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TAJUK PROJEK :

PARAFFIN CRYSTALLIZATION UNDER
THE INFLUENCE OF MAGNETIC FIELD

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CHAPTER I

BACKGROUND

1.0 Introduction

Under original reservoir conditions different fractions that compose crude oil (crude) are in thermodynamic equilibrium which has been achieved along the geological time. As the production process is started, crude is displaced from its original equilibrium condition. As it is forced to move upwards, crude goes through a continuum of phase equilibria where solid phases might appear. The composition of these solid phases may range from predominantly paraffinic to predominantly asphaltenic. If favorable hydrodynamic conditions are achieved, these solids can agglomerate and migrate to an interface, thus forming the so-called organic deposition (paraffin and/or asphaltene deposition). In general, actual paraffin deposits are a complex mixture of heavy solid alkanes, crude droplets, small amounts of asphaltenes, sand grains, precipitated salts, rust and water, which are entrapped during the deposition process. Diffusion process is the key factor controlling paraffin deposition phenomenon under the actual field conditions. Independently of its paraffin content should an adequate thermal gradient be applied to a crude, a paraffinic deposit will end up being formed. Once so-called wax (solid paraffin) appearance temperature (WAT) of crude is reached, paraffin crystallization starts and, below this temperature, a potential to generate a paraffin deposit by the crude is developed

Paraffin deposition is a well-known phenomenon that plagues the oil industry all over the world. As a rule paraffin problems can be solved in onshore fields with inexpensive physical and chemical methods. However as the oil industry is continuously moving to deep water scenarios where paraffin deposition takes place in difficult-to-reach subsea-flow lines, manifolds and wet Xmas trees, no inexpensive solutions are known.

Conversely, operators are concerned to paraffin deposition problems in deepwater production facilities for they are costly, time-consuming and means a serious menace to the economical feasibility of their enterprises

So far the Lorentz forces are concerned it is difficult to explain the interaction between a magnetic field and a hypothetical crude which only contains non-polar molecules. The Lorentz force is addressed as the interaction between polar charged species and magnetic fields

CHAPTER II

OBJECTIVE AND SCOPES

2.0 Objectives

- (i) to conduct a literature survey a magnetic effect on paraffin wax control.
- (ii) to set-up a laboratory scale flow system with an application of electromagnetic possibility.
- (iii) to establish an investigation the possibility to eliminate the tendency of paraffin wax deposition.

2.1 Scopes

Crude oil samples will be brought from several oilfields located in Terengganu and Sabah Offshores.

A unit of patented Electromagnetic Device will be installed in the simulated flow system during the initial investigation. This initial study required to use the patented model because to gather information and to identify uniqueness of EMF technique. Flow model will be constructed during the study. It consists of several sections including pumping and fluid control system. Electromagnetic section, flow line loop, deposition observation and cooling duct. The system will performs at the operating pressure below 10 Bar and the flow must be maintained in laminar flow regime at which exhibits the maximum tendency of deposition.

Parameters such as oil compositions, wax contents, dc voltage and heat transfer and the magnetic intensity are studied for both non-magnetized and magnetized systems. The flow system will be utilized piping and fittings materials that comprise of ferromagnetic components. However, caution must be taken to eliminate the effect of electromagnetic on the electrical and electronic devices. Disturbance will cause efficiency reduction on other devices.

CHAPTER III

LITERATURE

3.0 Introduction

In the pipeline transportation of fluids, a common concern is the accumulation of impurities, contaminants, or constituents on the inner walls of pipelines from crude, unprocessed fluids such as crude oil or other similar petroleum products. For example, paraffin or wax is a constituent or component of crude oil, which has the tendency to collect on the internal surfaces of piping and pipelines. Accumulations of such constituents can rise to a level where a pipeline would be inoperable due to the congestion. The pipeline flow has to be interrupted to insert a "pig," or for applying hot oil treatment or other pipeline servicing device or method is used to clear the blockage. Furthermore, the paraffin hardens, adding additional wear to such servicing devices such as pigs. Such servicing operations typically take several hours and are time consuming and expensive.

As a result from problems by paraffin scale/wax/asphaltene in the pipeline, electromagnetic concept was introduced to eliminate or reduce the conventional method of pipeline servicing. For the decade, many of inventor and researcher introduce their theory concerning electromagnetic fluid conditioner which how electromagnetic field interact with fluid to prevent scale build up. Basically an electromagnetic conditioner for oil field purpose is innovations from magnetic fluid conditioner for treating scale forming in crude pipeline and water and was modified from it. The following article and discussion viewing how and why electromagnetic concepts were using in paraffin scale treatment.

3.1 US Patents Literature

According to Petrovic (1986), a fluid treatment apparatus and method was disclosed for preventing or removing the formation of paraffin, scale, salt encrustation, emulsion, and the like on the interior surface of a conduit carrying a fluid. The fluid treatment apparatus comprises a turbulent flow generator, a plurality of support cylinders inside the apparatus, symmetrically opposed lower and upper flow distribution holes in the support cylinders, a plurality of permanent magnets within the support cylinders oriented with adjacent magnets having the opposite polarity, magnetic field intensification disks disposed between each magnet, and two magnetic field closure rings engaged with the support cylinders for securing the position of the cylinders and magnets and for closing and concentrating the magnetic fields at both extremities of the plurality of magnets. The method for preventing or removing the formation of paraffin, scale, salt encrustation, emulsion, and the like from the interior surface of a conduit transferring a fluid consisting of inducing the turbulent flow of the fluid with the conduit, subjecting the fluid to a plurality of magnetic fields, and inducing further the turbulent flow of the fluid within the conduit.

Beside that Dean L. Moody (1996) disclosed Method and Apparatus for Treatment of Flowing Liquids to Control Deposition of Solid Matter Therefrom. Actually, the alluded-to patent presents an excellent description of how the treatment is effected where diamagnetic substances are contained in the liquid flowing through the pipe. The patent mentions scale and paraffin. Scale can take various forms but typical of the substances creating scale problems are calcium carbonate, calcium sulfate, barium sulfate, sodium chloride, magnesium sulfate, as well as various oils, waxes and greases in addition to paraffin.

