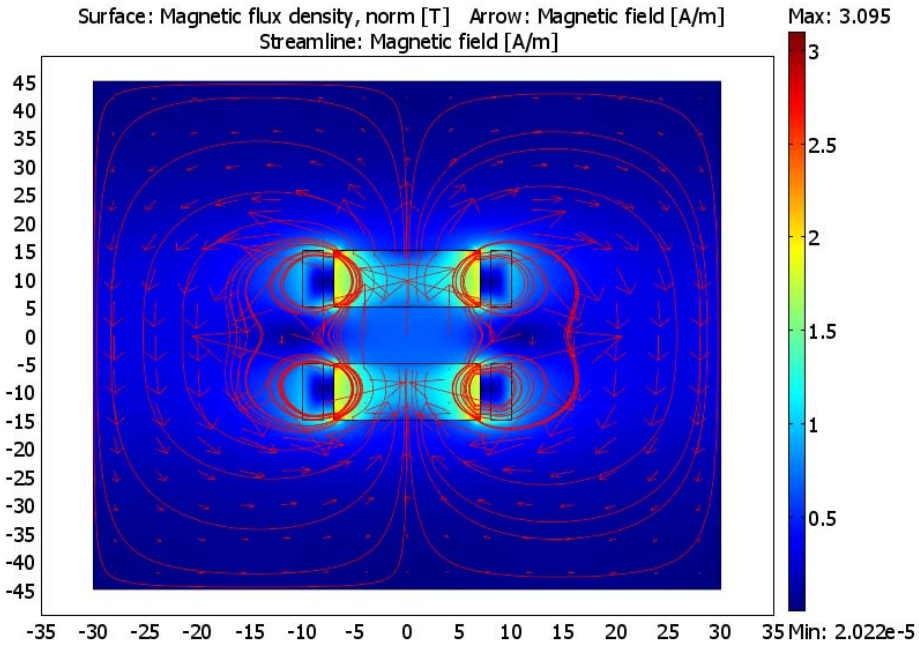


Figure 5.5: Magnetic field distribution for an exciting current of 25 A; current direction of Top (+ -) and Bottom (+ -)

The variation of magnetic flux density through the middle of the water pipe is shown in figure 5.6. It is seen that the maximum value of the magnetic flux density reached is 0.7 T.

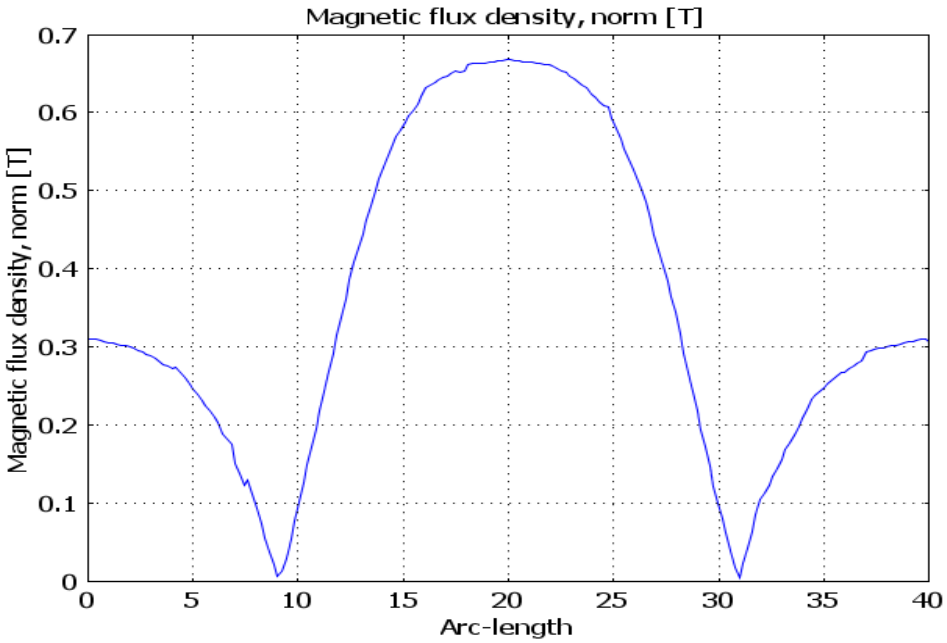


Figure 5.6: Variation of magnetic flux density through the middle of the water pipe

The variation of magnetic flux density at the middle of the water pipe as a function of current is shown in figure 5.7. The generated magnetic flux density is linearly proportional to exciting current.

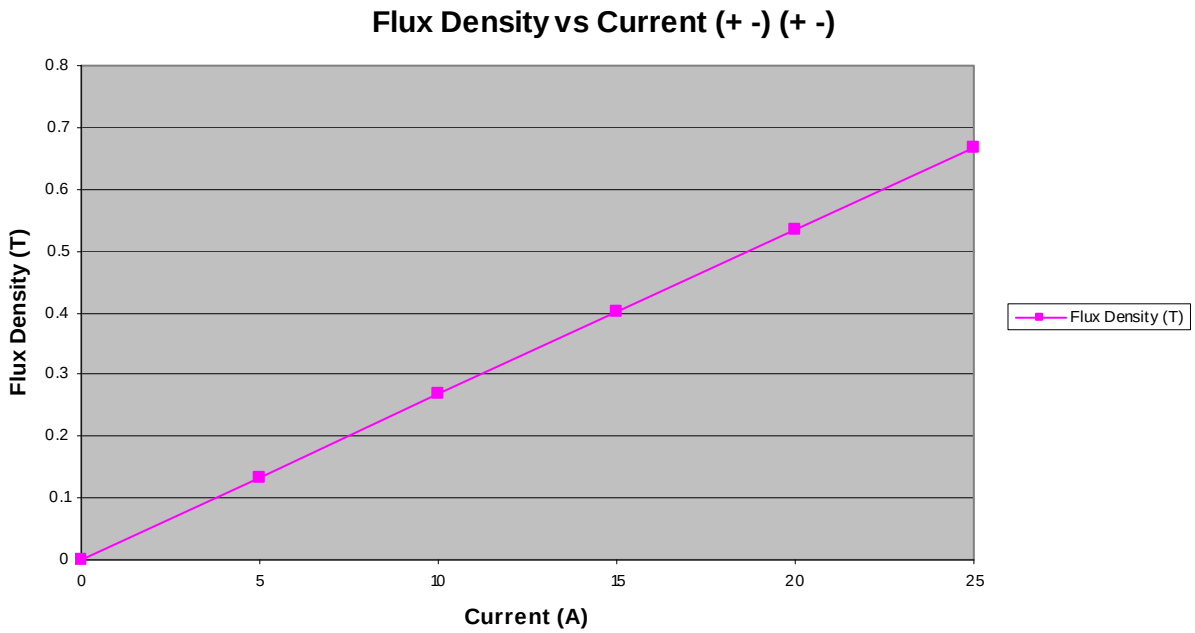


Figure 5.7: Variation of magnetic flux density as a function of exciting current

Figures 5.8 to 5.16 show the characteristics for the following three different connections of coils of the electromagnet.

(i) Top (-+) Bottom (-+)

(ii) Top (+-) Bottom (- +)

(iii) Top (- +) Bottom (+-)

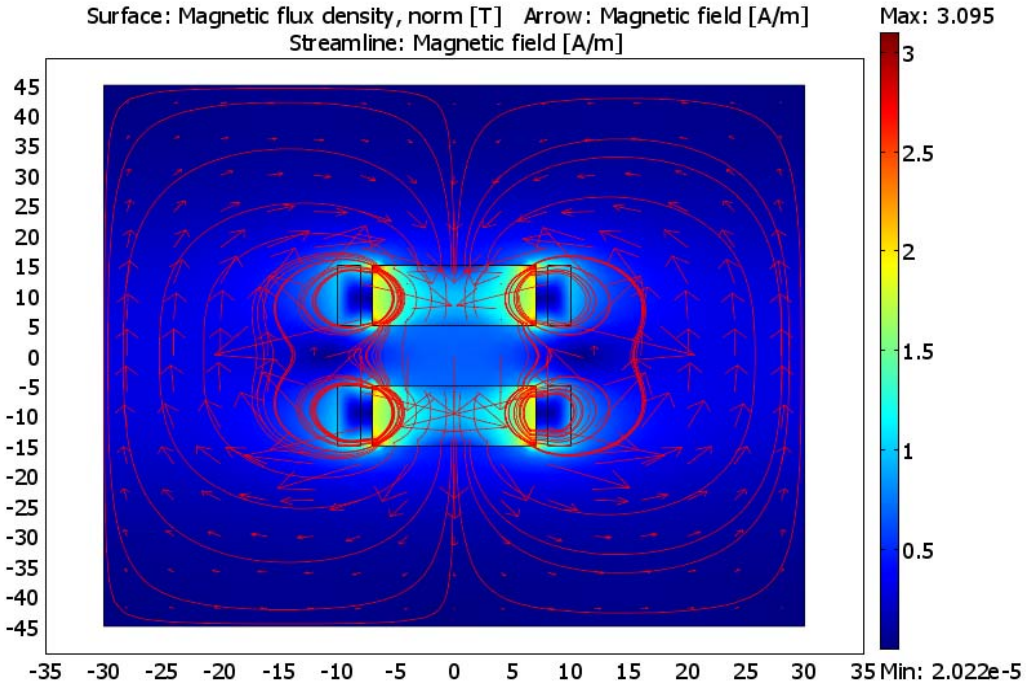


Figure 5.8: Magnetic field distribution for an exciting current of 25 A; current direction of Top (-+) and Bottom (-+)

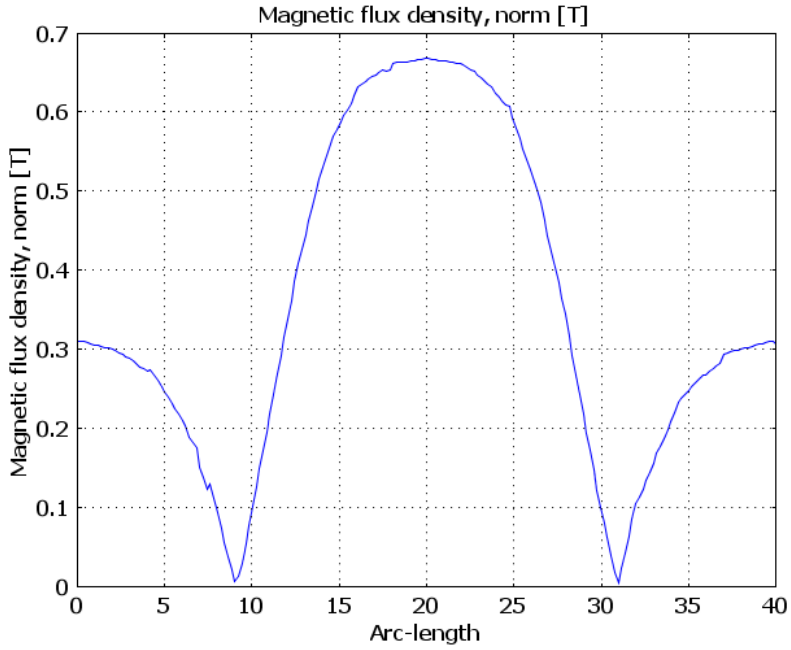


Figure 5.9: Variation of magnetic flux density through the middle of the water pipe

