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Magnetic Field Application: An Underappreciated Outstanding Technology

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Abstract

In diverse machines, as much as 90% of all particles suspended in the oil can be iron or steel and can be particularly troublesome to operators. This article looks at magnetic filtration advantages and benefits; moreover, it focuses on how this physical technology can often outperform traditional methods. Magnetic filtration is a process in which two objects are separated; one of them has to be metallic, to be attracted by means of magnets. Magnetic systems ideal for the food industry, as they protect the final product and the machinery used in its production process. Another important magnetic field application is in the water treatment technology. Despite the great achievements in the application of the magnetic field through the above-mentioned domains, more efforts should be performed to promote this green technology implementation in the industries in terms of practical usage. More attention has to be accorded by researchers to better familiarize industrials with this hugely promising technique.

Subject Areas

Civil Engineering

Keywords

Magnetic Field (MF), Magnetic Filtration, Iron, Separation, Magnetic Water Treatment, Green Technology

1. Introduction

Since industrial filtration techniques persist to progress, occasionally selecting one may be a many-sided resolution. There are a set of parameters, which interfere when deciding the most performant technique. In many situations, the integration of techniques is really the most convenient choice. One that appears to be an underused technique in the industry is magnetic filtration [1] [2].

Most processes not presently employing a type of magnetic filtration in its running may hugely profit via applying it. Equipment operators, maintenance technicians and reliability engineers all are aware and comprehend the significance of clean oil in attaining machine accuracy. Further, most experimented oil analysts come to an agreement that in numerous machines, as much as 90% of all solids suspended in the oil may be iron [3] or steel. These sorts of particles may be very disturbing [1] [4].

Typically, one or both of any lubricated, sliding, or rolling surfaces will have iron or steel metallurgy. These may comprise any number of frictional surfaces employed in gearing, rolling-element bearings, piston/cylinders, etc. [1] [5].

2. Magnetic Strength

Through forming a magnetic field (MF) or loading zones that gather magnetic iron [6] [7] and steel particles, magnetic filters may usually exceed conventional, mechanical filters (**Figure 1**). With magnetic filtration technique, magnets are geometrically placed to induce an MF that has a non-uniform magnetic strength [1].

This technique is usually utilized with rotating drums employed for tool coolants with elevated degrees of machining waste. Moreover, filter housings may be employed with a full collection of magnets and no filter media, with an aim to only capture ferrous metals. In the end, there is a flow among magnetic filters in the application. These are filter housings where there is no filter element. Alternatively, the magnets are in plates fixed through a rod that plays the role of a classical filter element [1].

However, cannot mechanical filters eliminate particles that are almost the same size? Whereas it is correct that traditional mechanical filters may eliminate

Figure 1. Magnetic filters are frequently employed throughout the industrialization step in the automotive industry. Via generating an MF or loading zones that gather magnetic iron and steel particles, magnetic filters may usually surpass classical, mechanical filters [1].

solids in the same size range as magnetic filters, most of these filters are disposable and incur a cost for each gram of particles retained [1].

Furthermore, employing magnetic filters over particulate filtration will need lower power consumption. This is attributed to the flow limitation provoked by the fine pore-size filter media. As pores become plugged with solids, the limitation augments proportionally, pushing the power required to run the filter system efficaciously to rise [1].

3. Conditions

The resolution to apply the magnetic technique in a specified purpose has constantly to be affected by diverse machine circumstances and fluid cleanliness targets. As an illustration, what is the anticipated concentration of ferrous particles? What sort of oil is employed? What is the running temperature, surge flow, shock, and machine design? [1] [8]

Since there are many commercial products, arrangements and usages, some benefits and drawbacks debated in this work may not apply. Nevertheless, comprehending the diverse parameters may function as a major starting point for making the resolution of if the magnetic technique is an appropriate solution in a specific usage [1] [9] [10].

4. Benefits

More important, magnetic filtration is viewed as a reusable technique. This evidently significates that it is a more cost-efficient technique than a conventional mechanical filter. The price of retaining a gram of solids from the oil using a magnetic technique is a portion of that afforded when only employing disposable filters. Thus, from an apple-to-apple rapprochement, employing magnetic filtration as compared to the usual disposable technique will, in the end, be friendlier to the bottom line [1] [11].