As is recognized, in as much as the above-listed substances are diamagnetic, when subjected to a strong magnetic field, the field induces polarization in the substances in such a way that the diamagnetic molecule is repelled by the magnetic field and by other

polarized diamagnetic molecules. This is characteristic of diamagnetic substances and advantage is taken of this physical phenomenon to prevent the formation of objectionable scale deposits on the inside of the pipe. By inducing polarization as mentioned above, the diamagnetic substances are caused to move away from the inner surface of the pipe when under the influence of a sufficiently strong magnetic field equipped with magnetic means.

A strong enough field was designed, particularly on larger diameter pipes, so that a substantial proportion of the fluid flowing through the pipe is subjected to a field of such intensity and for a long enough period of time that the desired repulsion will be effected.

By the way Larson, Kenneth J in US Pat. 4865747 disclosed an electromagnetic field treating device includes a conduit formed of nonmagnetic material having an inlet and an outlet. So the fluid can pass through the conduit in a direction, which is parallel to the axis of the conduit, and a ferromagnetic core, which includes a corkscrew, shaped core portion, which is positioned within the conduit in parallel, spaced relation thereto. The electromagnetic fluid treating device also includes means for mounting the core in a fixed position within the conduit. At least one electromagnetic coil, which is electrically insulated from the conduit and is positioned adjacently outside of the conduit so that the central axis of each coil either intersects or nearly intersects the core. The electromagnetic fluid treating device preferably has one or two electromagnetic coils which are each mounted sidewardly from the conduit to face toward the ferromagnetic core such that the central axis of each coil is perpendicular to the conduit. Alternatively, the coil or coils could be entrained around the conduit. The electromagnetic fluid-treating device preferably further includes a power supply means, which is connected to the coils to provide an oscillating voltage across the coils. Preferably that voltage will oscillate within the radio frequency range of about 1 kilohertz to 1,000 megahertz so that the coil or coils act as antennae emitting radio waves. The core may include a longitudinal ferromagnetic rod portion, which extends axially inwardly into the conduit from near an upper end of the conduit. Such a ferromagnetic rod portion preferably would be connected to and coaxial with the corkscrew shaped core portion.

He also said, a first category of electromagnetic fluid treating devices includes those devices, which utilize permanent magnets, which are disposed in surrounding relation to the fluid carrying conduit. Examples of such devices are disclosed in U.S. Pat. Nos. 2,652,925 to Vermeiren, 3,349,354 to Miyata, 4,210,535 to Risk, 4,265,754 to Menold, 4,265,755 to Zimmerman, and British patent No. 675,369 to Vermeiren. A second category includes those devices with permanent magnets, which are located within a pipe or other container, which contains the fluid being treated. Examples of these devices are disclosed in U.S. Pat. Nos. 2,583,522 to Winslow, et al., 2,825,464 to Mack, 3,669,274 and 3,680,705 to Happ, et al., 3,680,705 to Happ, et al., 3,923,660 to Kottmeier, 3,951,807 to Sanderson, 4,157,963 to Jessop, et al., 4,167,480 to Mach, 4,216,092 to Shalhoob, et al., 4,278,549 to Abrams, et al., 4,289,621 and 4,417,984 to O'Meara, Jr., 4,428,837 to Kronenberg, and British patent No. 675,369 to Vermeiren.

With the two permanent magnet types of devices, the magnetic field lines generally are normal to the fluid flow only near the polar ends of the bar magnets. Also, the size of the magnetic field is limited by the size limitations of the permanent magnets. A third category of electromagnetic fluid treating devices includes those devices, which have one or more electromagnets, which surround or are positioned alongside the conduit or container containing the fluid being treated. Such devices are disclosed in U.S. Pat. Nos. 438,579 to Faunce, et al., 1,949,660 to Roberts, 2,596,743, and 2,652,925 to Vermeiren, 2,939,830 to Green, et al., 4,299,701 to Garrett, et al., 4,326,954 to Shroyer, 4,407,719 to Van Gorp, 4,659,479 to Stickler, et al., and British patent Nos. 625,732 and 675,369 to Vermeiren. U.S. Pat. Nos. 438,579 to Faunce, et al., 1,949,660 to Roberts, and 3,349,354 to Myata, also disclose imposing an electric field on the fluid in addition to the magnetic field. The patents to Faunce, et al. and Green, et al. disclose electric coils, which are positioned axially at right angles to the conduit on which they are mounted. The patent to Green, et al. also discloses an electromagnet, which is located within the container through which the fluid being treated flows.

A fourth category of devices is a variation on the third category wherein the device includes an impeller which is located within the fluid carrying conduit, and which is caused to rotate by the fluid flowing therethrough. Such devices are disclosed in U.S. Pat. Nos. 4,151,090 to Fava, 4,226,720, 4,288,323 and 4,347,133 to Brigante, and 4,427,544 to Foch. The impeller in these devices is a rotating core with a helical band or blade, which causes the core to rotate as the fluid, passes along side the core. A direct current is used to provide electrical power for the magnetic coils in these devices. Mechanical failure in these devices could cause the core to stop rotating. U.S. Pat. No. 4,601,834 to Bailes, et al. discloses applying a unidirectional, varying electrical field across a portion of the flow path of a liquid dispersion to separate out the components of the dispersion. The treatment of a polluted medium such as wastewater by directly injecting audio frequency energy into an ionized waste material to dissociate the organic compounds is disclosed in U.S. Pat. No. 3,625,884 to Waltrip.

De Baat Doelman; Jan P in 1991 state that Calcium sulphate, calcium silicate and magnesium silicate form scale because, as the liquid in which they occur evaporates, the concentration of these salts increases and approaches the saturation point at which the salts crystallize out and attach themselves to a wall. Calcium carbonate, for example, forms a very soft scale or sometimes, a precipitate. The most persistent form of scale is calcium sulphate, which adheres to the metal walls of pipes, boilers etc. so strongly that the latter have to be put out of use in order to remove the scale.

The occurrence of scale in, for example, steam boilers results in a reduced heat transmission and therefore in a higher fuel usage, in addition to the possibility of pipe blockage. Even a layer of scale of approx. 0.2 mm can give rise to local overheating and damage the boilers.

The said ions of calcium and magnesium and any manganese, iron and aluminum impurities are also very detrimental to domestic usage because they react with soap. As a result of the formation of calcium, magnesium, iron and aluminum salts, which are insoluble and form, a sticky substance on materials which are being washed in water

which contains these impurities.