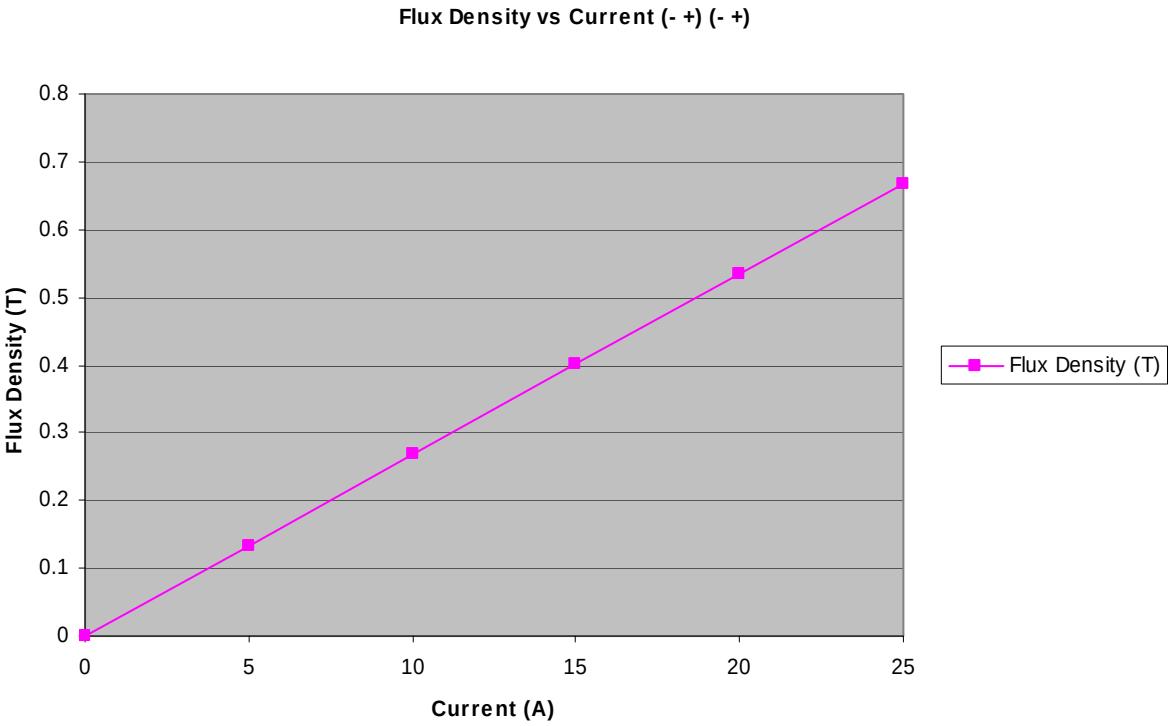


Figure 5.10: Variation of magnetic flux density as a function of exciting current

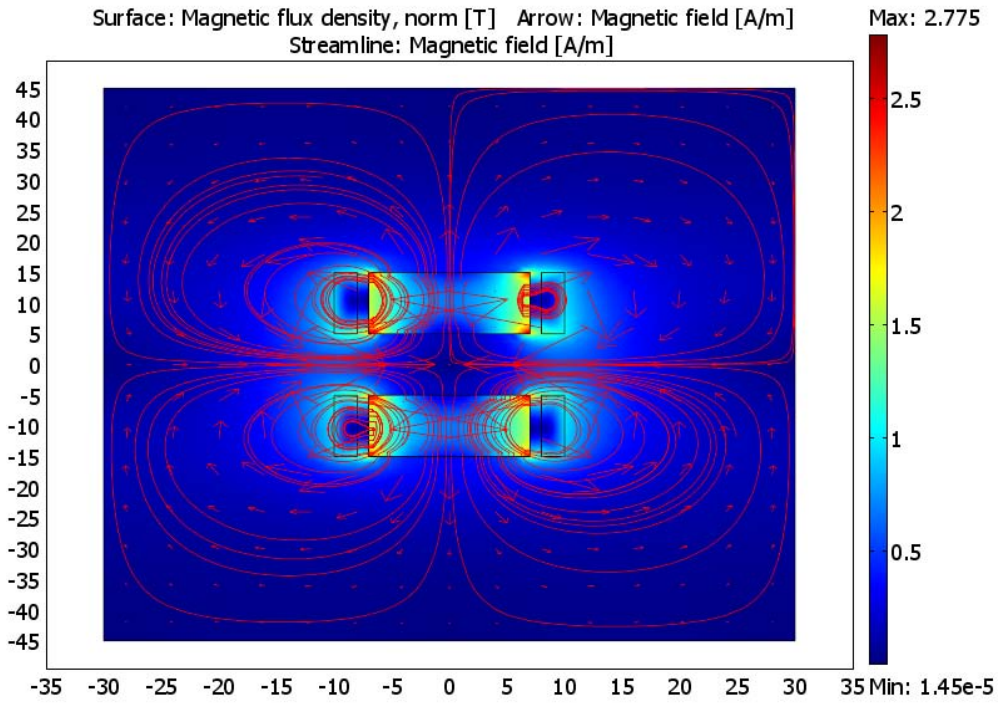


Figure 5.11: Magnetic field distribution for an exciting current of 25 A; current direction of
Top (+-) and Bottom (-+)

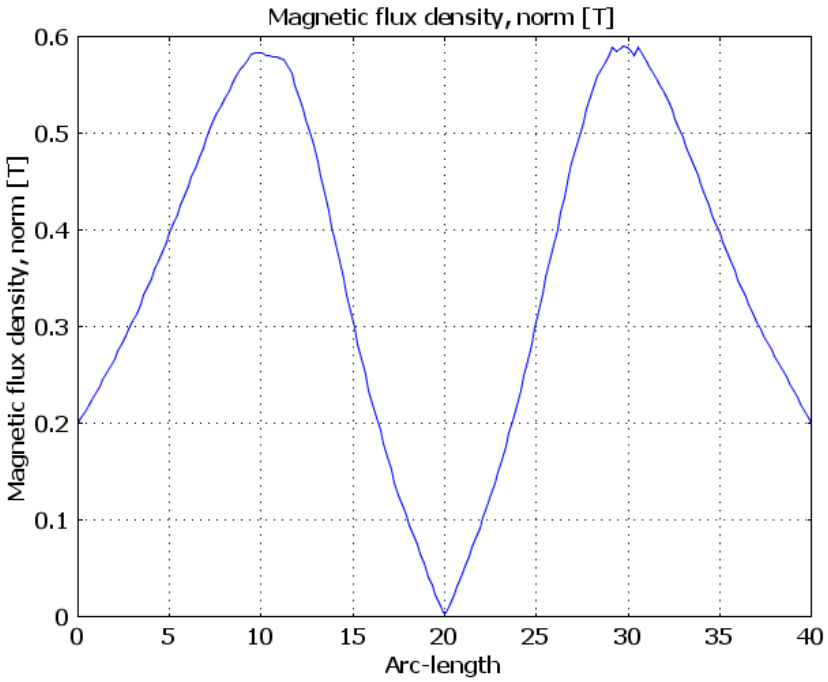


Figure 5.12: Variation of magnetic flux density through the middle of the water pipe

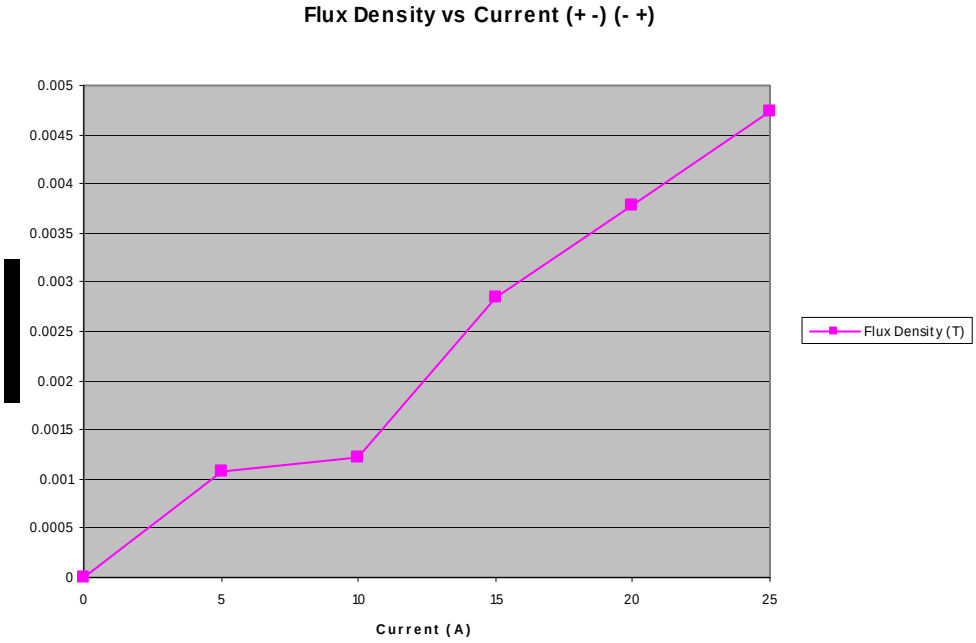


Figure 5.13: Variation of magnetic flux density as a function of exciting current

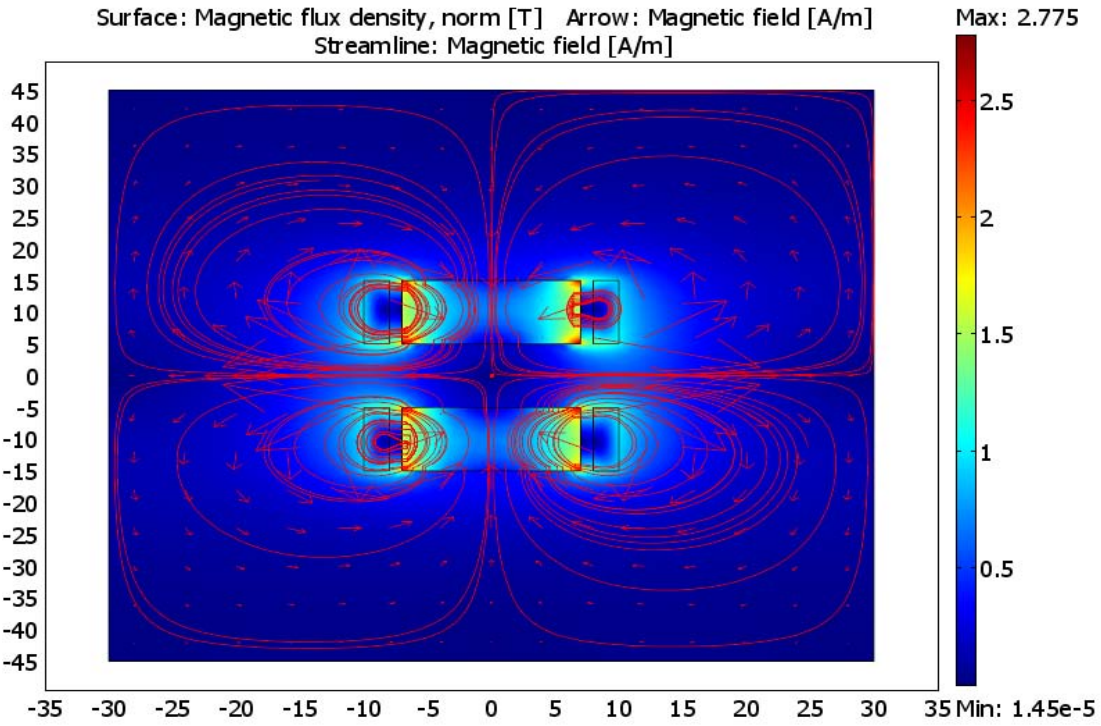


Figure 5.14: Magnetic field distribution for an exciting current of 25 A; current direction of Top (-+) and Bottom (+-)