Moreover, there is the problem of flow limitation as the filtration is in utilization (**Figure 2**) [12]. Different from traditional filters, most magnetic filters do not manifest an elevation in flow limitation since they load with solids. This may be greatly beneficial. While classical filters may go into bypass at what time they begin to be plugged with solids, magnetic filters persist to eliminate solids and let oil flow [1] [9] [13].

5. Augmented Performance

One of the largest benefits of magnetic filtration is that it does not consistently have to be an "either/or" case. Indeed, if employed in simultaneity with traditional mechanical filters, magnetic filtration can conduct to an elevation in the mechanical filter's efficient service life. The effect may be so huge that in some situations, two or three times as much may augment a mechanical filter's life. A popular instance of this is employing a magnetic insert on a bag filter housing [1] [10].

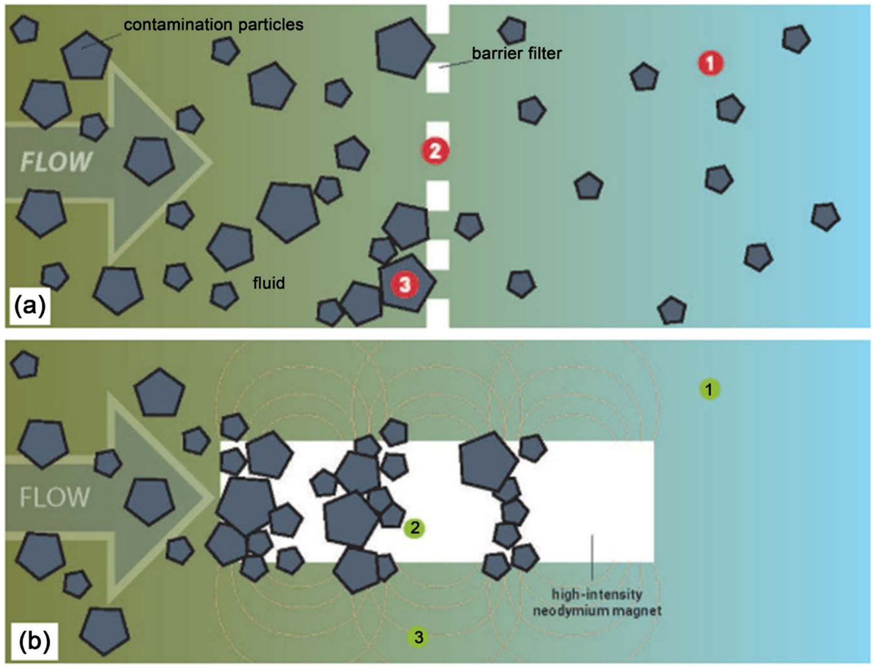

Figure 2. (a) Barrier filtration ((1). Particles smaller than the pore size remain in the fluid, reducing its efficiency and increasing wear on machinery and cutting tools. (2). Once full, the contaminated media is disposed of (along with fluid held in it). (3). The filter can become clogged causing blinding and back pressure), and (b) magnetic filtration ((1). High intensity magnets remove all particles and clean fluid continues uninterrupted on its way. (2). Once full, the contamination is removed from the magnet and can be recycled with minimal fluid loss. (3). Patented magnetic design means that the filter will not block so there is no blinding or pressure build up) [12].

The following main advantage of employing magnetic filtration is how it saves the equipment that the liquid is running through. More important, servo and solenoid valves may be excessively deteriorated by solids that are magnetic (like iron and steel). Through constantly eliminating such solids using magnetic filters, the accuracy of such valves may be basically ameliorated [1].

Moreover, magnetic filtration will better keep against early oil oxidation, which may conduct to varnish, sludge, and corrosion. Everything else being equal, the persistent elimination of iron and steel particles via magnetic filters has to possess a favorable influence on oil service life [1].

6. Magnetic Filtration

Both the set of magnets employed and manners in which magnetic filters and separators may be installed in a product's design are both crucial parameters that touch magnetic filtration. There is much more to their efficiency than just the strength or gradient of the MF. For instance, the size and design of the flow chamber, the total surface area of the magnetic loading zones, and the flow path and contact period of the oil are all substantial design parameters. These parameters affect the yield of separation, the size of solids being retained, and the global capacity of solids hold by the separator [1].

