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HIGH GRADIENT MAGNETIC FILTRATION OF MAGNETIC AND NON-MAGNETIC CONTAMINANTS FROM WATER

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1.0 INTRODUCTION

Magnetic separation techniques have been used since the nineteenth century to remove tramp iron and to concentrate iron ores.[1] A variety of conventional magnetic separation devices are in wide use today. These devices generally separate relatively coarse particles of highly magnetic material containing large amounts of iron from non-magnetic media.

In recent years magnetic devices have been developed which are capable of separating even weakly magnetic materials of micron size at inherently high flowrates.[2,3] These so-called "high gradient magnetic separators" have been designed to maximize the magnetic forces on fine, paramagnetic materials.[4] They are capable of efficient separation of even weakly magnetic suspended solids or precipitates for which conventional magnetic separation techniques are ineffective. The separations may be carried out economically and at process rates of several hundred gpm/ft^2.

For normally non-magnetic colloidal material in polluted water the addition of small quantities of magnetic iron oxide (magnetite) renders these colloids sufficiently magnetic to be removed by high gradient magnetic separation devices.[5,6] This technique provides the rapid filtration of many pollutants from water, with a small expenditure of energy. Removal is much more efficient than with sedimentation because the magnetic forces on fine particles may be many times greater than gravitational forces. This technology has a strong potential for application to water pollution control.

High gradient magnetic separation is currently used in the kaolin clay industry[7] for the removal of weakly magnetic impurities less than 2 microns in diameter from clay. High gradient magnetic separation devices treating up to 60 tons per hour of dry clay as a 30 percent slurry are standard-size industrial units. The development of these high gradient magnetic separation devices results from the development of a filamentary ferromagnetic matrix[8] and a large volume high field magnet.[9] This combination of an efficient magnet and high gradient matrix permits the economical production of strong magnetic forces over a large surface area in the active volume of the separator.

This review describes the removal of specific pollutants by direct and seeded high gradient magnetic filtration techniques and the application of this treatment to polluted natural waters and industrial waters.

2.0 PRINCIPLES OF HIGH GRADIENT MAGNETIC FILTRATION

2.1 Magnetic and Competing Forces

High gradient magnetic separators, like all magnetic separators, utilize the interaction of magnetic and competing forces on a mixture of magnetic and non-magnetic particles to provide separation based on the magnetic properties of the particles.[10] This concept is illustrated in Figure 1 which shows a conventional drum separator. The magnetic forces on the surface of the drum hold the black, magnetic particles to the surface as the drum rotates. The competing force is that of gravity which causes the non-magnetic particles to fall off the drum. In this way the non-magnetic particles are separated from the black, magnetic particles that are held by