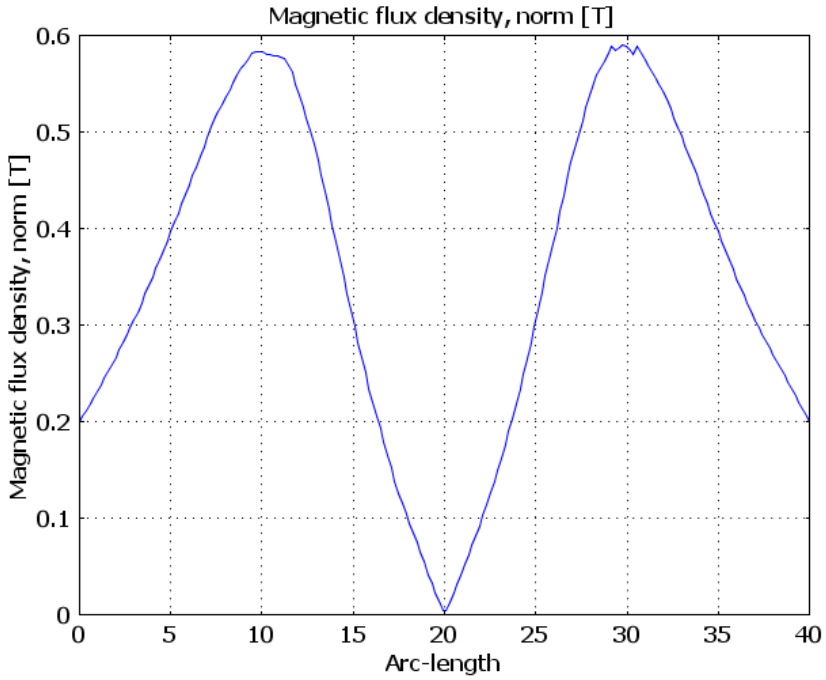


Figure 5.15: Variation of magnetic flux density through the middle of the water pipe

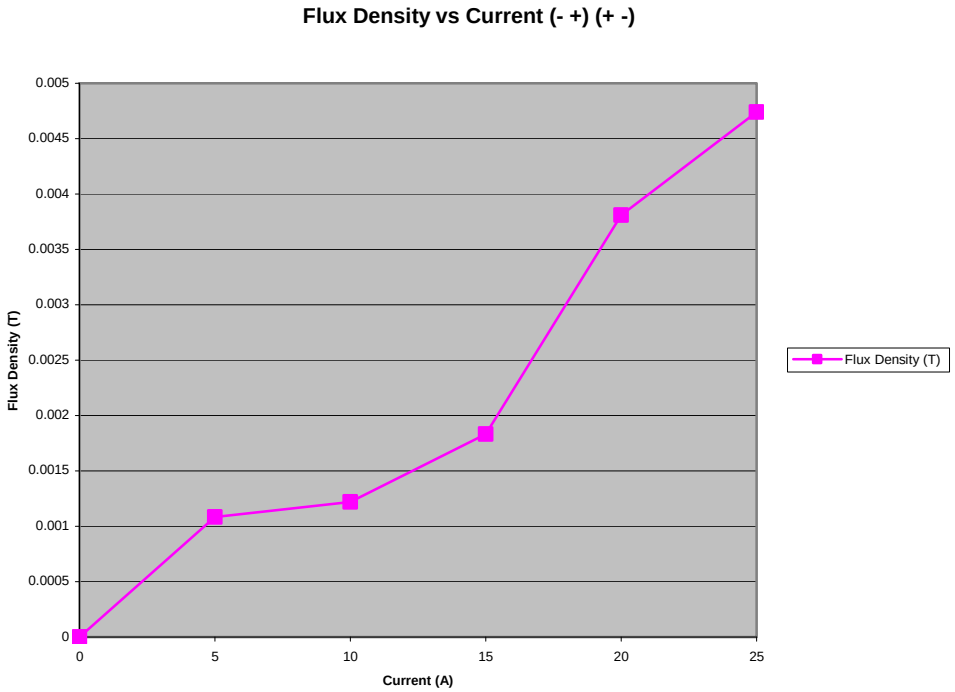


Figure 5.16: Variation of magnetic flux density as a function of exciting current

5.3 Conclusion

In this section the modelling of magnetic circle different configuration have been carried out for the analysis of field distribution, using the finite element software package COMSOL. It is seen that the magnetic flux density may be increased by increasing the current through the exciting coil of the electromagnet. This might lead to the heating problem of the magnetic circle. So a proper field and thermal analysis of the magnetic circle is important. It is also very necessary to investigate different ways of increasing the magnetic flux density produced by the magnetic circle.

CHAPATER 6

EXPERIMENTS AND RESULTS

6.1 Introduction

In the previous chapter TWS system (Magnetic Circle) was modelled using finite element analysis and characteristics obtained using MATLAB were presented. This section aims to support the results obtained from field modelling of the earlier chapter, by experimenting with different experimental set ups and the results are presented in this chapter.

6.2 Experimental Set Up

The experimental set ups are shown in following figures 6.1 and 6.2. As shown in figure 6.1 between the two electromagnets glass text tube had been placed. An iron bar also had been placed inside the text test tube. Using a DC power supply unit two electromagnets were powered. In second experimental set up (figure 6.2) copper wire (100 turns) had been wrapped around the test tube. And both times water with magnetic contaminants had been poured in to the test tube and at the bottom of the test tube water had been collected. And all the results plotted using Microsoft-excel are presented below.

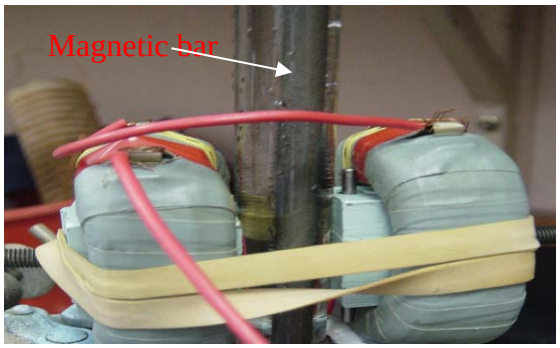


Figure 6.1: Experiment set up

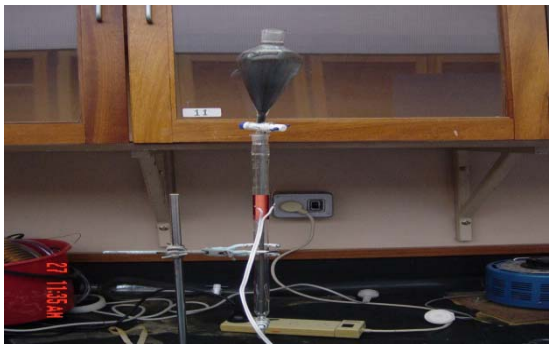


Figure 6.2: Experiment set up using copper wire

Using tesla meter the flux density at the mid-point between two electromagnets has been measured and the results are shown in table 1 and figure 6.3. It is seen from the table 6.1 and the figure 6.3 that when the distance between two electromagnets increases flux density gradually decreases. The diameter of the test tube used during this experiment is about 20mm. So the distance between the electromagnets is kept at 20mm and gradually increase the current has been increases to investigate the

relationship between flux density and current. We can see from the table 6.2 and figure 6.4 that once the current increases flux density also gradually increases. All the flux density measurements are measured using a tesla meter.

Table 6.1: Flux density between two electromagnets for different distances

Distance (mm)	Flux Density (T)
10	0.04548
15	0.0351
20	0.02742
25	0.02634

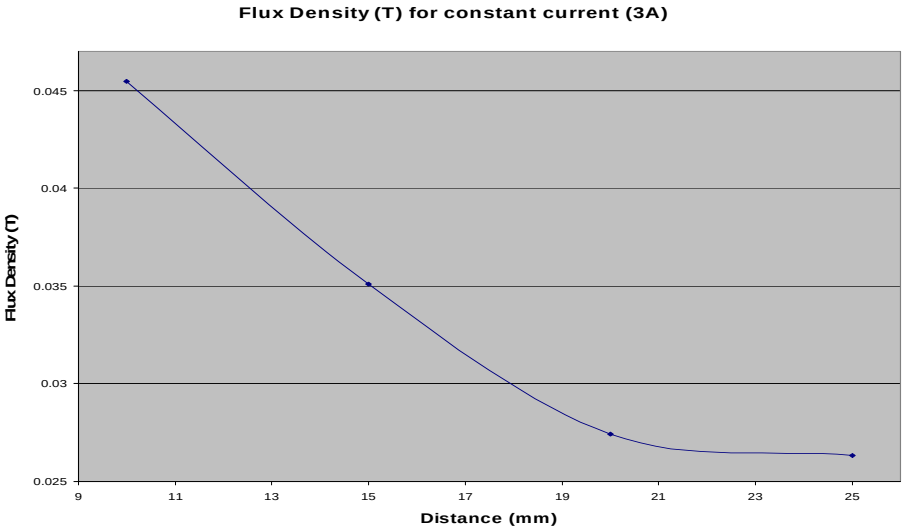


Figure 6.3: Relationship between flux density against distance

Table 6.2: Flux density between two electromagnets for different currents at a distance of 20mm

Current(A)	Flux Density (T)
1	0.0111
2	0.0212
3	0.02742
4	0.04391
5	0.07451

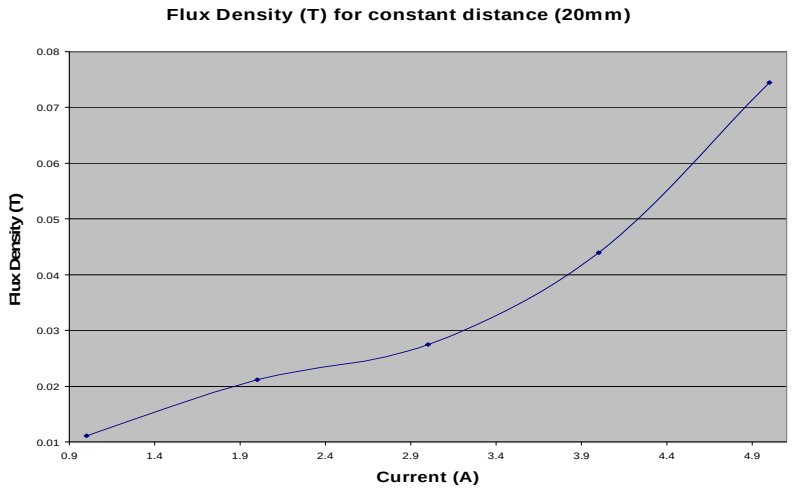


Figure 6.4: Relationship between flux density against current

Experimental set up as is shown in figure 6.1. An iron bar has been placed in the middle of the pipe to investigate the percentage of the magnetic particles that are attracted. It is seen from the table 6.3 that parentage weight attracted increases with the increase in current.