As is known, a moving charge in a magnetic field experiences a Lorentz force which depends on the applied magnetic field strength, the quantity of charge, the displacement velocity of the charge and the direction of the magnetic field lines with respect to the displacement direction of the charge. If the liquid contaminated with the said elements is now subjected to a magnetic field, the liquid molecules, for example water molecules, are oriented. As a result of which the said impurities, in particular the ions of calcium and magnesium, come out of solution and can be trapped, for example, by means of a filter to be placed in the liquid flow, with the result that no scale is consequently formed. The known apparatus provides for a solenoid-type electrical coil through the internal space of which, inter alia, the liquid to be treated is passed and which is energized with a direct current, an alternating current of fixed frequency or a pulsating current.

European Patent Application EP-A-0, 091,896 discloses, in this connection, a tubular ring through which the liquid is passed in order to drive it continuously into such a turbulent state in the region of the coil that it is possible for an energizing current with a fixed adjustment to be adequate.

In common with U.S. Pat. No. 2,596,743, this involves, however, a structure which has to be incorporated in a pipe of a system, which may present installation problems and be expensive, particularly in the case of existing pipe systems or when replacing the apparatus, and for which it may be necessary to put the system out of operation. In practice it has furthermore been found that the efficient operation of the known apparatuses is concomitantly dependent on the flow rate of the liquid to be treated.

The invention is consequently based in the first instance on the object of providing an apparatus of the type mentioned in the introduction with which a satisfactory, efficient operation over a desired range of flow rates of the liquid to be

treated is achieved without the necessity of structures which have to be incorporated in a pipe through which the liquid flows.

According to the invention, this is achieved in that the energizing unit is provided with means for generating an energizing signal to be varied in frequency. As a result of this, it is possible, if the flow rate increases, to increase the frequency of the energizing signal so that at higher flow rates a magnetic action can be exerted on the liquid correspondingly more frequently per unit of time, and vice versa. It has been found that in this case the coil for generating the magnetic field for achieving a desired action can be fitted outside an existing pipe through which the liquid to be treated is flowing without said pipe having to be disconnected.

A further embodiment of the apparatus according to the invention has the characteristic that the energizing unit is provided with means for frequency-modulating the energizing signal. Such a frequency-modulated energizing signal provides a magnetic field, which produces an average effect, which is satisfactory with time for various flow rates.

An embodiment of the invention which can be used for a large range of flow rates has the characteristic that the means for frequency-modulating the energizing signal are equipped to generate a signal varying in frequency between approximately 700 and 3000 Hz.

An embodiment of the invention suitable for obtaining more optimum results has the characteristic that at least one transducer for connection to a control input of the energizing unit. It's provided to generate a control signal dependent on the flow rate of the liquid in order to vary the frequency of the energizing signal to match the variation in the flow rate.

It has furthermore been found that, in order to exert a Lorentz force of suitable magnitude on the moving charges with the magnetic field, the magnetic field has to

become stronger with decreasing liquid flow rate, and conversely, that the magnetic field has to decrease as the flow rate increases. In the known apparatus as disclosed by the said US Patent which operates with a predetermined fixed magnetic field strength, it may even happen that, if the liquid velocity drops below a certain minimum value, the useful effect is zero, with all the disadvantageous consequences thereof. To make the magnetic field so strong that a good effect is in fact obtained at such low flow rates is not advantageous. Because it has been found that at higher flow rates the Lorentz force on the moving charges is then proportionately too large, as a result of which the useful effect is again less.

The strength of the magnetic field generated is determined not only by the number of windings and the dimensions of the electrical coil, but also by the amplitude of the energizing signal. In order to also achieve a magnetic field strength matched to the flow rate of the liquid, a further embodiment of the apparatus according to the invention has the characteristic that the energizing unit is provided with means for varying the amplitude of the energizing signal.

An automatic matching of the amplitude of the energizing signal to the flow rate of the liquid is achieved in yet a further embodiment of the apparatus according to the invention in that at least one transducer for connection to a control input of the energizing unit. It's provided to generate a control signal dependent on the flow rate of the liquid in order to vary the amplitude of the energizing signal inversely to the variation in the flow rate. This embodiment has the advantage that, during operation by a user, set values do not have to be adjusted to a change in the flow rate of the liquid.

A flowmeter incorporated in the liquid flow can be used as transducer. However, the preference is for transducers, which can be fitted outside a pipe or system without structural adaptations thereof. Transducers suitable for this purpose are in practice known per se. For example, transducers inductively or thermally coupled to the liquid flow.

A still more optimum effect is obtained in yet a further embodiment of the invention in that the means for varying the amplitude of the energizing signal are equipped to keep the product of amplitude and flow rate constant within the modulation limits of the

energizing unit.

As already stated above, even a thin layer of scale can give rise to damage to, for example, boilers as a result of reduction in the heat transmission. In the case of boilers for, for example, generating electricity, such damage can give rise to the shutdown of the electricity production, which may in practice have very extensive, disadvantageous consequences. In particular, in these applications it is important that the operation of the apparatus according to the invention can be monitored. For this purpose, an embodiment of the invention has the characteristic that the energizing unit is provided with means for indicating the state of energization of the apparatus. Yet a further embodiment also has the characteristic for this purpose that the energizing unit is provided with warning means for indicating that the apparatus is in the unenergized state.

In order to guarantee the operation of the apparatus in the event of a fault in the power supply or to achieve an operation independent of an external power source, an apparatus has the characteristic that the energizing unit is provided with an on board electrical power source means. For this purpose, use may be made of batteries, rechargeable batteries, solar cells and the like. For the purpose of illustration, in apparatuses used in practice, desired results are obtained with an energizing current of a few tenths of a microampere with a coil of only a few windings. The treatment of the liquid with the apparatus according to the invention is intensified in yet a further embodiment in that the at least one coil is made up of a plurality of coils. It's situated at a distance from one another in the flow direction of the liquid to be treated, which coils are connected to the energizing unit in order to generate mutually oppositely directed magnetic fields by means of at least two coils.

The use of mutually oppositely directed magnetic fields achieves the result that, at the plane of separation of the two fields, the magnetic field lines are directed virtually transversely to the liquid flow and, as a consequence, a maximum Lorentz force acts on the liquid molecules.

It is pointed out that the Belgian Patent Specification 901,884 discloses an apparatus for preventing scale deposits in which at least one coil is used which has to be fitted round a pipe containing liquid to be treated. However, this involves a so-called "open system" in which only one end of the at least one coil is connected to an energizing unit, the other end of the coil being free. This is in contrast to the apparatus according to the invention in which both ends of the at least one coil are connected to the energizing unit. Furthermore, a frequency-modulated energizing signal is not used.