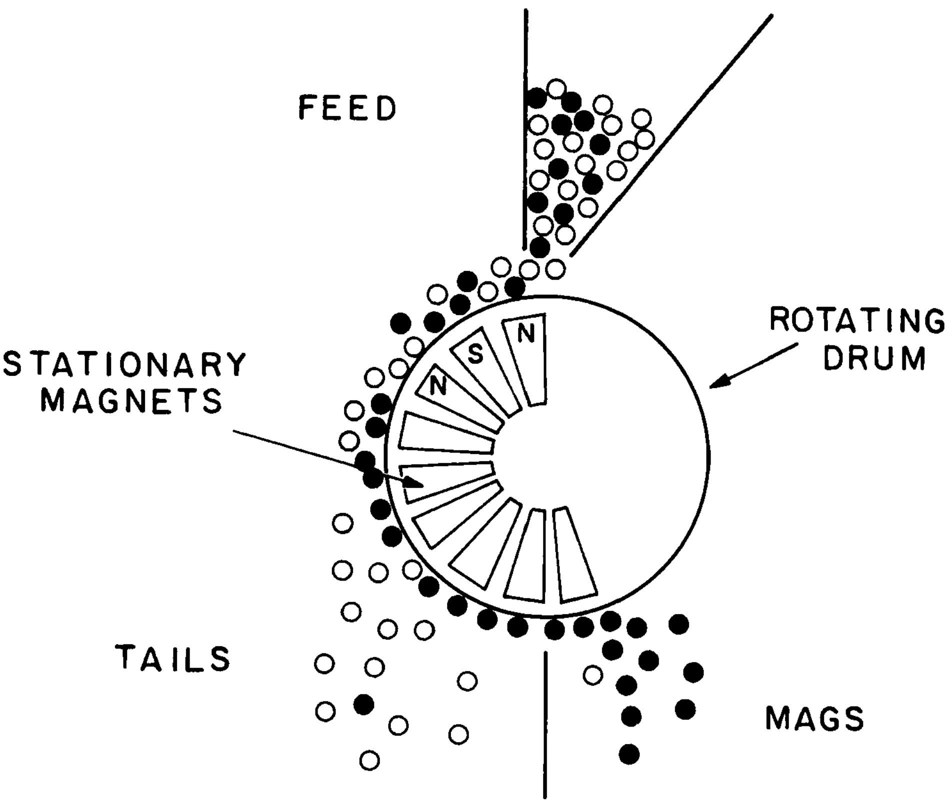


FIGURE 1

Conventional drum-type magnetic separator.

stronger magnetic forces to the drum until the drum has rotated past the end of the magnet. In an analogous fashion, as shown in Figure 2, the magnetic forces of attraction in a high gradient magnetic separator hold the magnetic particles to the edges of the matrix fibers while the competing hydrodynamic forces carry the fluid and non-magnetic particles through the separator. For small particles the forces of hydrodynamic drag are larger than gravitational forces and increase with the slurry velocity in the separator. Magnetic forces to trap these particles, therefore, must be large.

2.2 Maximizing the Magnetic Forces

High gradient magnetic separators effectively maximize the magnetic force on even weakly magnetic particles. The magnetic force on a particle is given by the following expression:

$$F_m = vM \text{ grad } H$$

where v is the volume of the particle, M is its magnetization, and grad H is the magnetic field gradient that acts on the particle. The magnetic field gradient appears in the expression for magnetic force for the following reason. Placed in a magnetic field, all particles develop north and south poles at either end as shown in Figure 3. In a uniform field the net force on a particle will be zero since the field exerts an equal and opposite force on either end of the particle. In a gradient magnetic field, however, the force exerted by the stronger field at one end of the particle will produce a net force on the particle. Therefore, the larger the change in field across the particle (magnetic field gradient), the greater the force on the particle. The low magnetic field gradients produced by the magnets within the drum