Table 6.3: percentage of weight attracted for different current settings

Current	% weight attracted
0A	0
1A	85.77199
2A	90.68991
3A	92.81442
4A	97.04396

Using the knowledge in previous experiments it was decided to do another experiment using 5 micron filter. Experimental set up is shown in figure 6.3 and figure 6.4. This experiment set is very similar to earlier experimental set ups. Only difference is the particles size bigger than 5-micron doesn't go through the filter. 100 turns had been wrapped around the filter and powered by DC power supply (Figure 6.3). An iron bar had been included in the middle of the filter to attract all the magnetized particles. Using two electric pumps water had been sent through the system. Experimental results are every similar to earlier value.

So this set up could use as a mechanical filter as well as a magnetic filter. This can relate to the TWS filter. At the moment TWS is using their SCUD as a purely a mechanical filter. But this experiment set up can improve the performance of the TWS filter.

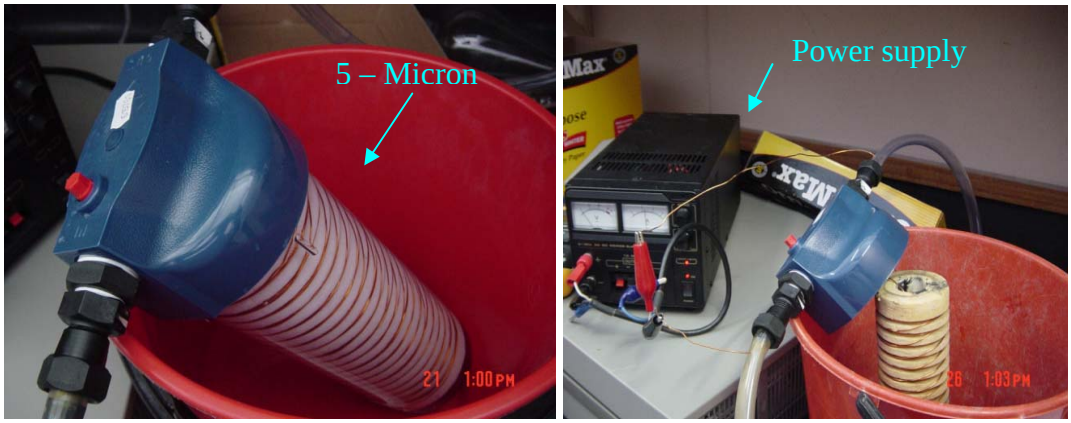


Figure 6.3: Experiment set up with 5 – micron filter

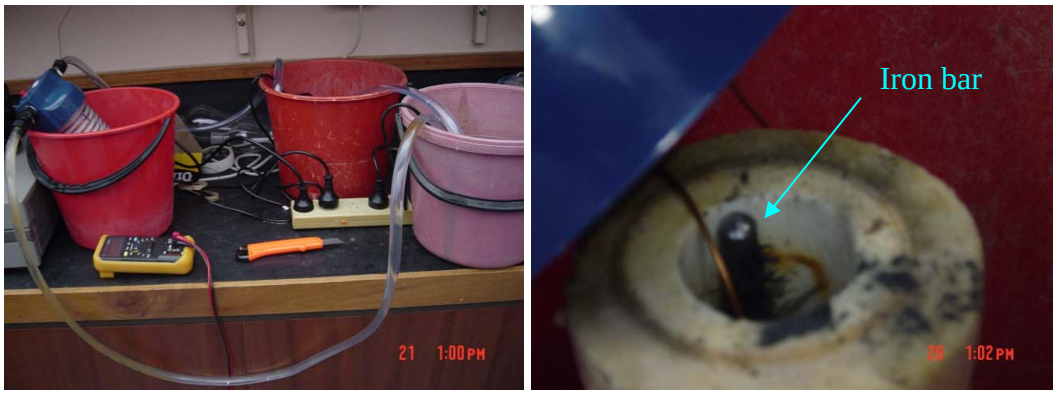


Figure 6.4: another view of experiment set up with 5 – micron filter and iron bar included in the middle of the filter

6.2.1 Development of a new system

We could see from the FEMLAB analysis that (chapter 5) TWS magnetic circle doesn't produce enough magnetic field to separate the particles from water as well as to give a separate path. A new design to produce higher magnetic field as well the higher gradient to give a better results has been planned. Figure 6.5 and Figure 6.6 shows the model and the actual design of the coil system. The new system has three rectangular coils and two circular coils each coil has 75 turns wrapped around. Actual experimental set up is shown in figure 6.7. It is seen in the figure 6.7 two power

supply units are required that's because complete system uses a two different current settings. First using a tesla meter magnetic field is measured to investigate the best place to keep the separation chamber (Figure 6.8).

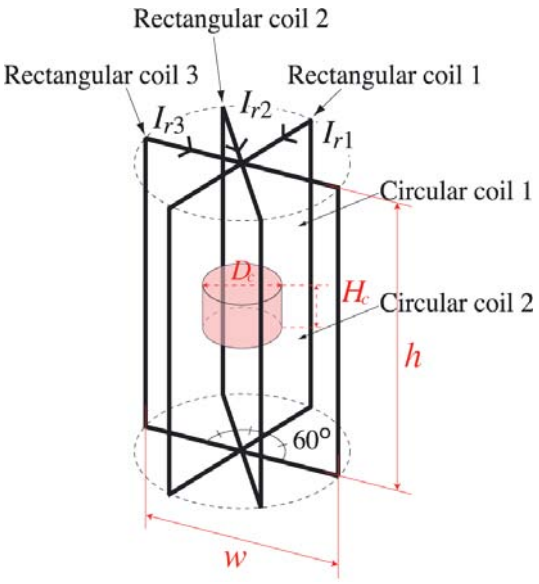


Figure 6.5: Model of the new design

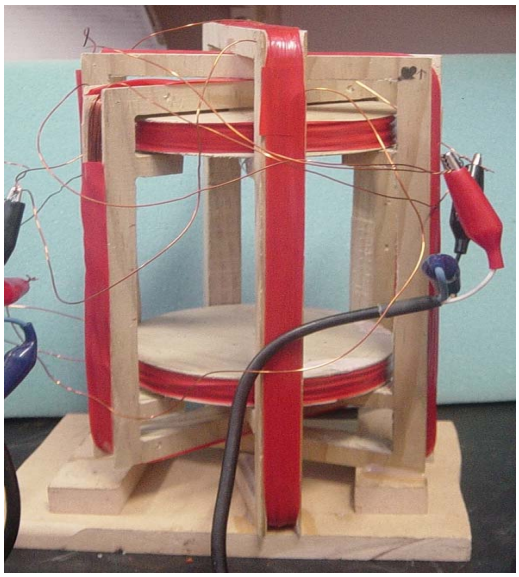


Figure 6.6: Actual design with coils

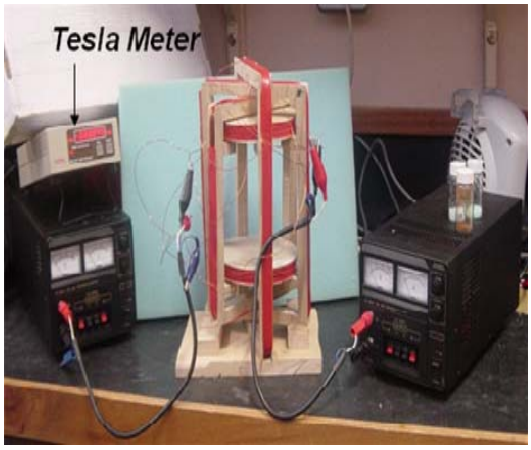


Figure 6.7: Actual experiment set up with coil design

Figure 6.8: Separation chamber

The principle of operation of the new coil system is shown pictorially in figure 6.10.

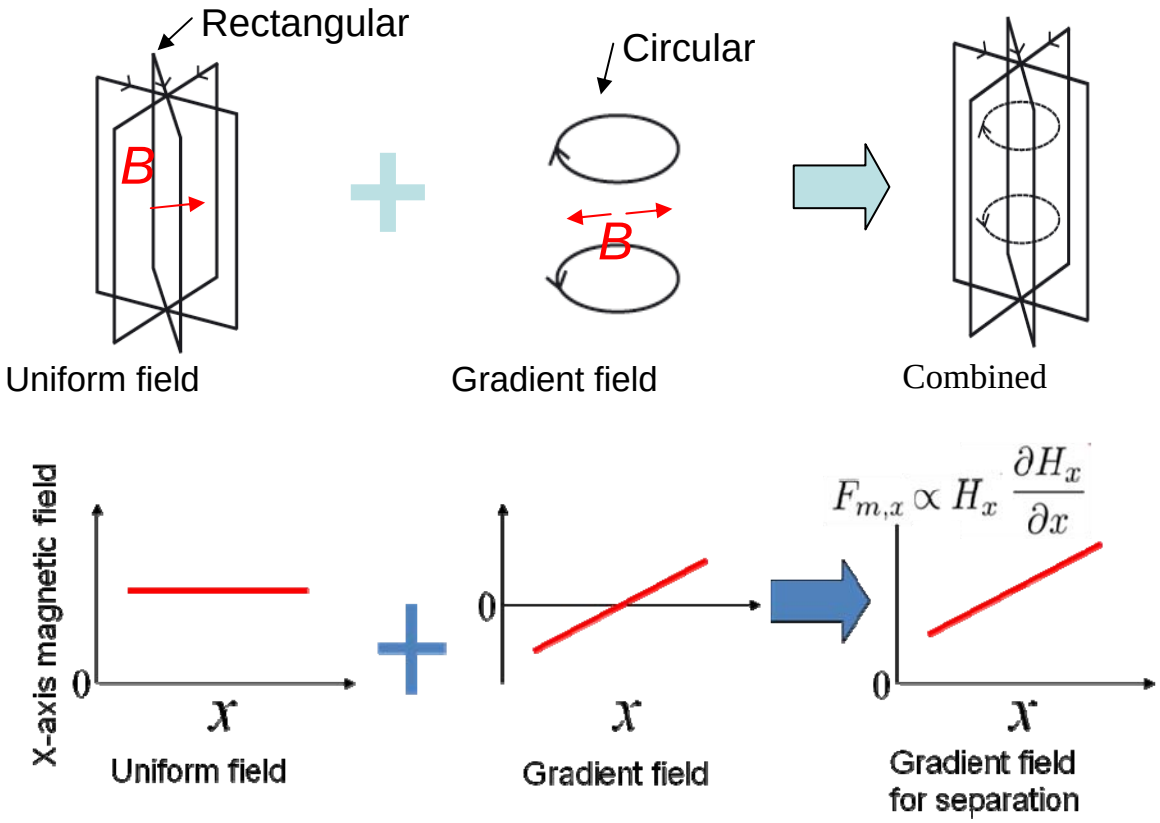


Figure 6.10: representation of generating gradient magnetic field using rectangular coils and circular coils

Figure 6.10 shows the how the uniform field and the gradient of the magnetic field had been created. Two circular coils generate the gradient of the field and three rectangular coils generate a uniform field.

$$F_{m,x} \propto H_x \frac{\partial H_x}{\partial x} \qquad [6.1]$$

As shown in equation 6.1we could see that magnetic field generated by the new design is proportional to uniform field and the gradient of the field.