It has been found in practice that such an open system is disadvantageous in a number of aspects. Firstly, the physical distance between the energizing unit and the coil has to be short in order to achieve an adequate effect over the entire length of the coil. This can be troublesome during installation. In addition, the coil forms an open LC circuit with respect to earth, as a result of which the current exhibits a peak in the coil and then rapidly dies out in the case of a pulsating energizing signal. The decay of the current in this manner causes interference signals far up into the high-frequency range, as a result of which interference in other electronic equipment, such as, for example, measuring and regulating apparatus, and radio and TV receivers is not ruled out. In particular, the possible interference with measuring and regulating equipment may in practice have very detrimental consequences. Furthermore, there is no magnetic field present between the peaks in the energizing current, with the result that the apparatus does not have any useful effect during these periods of time.

These disadvantages are avoided as far as possible with the apparatus according to the invention which is constructed as a closed system, that is to say, in which the two ends of the at least one electrical coil are connected to the energizing unit. In contrast to the disclosures by, inter alia, it has been found that the at least one coil for generating a magnetic field for acting on the liquid to be treated does not necessarily have to encompass said liquid or the pipe through which the liquid is flowing. Instead of fitting the at least one coil around a pipe through which the liquid to be treated is flowing, coil is provided with a protective sleeve for placing coil with its longitudinal axis as parallel as possible to a pipe.

In addition to a relatively simple installation, this also reduces the risk of a metallic pipe being attacked as a consequence of galvanic action in the event of damage to the insulation of the coil. The use of two coils to be mounted on top of one another around a pipe, of which coils the coil resting directly against the pipe is held at a negative potential with respect to the pipe (earth) by means of rectifying means, is disclosed in the International Patent Application WO-A-8,805,763 with the same purpose. It will be clear that this method is both more cumbersome and also less reliable than providing the at least one coil according to the invention with a protective sleeve and siting it adjacent to the pipe.

The useful effect of the coil is barely less if it is sited alongside a pipe instead of the pipe being encompassed by the coil because the greatest effect (Lorentz force) is produced by the magnetic field lines directed transversely to the liquid flow. In this case the pipe through which the liquid is flowing, which effect is in both cases virtually the same. In some cases, even a better effect may be expected as a result of a more favorable field distribution if the at least one coil is sited alongside a pipe.

The accommodation, according to the invention, of the energizing unit and the at least one coil in one housing eliminates the necessity for the separate installation of a coil and energizing unit. Particularly when used in environments in which the strictest requirements with respect to the liquid to be treated do not apply, but where the most important thing is in fact convenience of use and installation, for example for domestic use, such an apparatus is of advantage, in particular, in combination with its own power supply such as a battery.

The effect of the coil may, according to another embodiment, be increased in that the at least one coil is wound on a core of magnetic material, for example, a core of magnetically "soft" material such as soft iron or of ferrite in connection with the lower eddy-current losses thereof at higher frequencies.

Means are furthermore provided for placing the housing in the longitudinal direction of a pipe in a manner such that the longitudinal axis of the at least one solenoid-type coil is situated as parallel as possible to the liquid flow. The means may be equipped, in particular, for fixing the housing to a pipe. The invention also relates to an energizing unit, which can be used in combination with a coil and/or a transducer for the flow rate of the liquid to be treated.

3.2 Other Literature

The effect of a magnetic field on aggregates to control solidification of metals has been reviewed in technical literature. Lad'yandy, V. I., Novokhatskly, I. A., Koshukhar', I. Ya., Pogorelove, A. I., Ustyuk I. I. (Sverdlovsk): "Influence of Magnetic Field on the Viscosity and Structure of Liquid Metals" (1980) reported an experimental study of influence of magnetic fields on the viscosity and structure of liquid metals. Lad'yandy, et al., reported a substantial reduction in kinematic viscosity differences for metallic liquid using transverse and longitudinal magnetic fields. The mechanism of the observed effect is satisfactorily explained with allowance for structural micro irregularity in liquid metal. Lad'yandy, et al., stated that: "The oriented arrangement of clusters in magnetic field significantly influences numerous processes in liquid metals, in particular solidification processes. Within the framework of the quasi polycrystalline model, the process of liquid solidification can be considered to comprise the following successive stages: liquid cluster. \rightarrow crystal embryo. \rightarrow solid. It is supposed that the crystal embryo forms by association of several clusters with similar lattice orientation until it reaches a certain size. The crystal forms by growth of the embryo, primarily by attachment to it of other clusters, which are also in crystallographic alignment with the growing, crystal. In this case, embryos formed from clusters during the pre-solidification period are preferentially oriented along the magnetic lines of force of the liquid. The proposed mechanism of influence of magnetic field on processes of crystal nucleation and growth are in good agreement with available test results on the solidification of molten Al--Ni, Cd--Zn, Bi--

Cd and Al--Cu in constant magnetic field."

Some crude oil contains adequate concentration of iron to have a magnetic susceptibility. The ferro-magnetic fluid hypothesis is based on crude oil having obtained iron from the earth. The iron content gives magnetic susceptibility to the crude oil. Ferrofluids are stable colloidal suspensions of sub-domain sized ferrite particles dispersed in a liquid medium by a suitable surfactant agent. Ferrofluids have been successfully prepared using water, hydrocarbons, esters, diastase, fluorocarbons, and even liquid mercury. Two applications showing considerable promise are ferrofluid rotary shaft seals and scrap metal separators. Rotary shaft seals have been commercially available for several years. Magnetic susceptibilities are required and as laboratory analysis to determine the content of iron. For instance, the paraffin with ferromagnetic particles are mainly paramagnetic. Fossil water, the formation water associated with crude oil in the reservoir, normally contains iron in the range of 10-30 ppm.

The technical literature reports using magnetic fluids to control suspension stability by using magnetic saturation between 20 and 200 gauss. For example, Wooding, A., et al.: Proteins and Carbohydrates as Alternatives Surfactants for the Preparation of Stable Magnetic Fluids, University of Durham, England, Magnetic Master application. Conference on September 1987 reports one-stage preparation of stable aqueous magnetic fluids, whereby colloidal $F_3 O_4$ particles are dispersed using naturally occurring polymers and their derivatives (e.g., gelatin, polygalacturonic acid, carboxymethyl-cellulose and succinylated gelatin) as surfactant materials. Low-toxicity materials have been used to permit possible medical use of the fluids. Using a variety of surfactant concentrations at the time of particle formation, control of particle size has been achieved, and particles as small as 3.0 nm in diameter obtained. Stable fluids with up to 6% $F_3 O_4$ content can be produced.