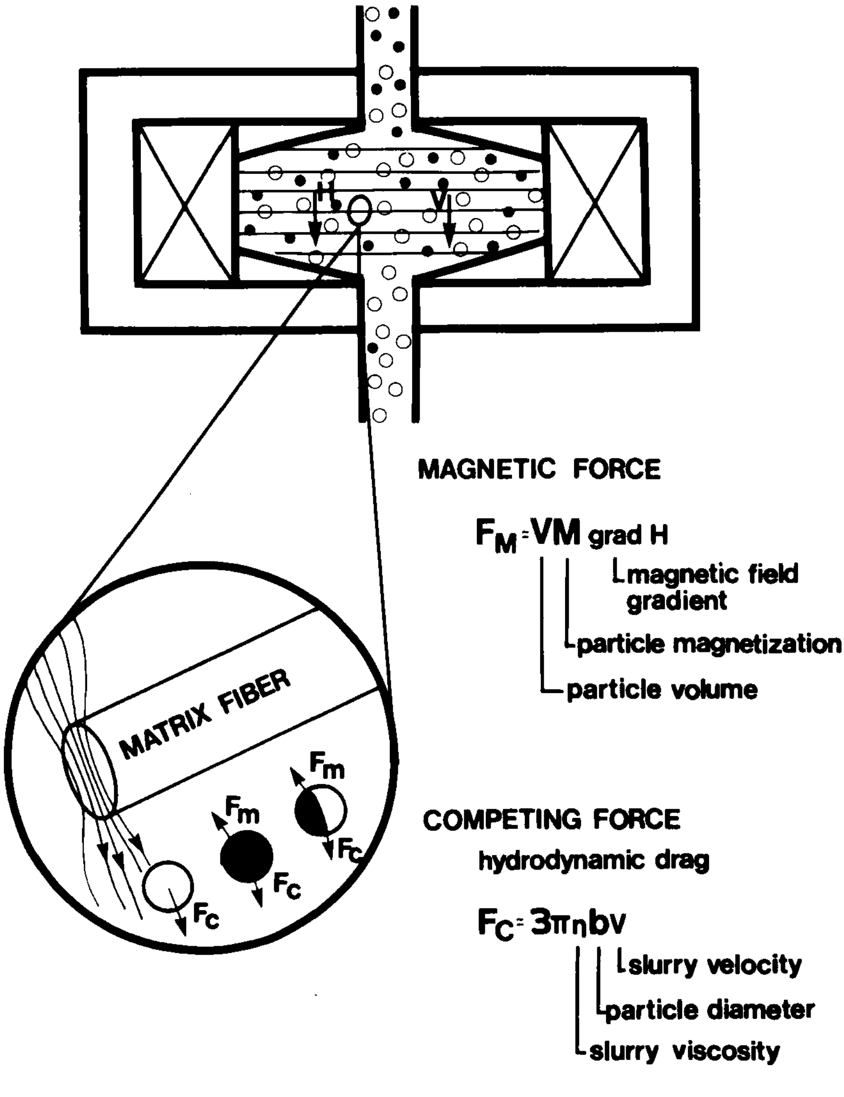


FIGURE 2

Diagram illustrating the competitive influences of the magnetic and hydrodynamic drag forces on the movement of particles through the high gradient magnetic separator.