The magnetic force acting on a solid is proportional to the volume of the solid. Nevertheless, it is also disproportional to the diameter of the solid. For example, a two-micron solid is eight times more attracted to a MF than to a one-micron particle. Due to this, big ferromagnetic particles are easier to retain from a fluid than smaller ones. The separating force is proportional to the MF gradient and the particle magnetization (the degree to which the particle's material composition is affected by a MF) [1].

Solids made of iron and steel are the most powerfully attracted materials. Nevertheless, red iron oxide (rust) and high-alloy steel (for instance, stainless steel) are just weakly attracted to MFs. On the contrary, several nonferrous compounds like nickel, cobalt, and certain ceramics are known to possess a powerful magnetic attraction. Materials that cannot be picked up with a magnet, such as aluminum are named paramagnetic substances [1].

7. Competing Forces

It is crucial to remember that there are competing forces that counter particle separation from the fluid. Oil velocity is one such example, which imparts inertia and viscous drag on the particle in the direction of the fluid flow. Relying on the design of the magnetic filter, the fluid velocity may send the particle on a trajectory toward or away from the MF. This competing viscous force is proportional to both the particle's diameter and the oil viscosity. If the particle's diameter or the oil's viscosity augments, the hydrodynamic frictional drag will augment proportionally [1].

The magnetic attraction augments by a factor of eight when a particle's diameter doubles, while the competing viscous drag sees only a two X multiple. This is significant to pay attention and then establishes how big particles are more facilely separated than small particles, even in an environment of considerable viscous drag [1].

Particle capture performance by magnetic technique may be classified into three factors listed in **Table 1** [1].

Most filtration operations will have some usage for magnetic filtration. If there are metal particles being filtered out in any way, it is usually a profitable

Table 1. Three factors determining particle capture efficiency [1].

Factor	Description
Factor #1: Particle properties	The larger the particle, the easier it should be to separate. Further, if it consists of a highly magnetic material (for instance, iron and low-alloy steel), it will be subject to great capture efficiency.
Factor #2: Fluid features	The fluid conditions that best facilitate the separation of magnetic particles are low oil viscosity and low oil flow rate. If these conditions are met, extremely small, one-micron particles can be separated from the oil efficiently.
Factor #3: Magnet design	Magnetic filters that use high-flux magnets and are installed in a fashion that grows high-gradient magnetic will be the most efficient.

technique. Whether substituting conventional filters or improving their performance, magnetic filtration may be extremely useful [1].

8. Magnetic Water Treatment

Comprehension of the MF impacts noted through and following its exertion on water and aqueous solutions remains a polemic question even if the influences have been published for several decades [14] [15] [16] [17] [18]. Chibowski and Szcześ [19] discussed the literature which concerns the magnetic force treatment influences. As a rule, the modifications in water construction by hydrogen bonding alterations, as well as in intraclusters and among interclusters were considered. However, the most notable development was attained seven years ago by Coey [20] who used the non-classical theory of nucleation mechanism of the generation of dynamically ordered liquid-like oxyanion polymers (DOLLOP) to interpret the MF contribution (**Figure 3**). His criterion for the MF impact to take place was experimentally confirmed (**Table 2**). It was as well demonstrated that the gradient of the MF is more significant than the MF strength itself [21]. Numerous useful procedures interpreting an improved evaporation yield of water through an MF are also reviewed.

Han *et al.* [53] exposed water (**Figure 4**) and KCl solutions to four diverse MFs for 20 min, respectively. They investigated the impacts of the MF on microscopic structures and macroscopic features of water and KCl solutions using FTIR and the continuous spectrum techniques of linearly polarized light in ultraviolet, visible and near-infrared areas (**Figure 5**). They observed that in the UV–vis area, the transmittance of all samples exhibited diverse phenomena when the incident light with different polarized, it resulted from the orientation of water molecules affected by the static MF and the spiral motion of ions in the MF. The IR spectrum showed that KCl had a significant structure-breaking effect when the intensity of the MF increased and the absorption in the spectrum of KCl was a reflection of the perturbations that water bore in the presence of K^+ and Cl^- ions.