Further, Jones, T. B. and Krueger, D. A., An Experimental and Theoretical Investigation of the Magnetization Properties and Basic Electromagnetic and Electromechanics of Ferrofluids reported basic research on magnetization properties and

the build response of ferrofluids to magnetic fields. From the fluid mechanical point of view, ferrofluids are a typical because they can interact with a magnetic field to produce a controllable body force on the fluid, a body force significant with respect to terrestrial gravity. From the basic physical point of view, ferrofluids are interesting because of the mechanisms, which are involved in the transformation of the forces on individual ferrite particles to the bulk of the liquid carrier. The Jones, et al., research program was divided into studies of the magnetization properties, and the electromechanics and applications. Also, Belorai, Ya., et al.: Application of Nuclear Magnetic and Electron Paramagnetic Resonance to Control Structural Changes During Pressure and Heat Treatments of Crudes: *Izvestiya Xysshikh, Gaz.* No. 1, July 1993. p. 51-55, from the Scientific Research Institute of Nuclear Geophysics and Geochemistry of Russia conducted research with non-newtonian crude oil. They reported research conducted using crude from the Uzen deposit with non-newtonian properties. The experiments were performed both on samples of crude and model specimens (mechanical solutions of paraffin, resins, and asphaltene in diesel fuel.) Belorai, et al., determine that Uzen crude oil was paramagnetic with a high content of paraffin.

Rheological parameters of the investigated model specimens and oils were determined on the "Rheotest"-type viscosimeter. They studied baroprocess and thermoprocess. It has been shown that both types of processing yield a considerable decrease in the shear stress. Based on the nuclear magnetic and electron paramagnetic resonance, pressure and heat treatment have a similar effect on the structure and rheological characteristics of oils. The shear stress reduction implies a considerable reduction in the viscosity of crude oil. Also, the authors considered that the effect on structure was significant.

Khalafalla, Aanaa and Reimers, George: A Method for Clarifying Slimes, Department of the Interior, Washington, D.C., August (1980) reported a method for clarifying slimes. The method is based upon the discovery that the unique flocculate described was useful in slime clarification. This discovery is based upon the further discoveries that the surfactant in this flocculate bridges the slime particles

electrostatically to the colloidal magnetic particles in this flocculate, and serves to stabilize the magnetic colloid. In the described method, a negatively charged slime was treated with an amine-stabilized magnetic colloid that has a net positive charge. The amine-stabilizing agent is a n-C10 to n-C15 aliphatic amine. A preferred amine is dodecylamine. A magnetic colloid containing dodecylamine in an amount that is approximately 25% of the magnetic particles, on a weight basis, and containing about 20 w/v% of the magnetic particles, which have a size ranging from about 50 to 100 \AA ., has a saturation magnetization of about 200 gauss. This colloid becomes unstable and flocculates when diluted to a magnetization less than about 1 to 3 gauss.

Parsonage, P.: Particle Interactions in Colloidal Suspensions, Warren Spring Lab., Stevenage, England 1987 has presented a review of the mechanisms of particle introduction in colloidal suspensions. Effects due to born repulsion, van der Waals forces, electrical interactions, hydration, structural and steric effects, hydrophobic effects and magnetic interactions were considered. A usable set of equations was presented for describing each of these effects in systems of identical spherical particles. Use of these equations allows prediction and interpretation of suspension behavior relevant to coagulation, flotation, filtration and rheological control. Some examples of the variation of interaction energy with particle separation were given to illustrate the influence of changes in the surface magnetic and solution properties.

CHAPTER IV

THEORY

4.0 Introduction

The magnetic technology has been cited in the literature and investigated since the turn of the 19th century, when lodestones and naturally occurring magnetic mineral formations were used to decrease the formation of scale in cooking and laundry applications. Today advances in magnetic and electrostatic scale control technologies have led to their becoming reliable energy savers in certain applications. For example, magnetic or electrostatic scale control technologies can be used as a replacement for most water-softening equipment. Specifically, chemical softening (lime or lime-soda softening), ion exchange, and reverse osmosis, when used for the control of hardness could potentially be replaced by non-chemical water conditioning technology. This would include applications both to cooling water treatment and boiler water treatment in once-through and recirculating systems.

The primary energy savings from this technology result from decrease in energy consumption in heating or cooling applications. This savings is associated with the prevention or removal of scale build-up on a heat exchange surface, where even a thin film can increase energy consumption by nearly 10%. Secondary energy savings can be attributed to reducing the pump load, or system pressure, required moving the water through a scale-free, unrestricted piping system.

For an oil field industry, the major problem in oil extraction and line transporting is the buildup of paraffin, restricting the flow. Hot oil, pigging, and chemicals have been the accepted means of controlling paraffin deposition in the past. Now, the Liquid

Conditioning System stabilizes the oil or petroleum product, keeping the paraffin molecules in suspension. Oil, like water and other fluids, has a molecular structure, which can be altered when exposed to an induction field. This electromagnetic bonding process stabilizes the paraffin molecule by bonding it to other molecules by Electro-kinetic energy. This stabilization process (forming of a molecular bond) neutralizes the paraffin molecule, and it loses its ability to come out of solution and build up on the inner pipe surface.

4.1 Typical Device of Fluid Conditioner

Devices are available in two installation variations and three operational variations. First to be discussed are the two installation variations: invasive and non-invasive. Invasive devices are those which have part or all of the operating equipment within the flow field. Therefore, these devices require the removal of a section of the pipe for insertion of the device. This, of course, necessitates an amount of time for the pipe to be out of service. Non-invasive devices are completely external to the pipe, and thus can be installed while the pipe is in operation. Figure 4.1 illustrates the two installation variations. Actually there are two-concept of device construction. The first one is using magnetic field concept (permanent magnet) and followed by using electromagnetic concept.