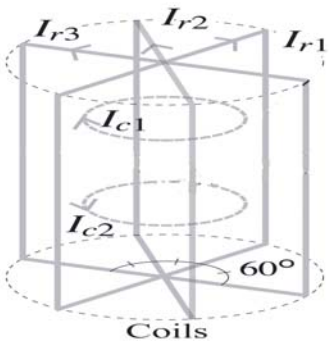


Figure 6.11: Current representation of the new design

Table 6.4: Different current settings for each coil

Currents of coils	Current strength (A)
I_{r1}, I_{r3}	1.5A
I_{r2}, I_{c1}, I_{c2}	3A

As shown in figure 6.11 and table 6.4 current strength of I_{r1}, I_{r3} rectangular coils are 1.5A and the current strength of I_{r2}, I_{c1}, I_{c2} one rectangular coil and the two circular coils are 3A.

6.2.2 Results

Actual experimental set up is shown in figure 6.7. And using a tesla meter magnetic field had been measured at middle. As shown in figure 6.12 middle space has been divided in to fifteen sections. All the field values were recorded horizontally as well as vertically. As shown in figure 6.12 grid of values had been taken using the tesla meter. And all the results had been plotted using Microsoft excel is presented below.

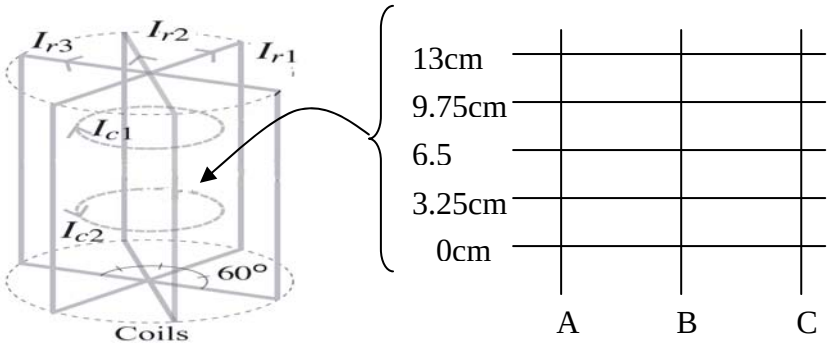


Figure 6.12: Field representation of the new design

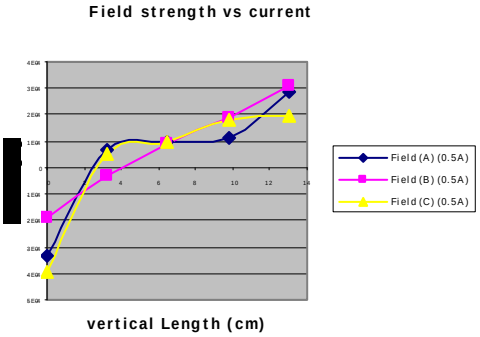


Figure 6.13: field strength at current I_{r1}, I_{r3} = 0.5A and I_{r2}, I_{c1}, I_{c2} = 1A

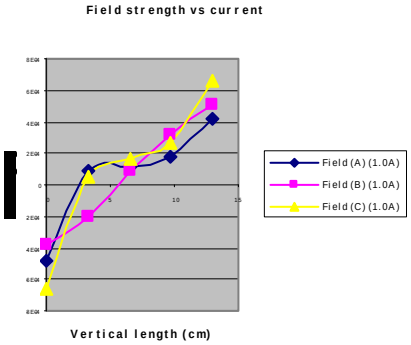


Figure 6.14: Filed strength at current I_{r1}, I_{r3} = 1.0A and I_{r2}, I_{c1}, I_{c2} = 2A

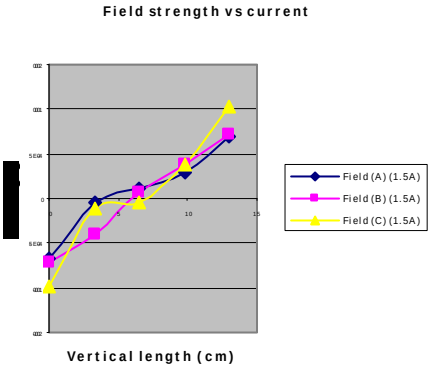


Figure 6.15: field strength at current I_{r1}, I_{r3} = 1.5A and I_{r2}, I_{c1}, I_{c2} = 3A

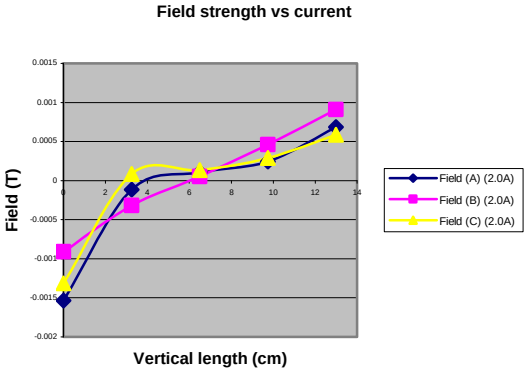


Figure 6.16: field strength at current I_{r1}, I_{r3} = 2A and I_{r2}, I_{c1}, I_{c2} = 4A

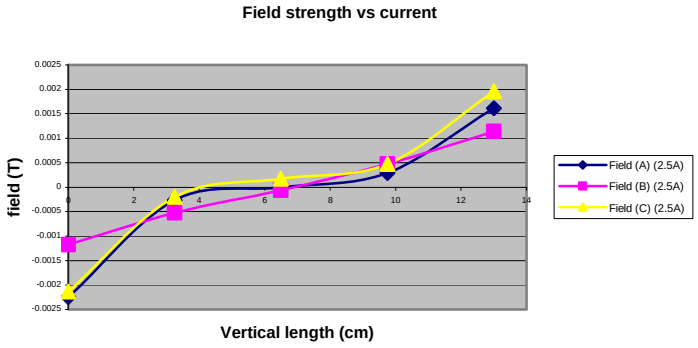


Figure 6.17: field strength at current I_{r1}, I_{r3} = 2.5A and I_{r2}, I_{c1}, I_{c2} = 5A

Above figures (6.13 to 6.17) represent field strength for different current values. And also distance varies vertically. Similarly we could see from above figures (6.13 to 6.17) when the current increase field strength also increases. And also we could see that in the middle field strength increase is quite steady. Close to the circular coils field strength is bit higher than everywhere else.

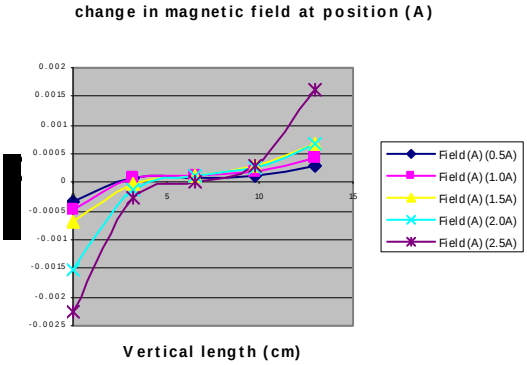


Figure 6.18: Change in field strength at position A for different current settings

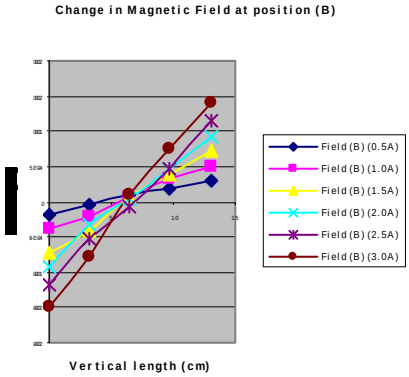


Figure 6.19: Change in field strength at position B for different current settings

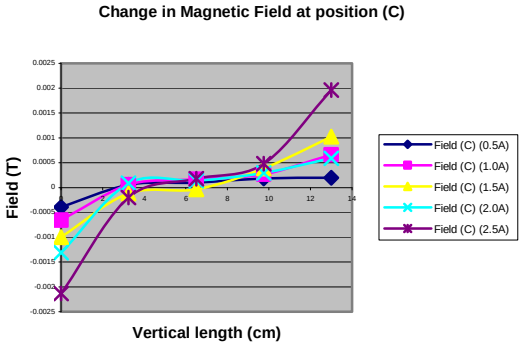


Figure 6.20: Change in field strength at position C for different

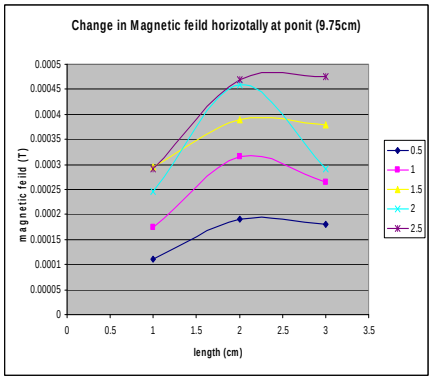


Figure 6.21: Change in magnetic field horizontally at point 9.75cm

Above figures represents change in field strength at positions A, B and C for different current values. We could see from the figures (6.18 to 6.20) that increase in current has slight increase in field strength. Again at the middle increase in field strength is very steady. We could also see that close to the circular coils field strength is bit higher than everywhere else. And from figure 6.21 we could see that at the middle field strength increases with current and also very steady.