In the last years, numerous investigations on the influences of the MF on the water (**Figure 6**) have been published; however, still, several arguments and

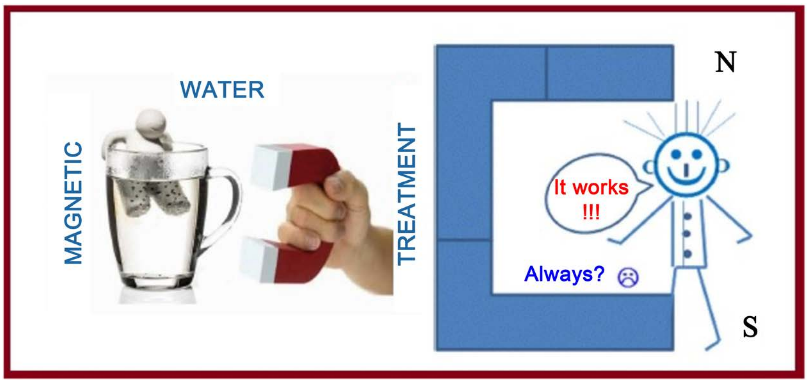

Figure 3. Magnetic water treatment [19].

Table 2. Published impacts due to MF treatment [19].

No	Phenomenon or parameter	MF effects and comments
1	Nucleation	Reduces the induction period, augments its rate. Slower nucleation of $CaCO_3$, altered crystalline structure.
2	Proton transfer	Faster transfer from HCO_3^- to water. Larger number of nuclei is formed.
3	Crystal forms	Influences $CaCO_3$ structure. More aragonite than calcite precipitates [22].
4	Particle size	Smaller particles. More stable dispersions [23] [24] [25].
5	Entropy of hydration [26]	MF effect depends on the entropy. Proportional to the entropy of ion hydration.
6	Zeta potential	Changes zeta potential of the precipitate due to ions adsorption [27] [28] [29]. It may reverse its sign [30] [31] [32].
7	Cluster transformation	Intercluster and intracluster transformation occur.
8	Hydogen bonds	Weakens the water intercluster bonds and strengthens the intraclusters bonds. Slight increase in the amount of the bondings.
9	Lorentz force	Affects the ion clusters, increase their mobility, weakens the solute/solvent interactions. The number of contacts of ion pairs increases and the amount of water pairs decreases.
10	Mobility of ions	Increases mobility, e.g. Na^+ and Cl^-. Diffusion mobility of cations increases and anion decreases [33] [34] [35]. (Simulated results).
11	Ion polarization	Especially bivalent ions [36] [37] [38]. More of cations because they are strongly hydrated than anions [38] [39] [40].
12	Surface tension	Increases or decreases surface tension [41] [42] [43]. (Contradictory results).
13	Viscosity	Increases viscosity. A larger increase at a higher temperature. (Contradictory results).
14	Memory effect [44]	The changes in physical properties may last up to 2 days.
15	Electrical double layer [45] [46] [47]	Shift of ions from the Gouy-Chapman diffuse part toward Stern compact part [48]. Charge neutralization [49] of the dispersed phase and sedimentation [50] [51] [52].
16	Evaporation rate	The rate can increase. Depending on the field direction, the Lorentz force may orient water dipole and thus enhanced evaporation.

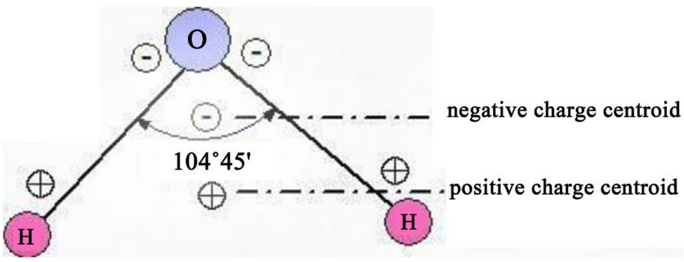

Figure 4. Model of individual water molecule [53].