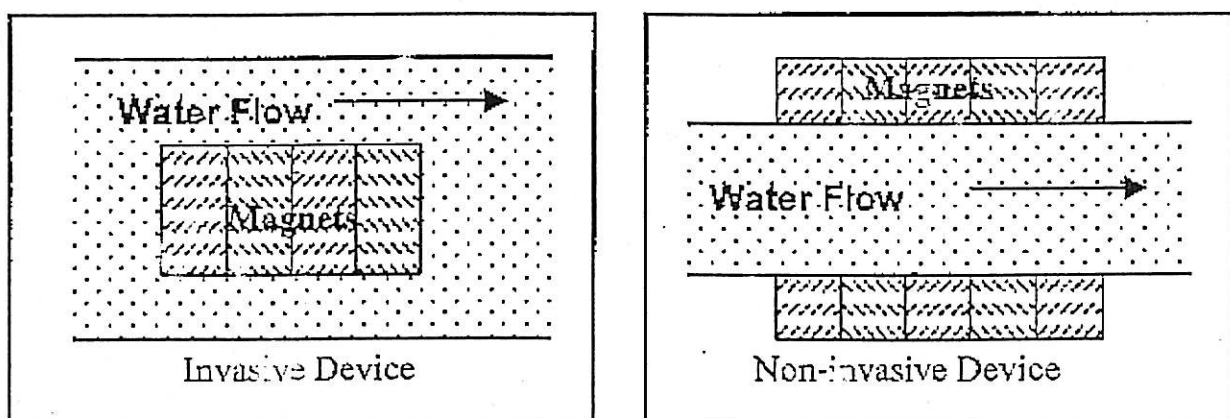


Figure 4.1: Illustration of Classes of Magnetic Devices by Installation Location

An electromagnetic concept produces both magnetic field and electrical fields while it generated by power supply, so this create many advantages to electromagnetic in way to prevent paraffin build up.

The operational variations have been mentioned above; illustrations of the latter two types are shown Figure 4.2:

- Magnetic, more correctly a permanent magnet
- Electromagnetic, where the magnetic field is generated via electromagnets
- Electrostatic, where an electric field is imposed on the water flow, which serves to attract or repel the ions and, in addition, generates a magnetic field.

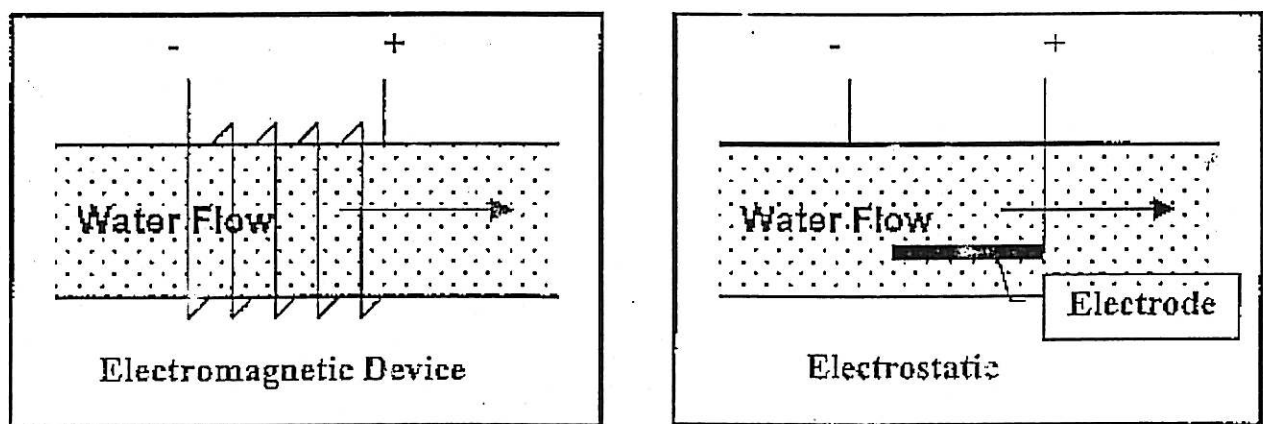


Figure 4.2: Illustration of Classes of Non-Permanent Magnet Devices

Electrostatic units are always invasive. The other two types can be either invasive or non-invasive. The devices illustrated in Figure 4.1 are examples of permanent magnet devices.

4.2 Electromagnetic Fluid Conditioner (EFC)

Basically electromagnetic fluid conditioner for water or crude oil treatment comprises three major components (Figure 4.2). It's include

- a. non-magnetic conduit having a first end and a second end, the conduit having an unobstructed passage for receiving and passing the fluid,
- b. means for generating a magnetic field, and given that the fluid has magnetic susceptibility, the magnetic field creates a Ferro-magnetic fluid, such that an electric field is induced in association with the magnetic field whereby the magnetic field is parallel to the flow of fluid in the conduit and the induced electric field is orthogonal to the direction of the flow of fluid in the conduit, and
- c. means for vibrating the magnetic field and the electric field to a sufficient intensity for controlling the nucleation phenomena of the molecules such that aggregation is inhibited and the molecules remain in solution.

By using an electromagnetic, the intensity and density of magnetic field may adjust simply for different crude oil. Electric field must have specific characteristics to achieve the efficiency while it generates from power source. So a high vibration frequency of the field is achieved using high frequency AC current or pulsed DC current. To achieve the coil for create magnetic field and electric field to a sufficient value, the voltage of power supply must have particular frequency modulation.

For certain device they are using range of radio frequency between 1 kHz to 1000 MHz to create coils act as antennae emitting radio wave. This wave can improve the effectiveness of paraffin prevention. By the way other inventor reported that frequency of current desired useful effect can be achieved for virtually all the liquid flow rates encountered in practice with an energizing signal varying steadily in frequency between 700 and 3000 Hz.

The intensity and density of an electromagnetic field (magnetic and electric) actually influences by several factors. They are

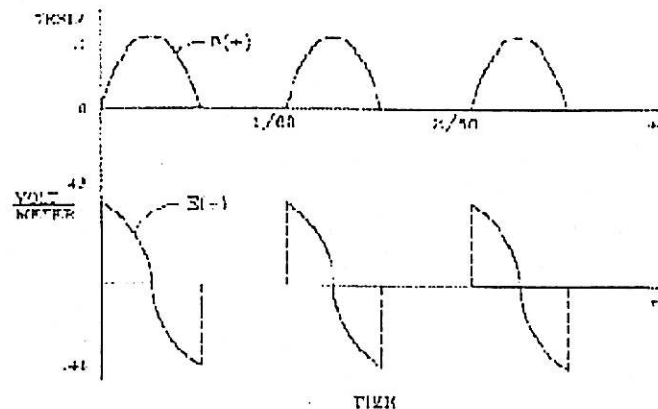
- a. number of layer winding by coil wire around the conduit
- b. number of coils using around the conduit (at least 1)

The continuous winding comprises multiple layers of wire. The wire can be of varying gauges and conductance. The wire is wrapped around the exterior of the conduit so as to form the winding. The winding has electrical connections. The electrical connections engage the electrical assembly. The preferred wire specifications are provided in Table 4.1.