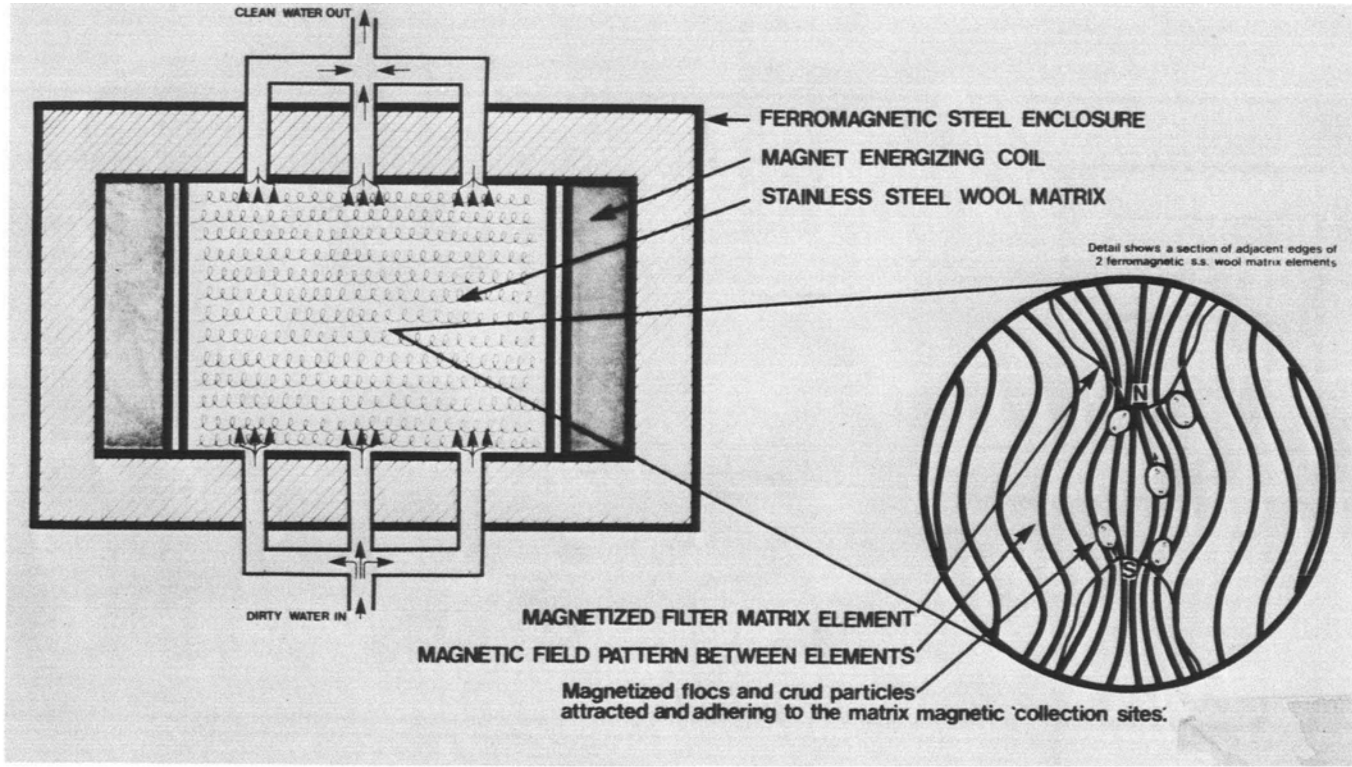


FIGURE 3

Detail on the right side of the figure shows the development of north and south poles in individual particles in a magnetic field.

separator like that shown in Figure 1 produce only modest magnetic forces.

The magnetization of ferromagnetic fibers like those in the high gradient magnetic separator matrix, however, produces extremely high magnetic field gradients. It turns out that the greatest force is produced on the particles when the diameter of the magnetized wire is approximately the same size as the particle to be trapped.[11] This matching of the fiber diameter to the particle size is utilized in high gradient magnetic separators to produce extremely large forces on even weakly magnetic particles.

2.3 The Ferromagnetic Matrix

In order to produce strong magnetic forces over a practical surface area, a filamentary ferromagnetic matrix magnetized by a strong applied field is used.[12] The effective trapping volume of this type of matrix is many times larger than the one achieved by the use of tacks, balls, or other small ferromagnetic objects which also produce large field gradients when magnetized. As shown schematically in Figure 4, the introduction of the ferromagnetic matrix into the uniform magnetic field produced by the electromagnets in the high gradient magnetic separator, produces a multitude of high gradient strong forces within the volume of the separator. A strong applied field is required to magnetize these fibers, and when this field is turned off the residual magnetization of the fibers is very low. For this reason even strongly magnetic particles are easily washed out when the applied field is reduced to zero.

2.4 Production of Strong Magnetic Fields

The ferromagnetic matrix is a relatively difficult magnetic structure to magnetize--that is, a large strong applied mag-