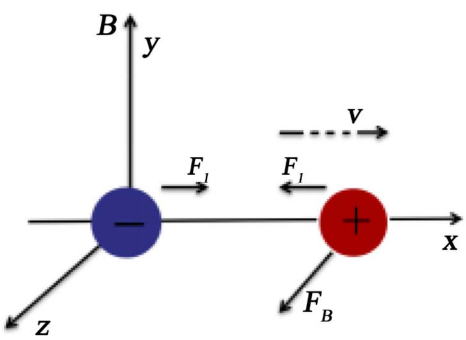

Figure 5. Diagram for electric dipole under the action of static MF [53].

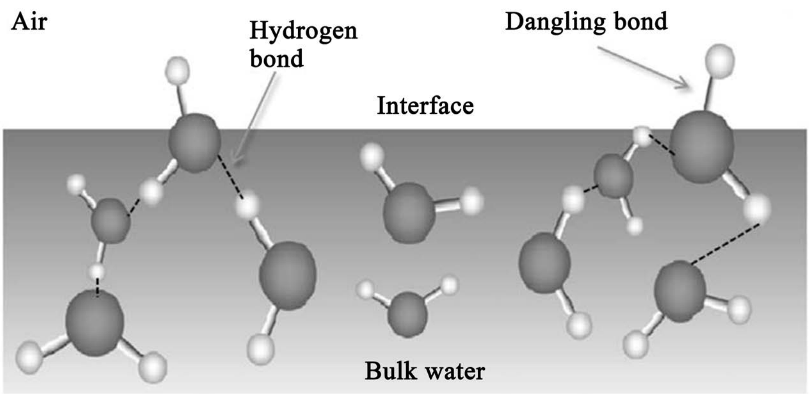

Figure 6. Water-air interface structure with dangling bond of hydrogen atoms in air above interface. Big and small spheres represent Oxygen and Hydrogen atoms, respectively [44].

doubts exist. Nevertheless, the augmentation in water evaporation because the existence of the MF is less in conflict. Seyfi *et al.* [44] examined the impacts of static MF on the quantity of deionized water evaporation in the existence of an MF with one, two or three permanent ferrite magnets perpendicular to the water-air interface. They demonstrated that the tangential MF at the interface does not alter the quantity of evaporation; however, when the MF is perpendicular to the interface, up to 18.3% elevation in water evaporation percentage is detected. An additional remarkable impact of the MF remains the memory effect, which appears when the MF is applied perpendicular to the interface with three magnets for 60 min after eliminating the magnets even up to 40 min more evaporation compared to non-magnetic water is still perceivable. These influences are interpreted and debated employing the kinetic energy of water molecules and Lorentz force on these moving charged molecules at the interface, which provokes weakening or breaking hydrogen bonds.

Lipus *et al.* [54] discussed electromagnetic water treatment, as an option solution for scale control in industrial water processing and tested a model setup with solenoid coils inserted into a cylindrical kernel inside a pipe for possible implementation at high water-flow capacity (few hundreds of m^3/h). A powerful MF (e.g. with maximum magnetic flux density from 0.1 T to 0.2 T) may be generated employing a DC electric supply resulting in total costs at least ten times lower than the expense of the scale-prevention ion exchange.

9. Conclusions

The main points drawn from this work may be given as:

1) Chibowski and Szcześ [19] reviewed the literature focusing on the magnetic treatment of water, mostly in the aspect of hard scale prevention, and concluded that there remains a lack of consistent theory of the field mechanism work. Nevertheless, the researches known through the last years obviously put forward our understanding of the field action which is based on changes in the structure of water via hydrogen bonding in intraclusters and between interclusters.

2) The contribution of the Lorentz force if acting perpendicularly to the water/air interface in the water evaporation rate was presented lately. Because a potential gradient exists at the interface and the gas phase susceptibility changes, the force enhances water evaporation. It is believed that new results of further studies applying the DOLLOP approach will be published soon thus developing our understanding of so far, not well-understood processes [19].

3) The FTIR and UV-vis-near IR spectrums depicted that the MF modifies the distribution of molecules and electrons, induces displacements and polarization of molecules and atoms, and conducts to changes of dipole-moment transition and vibrational states of molecules and variation of transition probability of electrons; however, it does not alter the constitution of molecules and atoms. Otherwise, KCl has a crucial structure-making impact. These findings are useful in investigating the pathway of magnetizing water and solutions [53].

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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