Table 4.1: Wire coil specifications

Wire Size (AWG)	# 18	# 16	# 14	# 12	# 10	# 8	# 6	# 4
Standing	16	16	16	16	16	16	16	16
Voltage - VDC	120	120	120	120	120	120	120	120
Amperes - RMS	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08
Resistance/1000'	7.95	4.99	3.14	1.98	1.24 ^f	0.778	0.491	0.308
Length of run -feet	2200	2200	2200	2200	2200	2200	2200	2200
Voltage Drop -VDC	72.76	45.67	28.74	18.12	11.35	7.12	4.49	2.82
Voltage Drop -%	60.63	38.06	23.95	15.10	9.46	5.93	3.74	2.35

However there is device using DC current and design the frequency in two primary modes. The first one in a 60 Hz frequency with half-wave, and second one in a 120 Hz frequency with full-wave (Figure 4.3).



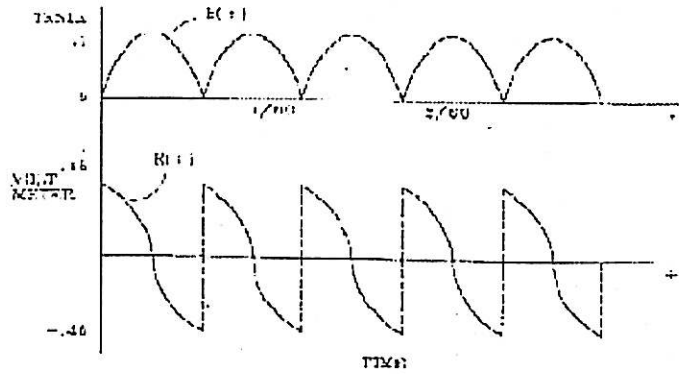


Figure 4.3: Optional wave diagram of DC current using in electromagnetic device

The electromagnetic fluid conditioning apparatus and method winding coil is protected by an aluminum or stainless steel case. The case allows high heat dissipation of the unit and better protection to from mishandling and the severity of the environment. The electromagnetic fluid conditioning apparatus is heavy-duty built and weather proof. The aluminum or stainless steel case protection makes the manufacturing process cost effective and faster. There is no need to embed any part of the electromagnetic fluid conditioning apparatus for protection. Consequently repairing, of the apparatus is easy and quick. The electromagnetic fluid conditioning apparatus has a non-magnetic metallic protection for the winding of the coil with high heat dissipation capability.

Peripheral devices are exterior of the aluminum or stainless steel case and are easily attached or unattached for flexibility of application or substitution of any peripheral part. Thus, the present invention has great flexibility of application to specific situations. It is easy and cost effective to change defective peripheral parts. The manufacture is easier and faster without peripherals being incorporated permanently in the main body of the apparatus. Using the mathematical model in combination with the discussed understanding of the mechanisms of paraffin or/and asphaltene deposition make the design of the present invention for specific application readily achievable. The electromagnetic fluid conditioning apparatus and method of the present invention is not only applicable to control the deposition of paraffin and/or asphaltene, but is also

applicable to any deposition of substances with molecules and/or aggregate in colloidal solution susceptible to the effect of a combined vibrating magnetic field and an electric field. The present invention is also, suitable for scale deposition control and other applications such as static control and the like.

The electromagnetic fluid conditioning apparatus and method of the present invention has a distinct advantage in comparison with any magnetic units based on magnetohydrodynamic principles. The present invention controls the intensity of the electric field output at a practical level. Any invention based on magnetohydrodynamics depends on restrictions to increase velocity of the fluid in the conduit and the conductivity of the fluid passing through a static magnet. Any restriction in the production piping section of a production system is detrimental to the production of an associated oil well.

4.3 Anti-waxing Mechanism of Paraffin Scale Deposition

Deposition of paraffin, asphaltene or any other substance susceptible to the effect of the vibrating magnetic and electric fields provided by the present invention is a consequence of several mechanisms that transport both dissolved and precipitated wax residue laterally. When oil is cooling, a concentration gradient leads to transport by molecular diffusion with subsequent precipitation and deposition occurring at the wall of the conduit. In addition, small particles of previously precipitated wax can be transported laterally by Brownian diffusion and shear dispersion.

A small fraction of crystals that are being carried along in the bulk oil can be thus transported laterally and incorporated into immobile deposit. The total immobile deposit consists of approximately 14 to 17 percent solid phase in a porous structure with the pore structure being filled with liquid oil. The deposition occurs when the oil is below the cloud point temperature

Polarization at the molecular level is described as physiosorption hypothesis.

Physiosorption hypothesis is stated as follows:

The electromagnetic field generated by the present invention could polarize molecules within the dielectric medium. Large molecules such as paraffin and asphaltene have a relatively large polarizability and are therefore particularly sensitive to the electromagnetic field.

The large paraffin and asphaltene molecules are normally randomly oriented and have a strong tendency to precipitate and bond to a solid structure such as the wall of the pipe. When the electromagnetic field is applied, the most polarizable molecules will align themselves along the field such that molecular polarization results. This effect reduces the strength of the physiosorption interaction between the molecules and the walls of the pipe. The sticking coefficient of the molecules is thereby reduced preventing sedimentation. This process is explained as physiosorption.

The polarization at the molecular level, if any, is not a permanent effect. Thus, the effect of reducing sedimentation is lost immediately after the fluids leave a polarization unit. A high intensity magnetic field is required to produce molecular polarization. To control paraffin, asphaltene or the like in crude oil requires the control of the growth of the crystalline formation associated with paraffin, asphaltene or other substances. Molecular polarization fails to address the growth of crystal in paraffin. The alignment of paraffin molecules by the magnetic field and effect of the physiosorption interaction among molecules and between paraffin molecules and the walls of conduit is not sufficient. Thus, the molecular polarization fails to explain the inhibition of paraffin crystals in the colloidal suspensions. The tendency to create center of conglomerations by physiosorption, in the colloidal suspension, will help crystals to reach a critical size and will promote deposition.