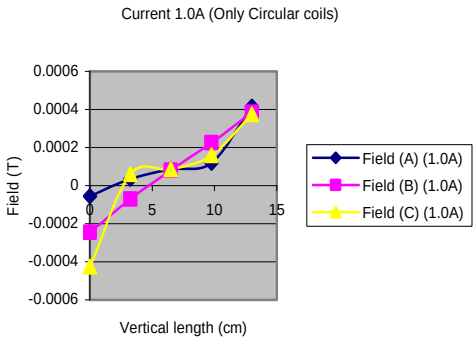


Figure 6.22: Change in magnetic field strength at current 1.0A (only circular coils are present)

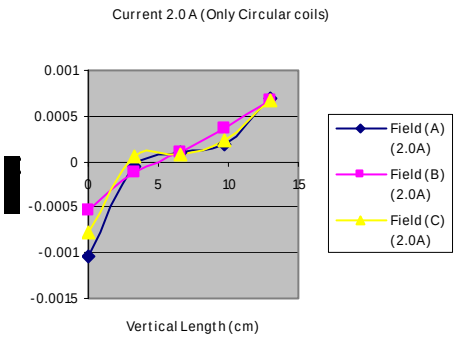


Figure 6.23: Change in magnetic field strength at current 2.0A (only circular coils are present)

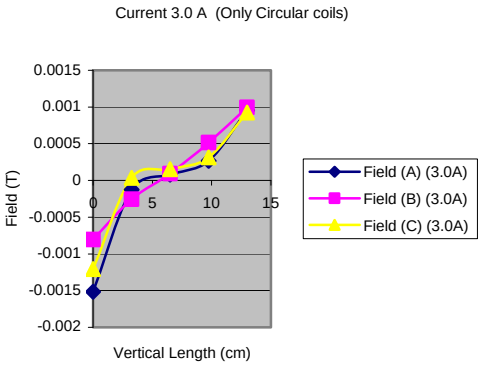


Figure 6.24: Change in magnetic field strength at current 3.0A (only circular coils are present)

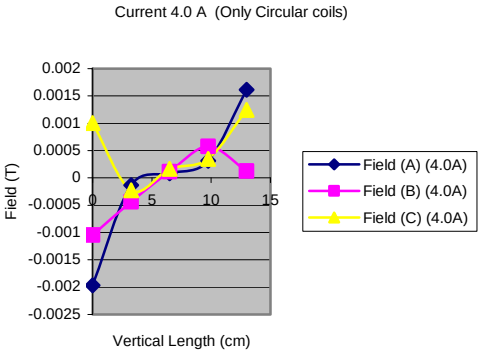


Figure 6.25: Change in magnetic field strength at current 4.0A (only circular coils are present)

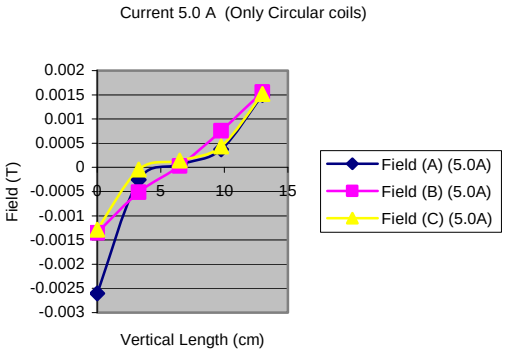


Figure 6.26: Change in magnetic field strength at current 5.0A (only circular coils are present)

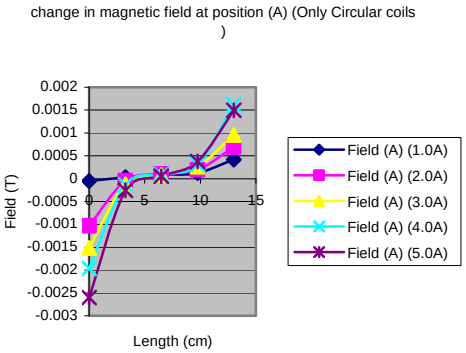


Figure 6.27: Change in magnetic field strength at position (A) (only circular coils are present)

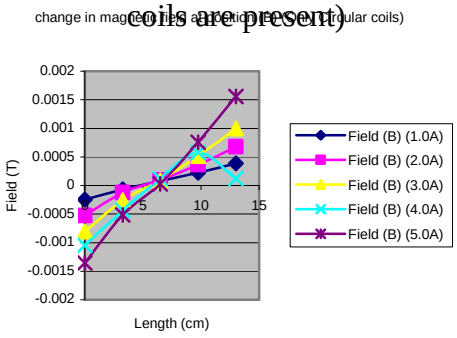


Figure 6.28: Change in magnetic field strength at position (B) (only circular coils are present)

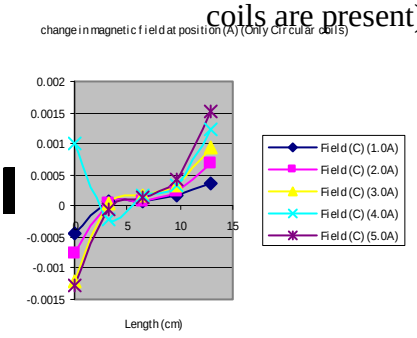


Figure 6.29: Change in magnetic field strength at position (C) (only circular coils are present)

Above figures 6.22 to 9.29 represent the change magnetic field strength only circular coils are present. First field strength had been measured by changing the vertical distance and current. All the values are plotted using Microsoft excel. We could see

that from figures 6.22 to 6.26 that field strength increases in increases in current. And from figures 6.27 to 6.29 at fixed horizontal points field strength had been measured by varying vertical distance. We could see that with change in horizontal distance values of field strength magnitude remains the same. And I have presented some more results with only rectangular coils are used.

Following figures 6.30 to 6.36 represent the change in magnetic field strength when only rectangular coils are present.

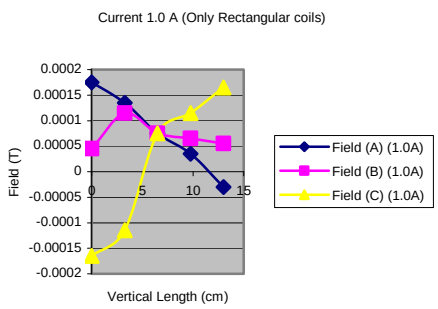


Figure 6.30: Change in magnetic field strength at current 1.0A (only rectangular coils are present)

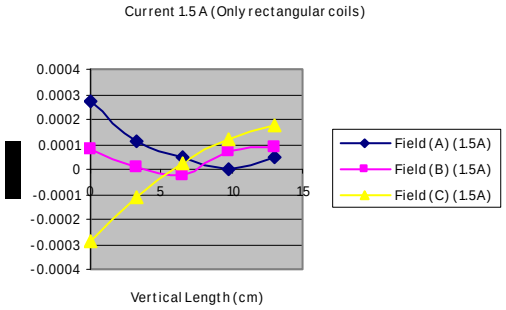


Figure 6.31: Change in magnetic field strength at current 2.0A (only rectangular coils are present)

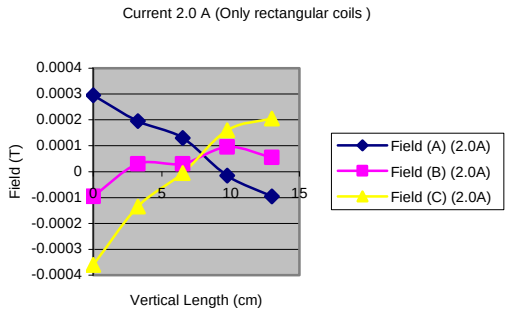


Figure 6.32: Change in magnetic field strength at current 2.0A (only rectangular coils are present)

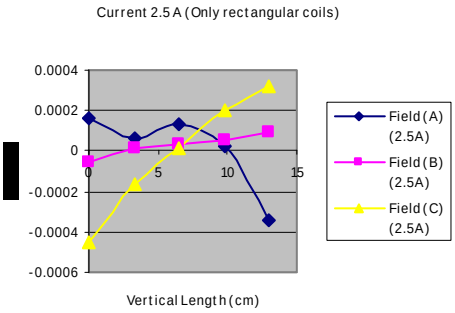


Figure 6.33: Change in magnetic field strength at current 2.5A (only rectangular coils are present)

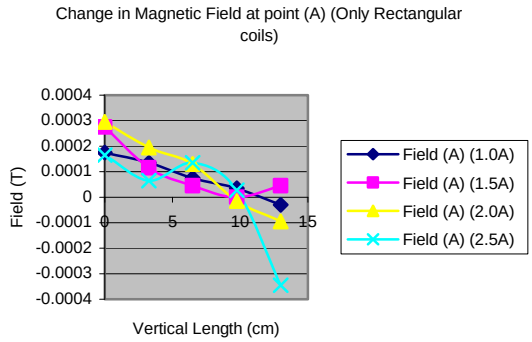


Figure 6.34: Change in magnetic field strength at position (A) (only rectangular coils are present)

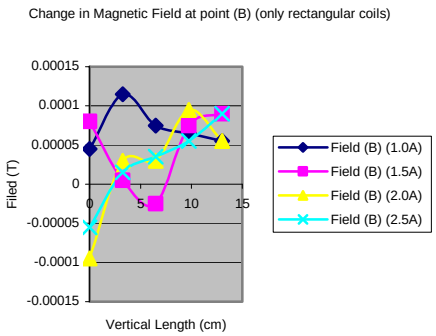


Figure 6.35: Change in magnetic field strength at position (B) (only circular coils are present)

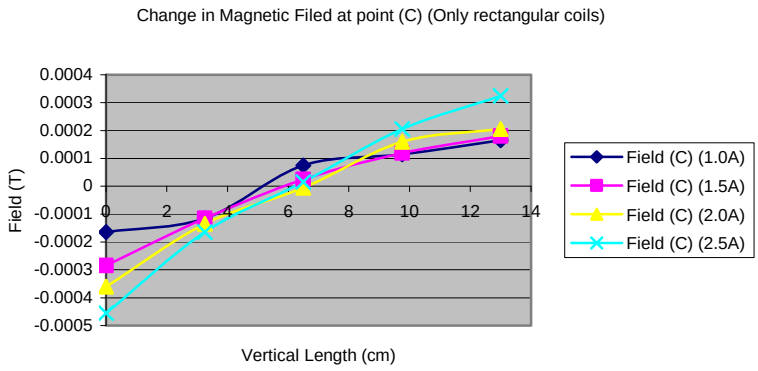


Figure 6.36: Change in magnetic field strength at position (A)
(only rectangular coils are present)

6.3 Conclusion

It has been explained earlier SCUD can be used as a mechanical filter as well as a magnetic filter using figure 6.38 design. It is expected to obtain better filtration performance compared to the existing system.

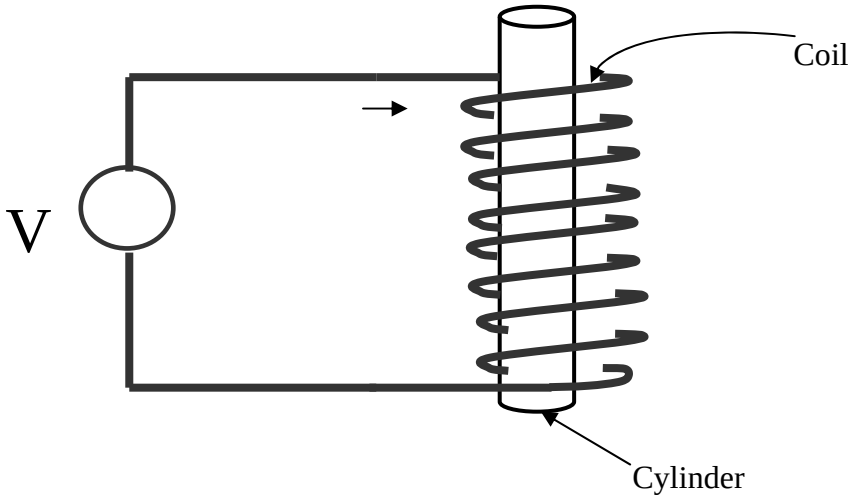


Figure 6.38: Design improvement for SCUD

The design as shown in figure 6.39 provided good simulation as well as experimental results. Some more experiments need to be carried out to determine the optimum size, current for optimum performance.