Increasing deposition with increasing crystal size magnifies deposition mechanisms. Changing the sticking coefficient of the molecules is not going to prevent

deposition. A more reasonable hypothesis that explain the effect of an electric and magnetic field in interrupting the natural mechanism of crystal growth will be more suitable to explain the phenomenon controlling deposition in paraffin and/or asphaltene. The major drawback of this hypothesis is that the polarization at molecular level, if any, is a non-permanent effect and it should be lost immediately after the fluid leaves the polarization unit. Just alignment will not prevent paraffin or asphaltene from depositing.

The effect of the present invention on controlling paraffin deposition is based on *aggregate/disaggregate hypothesis* individually or combined *with ferrofluid hypothesis*. The aggregate and ferrofluid theories are proven and well developed theories in physical chemistry and chemistry. Nowadays these theories have a great range of applications in science and technology. The aggregate/disaggregate and ferrofluid theories are considered hypothesis in paraffin and/or asphaltene deposition control in crude oils. It is believed that the controlling effect of paraffin and or alphaltenes can be explained by aggregate hypothesis and ferrofluid hypothesis, individually or combined.

The Aggregate/Disaggregate Hypothesis states as follows:

When paraffin and/or asphaltene colloidal suspension under dynamic conditions are exposed to a combined effect of electrical and magnetic fields of adequate intensity and vibration, the aggregate size is reduced. A critical mass is never reached and paraffin crystals are not formed. In principle, the electromagnetic field affects the nucleation phenomena taking place with the crude oil by disturbing the crystal centers formation. When the formation of the crystal centers is disturbed the crystallization process is prevented.

The first three measurable consequences, according this hypothesis, to be detected in a dynamic fluid exposed to electromagnetic fields (magnetic and electric) are:

- a. a significant reduction in shear stress that will result in an instantaneous reduction of viscosity (absolute and kinematics)
- b. no presence of paraffin, asphaltene or similar crystals in static fluid, and

- c. colloidal stability under dynamic conditions. Field test results show an increase in production, and flow rate, with no deposition of paraffin, asphaltene or similar substance. The increase of production can be explained by viscosity reduction due to reduction of shear stress in the fluid. Colloidal stability also has been shown in field tests.

Precipitation of particles of paraffin, asphaltene or similar substances requires that the particles meet their real critical crystal size. The present invention vibrates the electric and the magnetic fields at a frequency, which maintains the particles below the critical size. The vibrating fields breaks up the particles or aggregate of paraffin, asphaltene or similar substances so they do not reach critical mass and consequently the particles do not produce deposition. This concept is concerned with molecular mass. It has been found that by using a combined effect of electrical and magnetic fields with adequate intensity, unique results can be achieved. The nucleation phenomena can be controlled. By applying the present invention there is no driving force, no starting point where small crystal to form and precipitate. The aggregate size is reduced. With a lower aggregate size, the critical mass is not achieved and crystals are not formed. Vibrating the magnetic field and electrical field enhances this process.

To break up an aggregate of paraffin or asphaltene or any other substance susceptible to the process of the present invention, a magnetic field, and an electric field, are required. Using electromagnetic fields to break up an aggregate is the same principle as that of the shear viscosity or shear thinning and is effective under shear dispersion. However, as it sets for a while, it will aggregate again. Aggregate solution studies are very important area of research in physical chemistry. The aggregate concept is used extensively in chemistry and physical chemistry to control the stability of a variety of different solutions, especially with respect to the stability of polymer solutions.

Oil, like water and other fluids, has a molecular structure, which can be altered when exposed to an induction field. This electromagnetic bonding process stabilizes the paraffin molecule by bonding it to other molecules by Electro-kinetic energy. This

stabilization process (forming of a molecular bond) neutralizes the paraffin molecule, and it loses its ability to come out of solution and build up on the inner pipe surface.

On the other hand electromagnetic induction energy is never contained within the length of the coil. Its effects through polarization can be measured in both directions for an infinite distance. An example of this law of physics is to place a short induction coil in the center of a long length of steel tubing. When the coil is energized, the entire length of tubing becomes magnetized. **Figure 4.4** showing the step how molecules interact with electromagnetic field to prevent paraffin buildup.

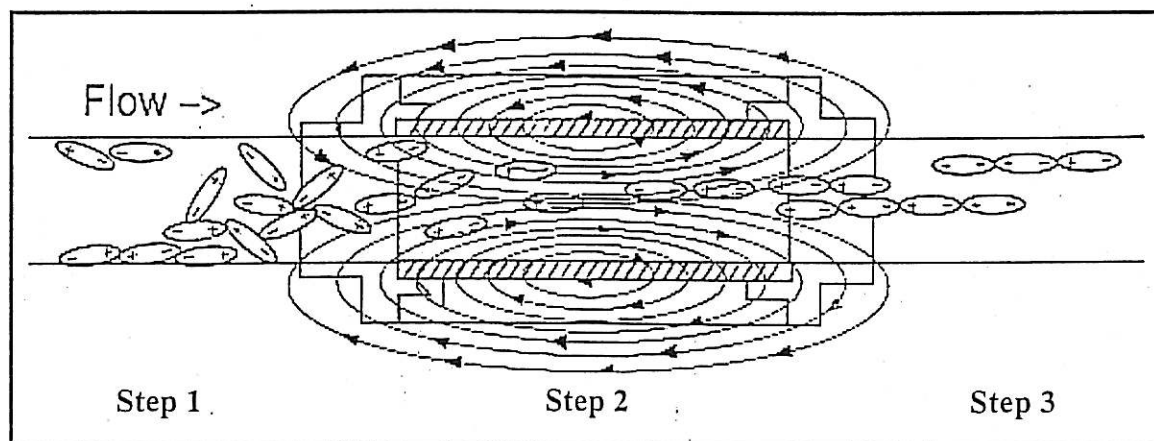


Figure 4.4: Illustration of interaction between electromagnetic field and molecules

Step 1 - The molecules as they appear at random and clinging to the sides of the pipe under normal conditions in untreated liquid.

Step 2 - The path of the flux field. This force creates the proper energy to polarize the molecules within the liquid conditioning system.

Step 3 - The molecules after they have been treated with the system. The internal forces orient the positive and negative poles in such a way as to produce a molecular chain.