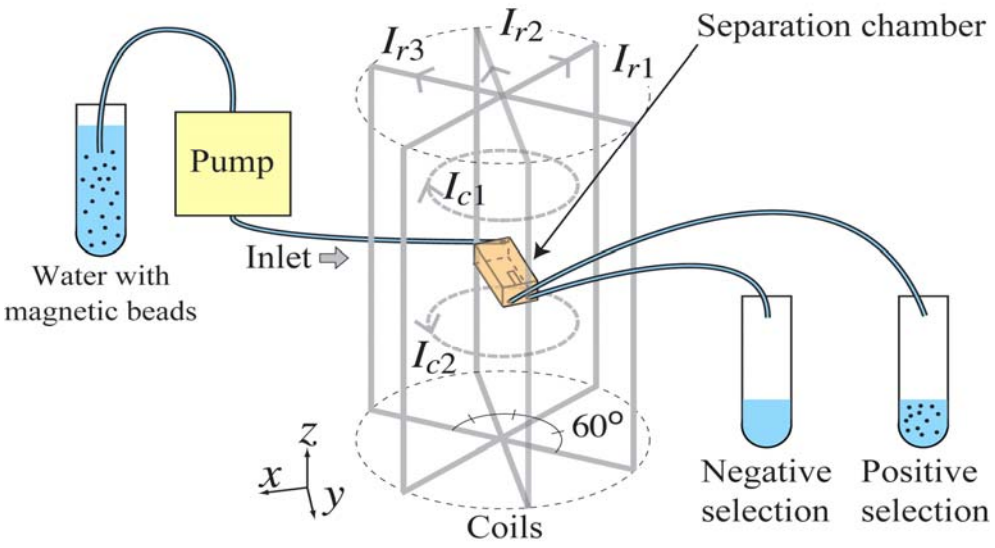


Figure 6.39: system under test (New Design)

CHAPTER 7
SENSORS and SENSOR NETWORKS IN WATER QUALITY MONITORING

7.1 Introduction

Water is of vital importance to the community for its life-supporting capacity and cultural, aesthetic, recreational and economic value. Water is essential to human life and to the health of the environment. As a valuable natural resource, it comprises marine, estuarine, freshwater and groundwater environments, across coastal and inland areas. Water has two dimensions that are closely linked - quantity and quality. Water quality is commonly defined by its physical, chemical, biological and aesthetic characteristics. A healthy environment is one in which the water quality supports a rich and varied community of organisms and protects public health.

Drinking water contamination is critically important in protecting the environment, human and animal life, community health and the economy. The value of real-time environmental monitoring and prediction has become increasingly important given the atmosphere that has been created by the potential for both accidental and intentional introduction of contaminants in water supply.

7.2 Water Quality parameters and monitoring

In water quality monitoring water temperature, total dissolved solids (TDS), pH, Dissolved Oxygen (DO), Turbidity and chemical oxygen demand (COD) are the most important parameters.

7.2.1 Water Temperature

Knowledge of water temperature is important because temperature is a critical factor in determining where marine organisms live and how well they thrive.

Temperature also affects the solubility of oxygen in water. Dissolved oxygen is critical for the survival of aquatic of organisms that use it in respiration as the water temperature increases, the solubility of oxygen decreases. Using a temperature sensor measures the temperature of the water.

7.2.2 Total Dissolved Solids (TDS)

Total dissolved solids are the total amount of mobile charged ions, including minerals, salts or metals dissolved in a given volume of water, expressed in units of mg per unit volume of water (mg/L), also referred to as parts per million (ppm). TDS is directly related to the purity of water and the quality of water purification systems and affects everything that consumes, lives in, or uses water, whether organic or inorganic.

7.2.3 pH

The pH of a solution is a measure of its acidity. The pH is defined as the negative logarithm of the hydrogen ion concentration is solution, and the pH scale ranges from 0 to 14. Distilled water is neutral and has a pH of 7.

Solutions with a pH less than 7 are acidic, and those with pH grater than 7 are basic (alkaline). Because the scale is logarithmic, when the pH increases or decreases by a whole number, the acidity changes by a factor of 10. Using a pH probes measures the pH difference in the water.

7.2.4 Dissolved Oxygen (DO)

Oxygen saturation is a relative measure of the amount of oxygen that is dissolved or carried in a given medium. The concentration of dissolved oxygen in water is affected by many factors including ambient temperature, atmospheric pressure and ion activity. Accurate data on the concentration of dissolved oxygen (DO) in environmental water resources are essential for documenting changes that result from natural phenomena and human activities. Sources of DO in water include atmospheric aeration and photosynthetic activities of aquatic plants. Many chemical and biological reactions in ground water and surface water depend directly or indirectly on the amount of available oxygen. Dissolved oxygen is necessary in aquatic systems for the survival and growth of many aquatic organisms and is used as an indicator of the health of surface- water bodies.

7.2.5 Turbidity

Turbidity is a measure of the ability for light to transmit down through the water. Turbidity refers to how clear the water is. Turbidity is linked to the look of water and therefore the public’s perception of water quality. People generally prefer water of

high clarity for recreation and consumption. The turbidity of the water is determined by the type of river bottom, the pollutants, or the plant and animal life in the river. Turbidity is commonly linked to total suspended solids (TSS) because water with high TSS levels typically looks murkier and have higher turbidity measurements. Common suspended solids are clay, silt, and sand from soils, phytoplankton (suspended algae), bits of decaying vegetation, industrial wastes and sewage.

7.2.6 Chemical Oxygen Demand (COD)

Chemical oxygen demand was used as a measure of purification of the water. In environmental chemistry, the chemical oxygen demand (COD) test is commonly used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in surface water (e.g. lakes and rivers), making COD a useful measure of water quality. It is expressed in milligrams per litre (mg/L), which indicates the mass of oxygen consumed per litre of solution. Older references may express the units as parts per million (ppm).

7.3 How to measure the water quality parameters

A taste sensor, the electronic tongue, has been used to differentiate the quality of water. One method is called LAPV (amplitude pulse voltammetry) principle. In this method current is measured at different potentials. Measured current is indicate the redox-active components that are either oxidized or reduced at the working electrode.

In this sensor shown in Figure 7.1 has two microelectrodes made out of gold and platinum, both with a diameter of 1mm. And all the data have been sent to the computer via a USB-based data acquisition device.

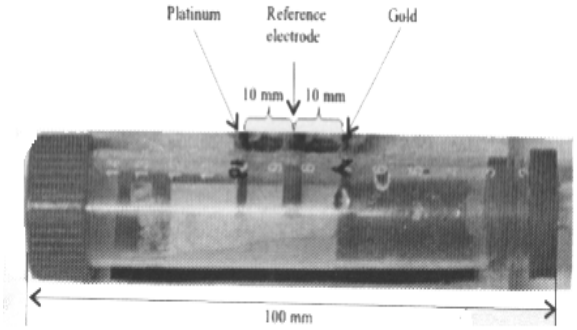


Figure 7.1: Electrode Sensor

Optical fibre sensors capable of detect low concentrations of toluene in water. It is possible to use Single-Walled Carbon Nanotubes (SWCNTs) as sensitive nanostructured material for the development of an optoelectronic sensor that can perform chemical detection in water quality. The toluene sensor has been performed by lighting the optical fibre sensing interface with a super luminescent operating at a wavelength of 310 nm and continuously monitoring the amount of reflected power.

$$I = k.\ R \qquad [7.1]$$

In the above equation I is the sensor output consists of the ratio between the signal reflected at the sensing interface and the one corresponding to the amount of power emitted and R is the film reflectance and *k* is a constant.

Image processing systems also have been used in water quality monitoring. Computer vision and dynamic image understanding to can be used in monitor the water quality.

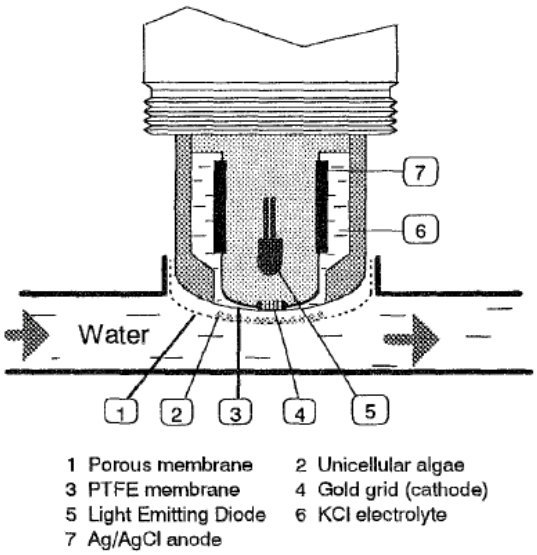


Figure 7.2: Modified clark electrode

Figure 7.2 shows a sensor is based on the common Clark electrode used for measuring dissolved oxygen concentration. Modified electrode is immersed in water when oxygen molecules migrate through the PTFE membrane the following equations (Equations 7.2 and 7.3) take place:

Cathode: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ [7.2]

Anode: $4Cl^- + 4Ag \rightarrow 4AgCl + 4e^-$ [7.3]

So the electrode current is proportional to oxygen content in water.

7.4 A review of published literature

There are lot of technical literature available on this topic. Only few of them have been described here.

In paper [50] authors discussed the development of field testing of a water quality sensor package to measure gross water parameters from buoy and other unattended marine platforms. Chlorophyll, conductivity, Dissolved Oxygen, pH, temperature and turbidity are measured.

In the paper [51] the two biosensors modified dissolved oxygen sensor and infrared chlorophyll fluorescence are described. A Biosensor has been developed to sense phytotoxic or nutrient substances in water.

The objective of paper [52] is to present the project, design and implementation of a low cost testing bath with automated temperature control for environmental monitoring sensors characterization. The developed testing apparatus proved to be an efficient tool to test and characterize sensors fro in-situ water quality monitoring.

Paper [53] describes an electronics package for a new water quality monitoring system for lakes, rivers and estuaries. This robot like system can provide early warning of water pollution, quantitative results for regulatory action and capabilities for scientific studies heretofore unavailable.

Paper [54] authors describes results obtained from the E-Tongue 3 system used in characterize residual contaminates in water. This apparatus contains nine planar electrochemical cells and a conductivity sensor and its intended for use in water quality measurements for ISS (International Space Station).

In the paper [55] authors have developed a novel deferential synchronous demodulator intended for signal conditioning in a network of conductivity sensor for water quality monitoring. The circuit merges the demodulating and low-pass filtering stages in a single integrator stage and yield the quality performance inherent to coherent demodulation with the added advantages of compactness and low-cost.

In this article [56] authors have designed and built a monitoring system of water quality to investigate process of oxygen consumption in bottom layer of the seto Inland sea. And the system consists of three main instruments. It has the specially

designed elevators in which various in situ water quality sensors are attached and the vertical distribution of water quality is obtained by moving the elevators vertically.

In this article [57] the possibility to use single – walled carbon Nantubes (SWCNTs) as sensitive nanostructured material for the development of an optoelectronic sensor that can perform chemical detection in water has been investigated and demonstrated for the first time. The sensor has been fabricated and employed in a reflectometric system involving single wavelength reflectance measurements.

Paper [58] authors explains a method based on computer dynamic image understanding to measure the water quality, which adopts computer vision to detect the ecological conditions of biological organisms, such as small fish. The water quality bio – monitoring sensor system integrates water quality bio – monitoring technology, computer vision technology and wireless network communications technology, and etc.

Article [59] explains the design of a distributed multi – platform system for water quality monitoring, enhanced with Internet capacities. Temperature, Turbidity, pH, Dissolved Oxygen, and electrical conductivity are the measured variables. There are several services offered to the user, like e-mail alarm notifications, automatic storage of measured data in a remote machine via the FTP protocol, dynamic generation of HTML reports, real time graphs and indicators visible from a remote web browser, etc.

The paper [60] describes a sensor system suitable for measuring qualitative changes in the chemical and the bacterial content in drinking water is presented. The sensor, an electronic tongue, is based on a voltammetric technique and is therefore robust, simple and sensitive to small changes of water quality in the measured sample.

In this paper [61] authors explains the interpolation of environmental data using fuzzy splines in order to monitor the water quality in a river.

Paper [62] describes a design and fabrication of the deposition chamber and ceramic substrates that form the basis for the ion selective electrodes (ISEs).

In paper [63] explain the research on The research on the optimal algorithms determination using the Hyperspectral remote sensing data willfacilitate the water quality monitoring using the multi-spectral remote sensing data, like TM, MODIS, etc.

Paper [64] describes a distribution and operation protocol for the placement and utilization of in situ environmental sensors by combining (1) new algorithms for spatial-temporal data mining, (2) new methods to model water quality and security dynamics, and (3) a sophisticated decision-analysis framework.

These authors in paper [65] describe how wireless sensor networks (WSNs) can increase the spatial and temporal resolution of operational data from pipeline infrastructures and thus address the challenge of near real-time monitoring and eventually control. Their prototype development has led to the development of a reusable, field – reprogrammable software infrastructure for distributed high-rate signal processing in wireless sensor networks.

In the paper [66] describes versatile microelectrode array sensor for water quality monitoring. The array fabrication, based on batch microelectronic fabrication processes, results in a highly stable passivation of the silicon chip surface and provides the possibility to use a backside contact. Applications like chlorine monitoring in drinking water, ozone monitoring in deionized water, dissolved oxygen in activated sludge and preliminary measurement of trace arsenic.

Paper [67] authors describe images acquired by the MODIS satellite spectrometers are used for retrieving water quality information in the Baltic Sea.

In the paper [68] a method is presented for fast online quality assessment based on electronic tongue measurement. The method is implemented in two steps. First we apply a fuzzy clustering technique to obtain prototypes corresponding to good and bad quality from a set of training data. During the second, online step we evaluate the membership of the current measurement to each cluster and make a decision about its quality.

Paper [69] describes then designing and implementing a distributed measurement system for water quality monitoring characterized by multi-parameter measurement capabilities and SDI-12 data communication. The water quality sensors considered are pH, temperature, conductivity and turbidity and are components of multi-parameter measurement nodes of water quality SDI-12 based network, each of them being characterized by different communication standards including 420mA and RS232.

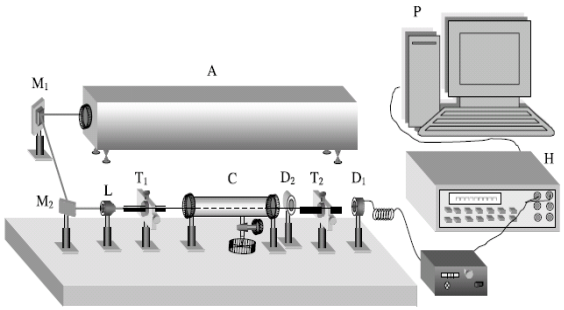


Figure 7.3: Schematic diagram (A= Ar^{+} laser, M1 – mirror 1, M2- mirror 2, L – lens, T1 – X-Y translator, T2 – X, Y translator, C – glass cell, D1- detector 1, D2 – detector 2, H multimeter, P – personal computer)

Paper [70] discusses the details of fabricating an off-line fibre optic sensor (FOS) based on evanescent wave absorption for detecting trace amount of Fe^{+3} in water. One type uses the unclad portion of a multimode silica fibre as the sensing region whereas the other employs the microbent portion of a multimode plastic fibre as the sensing region. Figure 7.3 shows the schematic diagram the experiment set up.

Paper [71] describes the principles of operation and design of an optical turbidity meter. The process of this application is based in illuminating the medium with light of selected wavelengths and them measuring the backscattered light.

Paper [72] authors have described a thought provoking care study where limitations in currnt analytical technologies for water monitoring had fatal results and discuss new approaches to microbiological monitoring that might prevent similar disasters occurring in the future.

Authors in paper [73] describes a developing a tool for measuring the complex dielectric permittivity of materials over a wide range of frequencies (10-1000MHz). And they hope to add a magnetic susceptibility measurement as a complement to dielectric permittivity, for the purpose of detecting metal impurities.

Paper [74] describes the characteristics and the application of a multichannel electrode type sensor. It was based on eight membranes using various lipids as an effective and a simple potentiometric sensor for detecting water quality.

In the paper [75] recently developed multichannel taste sensor with global selectivity is being reviewed. This sensor is composed of several kinds of liqid/polymer

membranes for transforming information of taste substances into electric signals, which are analysed by a computer.

In the paper [76] concept of the electronic tongue is used to monitor the quality of water in a production plant for drinking water. In this method with the use of signal analysis and statistical multivariate methods we are able to estimate the water quality.

The humidity sensor (Figure 7.4 and Figure 7.5) using the sensitive capacitive dependent crystal and the probe sensitivity are described in paper [77]. The Sensor (Figure 7.5) C_x is an open capacitor distance between the open capacitor is about 0.8mm. Sensor probe is made on Al_2O_3 basis together with electronics (Figure 7.4) and temperature-sensing element. Excitation of the entire humidity sensor with stochastic test signals and the humidity surface – measuring method also have been described in this paper.

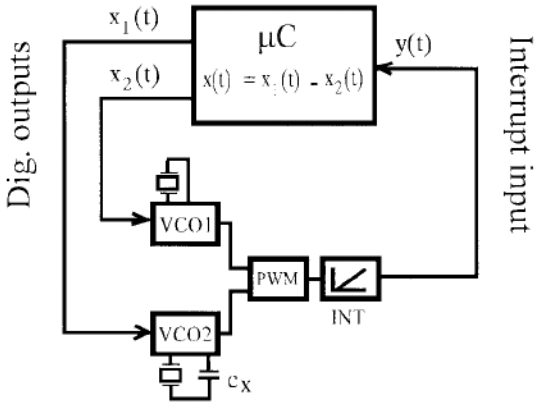


Figure 7.4: Sensor Structure

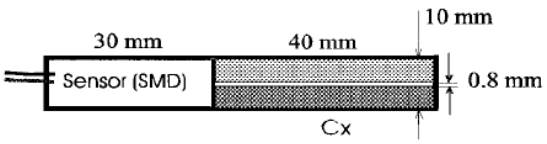


Figure 7.5: Humidity sensor

7.5 Conclusion

Different water quality parameters and some of the methods that are used in measuring most of the parameters have been explained in this paper. A review of

published literature on sensors and sensor networks in water quality monitoring has been done.

CHAPTER 9
CONCULSION AND FUTURE WORK

9.1 Conclusion

The works in this report include the characterization and experimental results on TWS (magnetic circle). The principles behind magnetic filtration have been used in many countries like USA, Canada and Japan. Field trials (Wanganui, Ratana and Cedenco) are done and new model has been designed and fabricated. Principle behind magnetic separation has been explained. Company overview has been explained in chapter 3 and some system design improvements also have been explained.

The magnetic circle was modelled using the using the finite element software FEMLAB (COMSOL 3.3). The magnetic field characteristics for a range of current values were calculated for TWS magnetic circle. In practice it is better to know the characteristics of the magnetic circle before doing any design improvements.

Hence, the TWS magnetic circle was characterized by experiments. Some design improvements have been suggested. Using TWS system some of the field trials were done. The field trials were Wanganui, Ratana and Cedenco. All the results and testing produces have been shown in the report. It can be conclude that TWS system didn't have any effect on Magnesium, Calcium, Sulphate and the slight effect on total hardness (due to the iron content). Some more experiments need to be done for more conclusive outcome.

Three types of experiments were done. Water with magnetic contaminants was passed through two electromagnets and results were recorded by varying the current as well as distance between the electromagnets.
Instead of two electromagnets copper wire has been wrapped around a test tube and water with magnetic contaminants was passed through the system and results were recorded for different values of current. The results obtained from these experiments show that there is a great potential of TWS system SCUD could be used as a magnetic filter as well a mechanical filter.

New design has been implemented to get an optimum outcome from the magnetic circle. Some experiments were done to place the separation chamber to obtain optimum results. New design can be implemented into the TWS system to better results. And some sensors and sensor networks used in water quality monitoring have been reviewed.

The thesis has described studies of magnetic filtration techniques to purify potable water and waste water. The TWS (Magnetic circle) has been characterized by finite element modelling and experimentation. Experiments were carried out with TWS system and with some new designs. The response from the field trials were reported was insignificant. Results were obtained and TWS system was analysed.

9.2 Recommendations and Future Work

Figure 9.1 shows the complete experimental set up of the new design. Some more experiments need to be carried out to determine the optimum size, current for optimum performance.

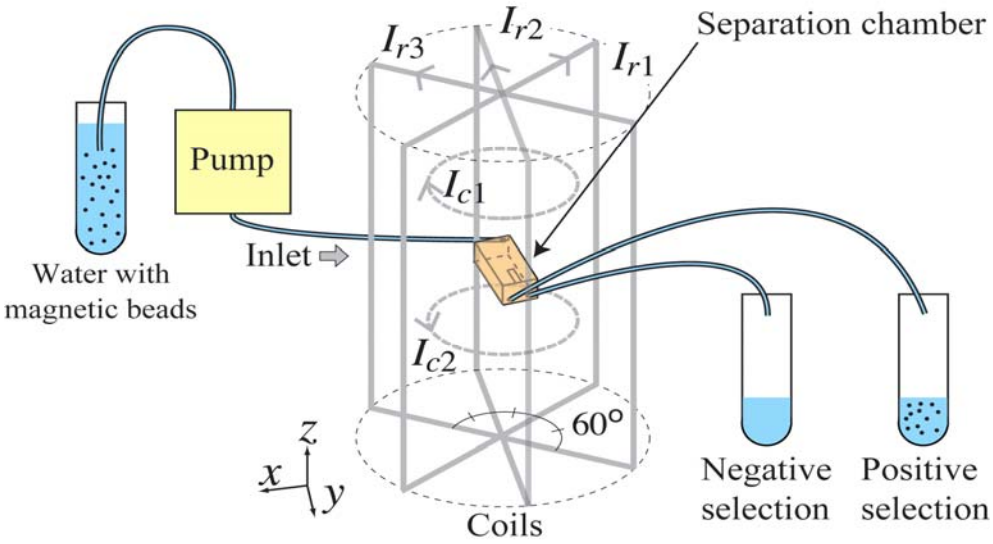


Figure 9.1: block diagram of the New Design

Using the system shown in figure 9.1 some experiments need to be done using some seeding material. Some more experiments with seeding materials need to be done using TWS system. And some experiments need to done at Wanganui, Ratana and CEDENCO with the suggested system.

CHAPTER 10
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