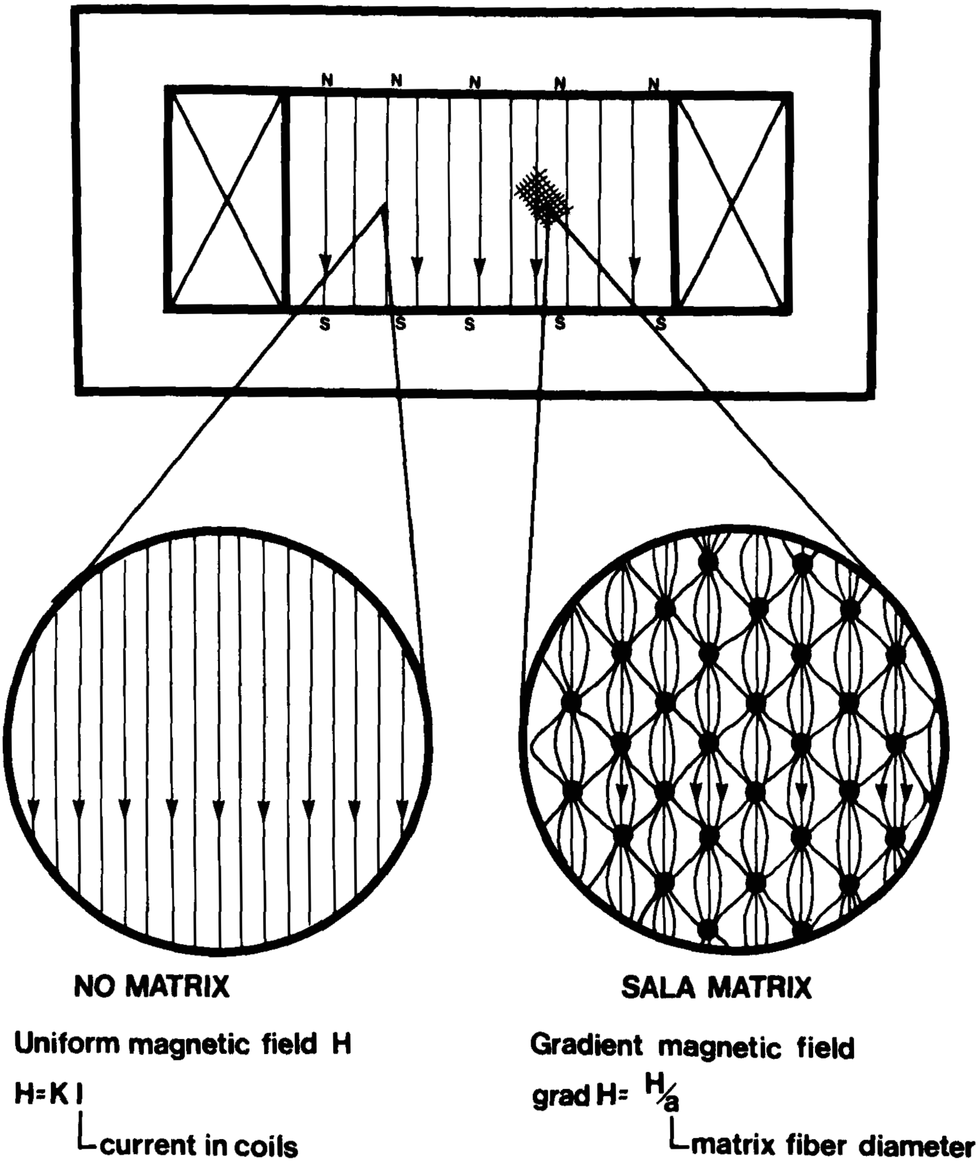


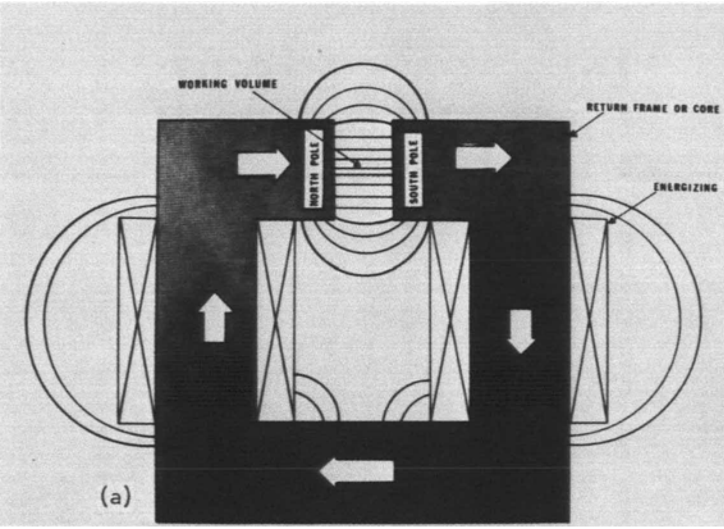
FIGURE 4

Effect of a matrix on uniform magnetic field.

netic field is required to produce high field gradients along the matrix filament edges. The magnetic fields in conventional magnetic separation devices are not sufficient to magnetize the ferromagnetic matrix. Therefore, practical realization of high gradient magnetic separation depends as much on the production of an economical, intense magnetic field as it does on the ferromagnetic matrix.

It is useful to compare the design of prior art magnets with those used in high gradient magnetic separators. Figure 5a shows a magnetic circuit commonly used for producing strong magnetic fields in conventional and some competing high intensity magnetic separators. The magnetic field in the working volume is produced by magnetic poles in the iron on either side of the gap. The electromagnetic energizing coils are placed on vertical legs of the magnet circuit in order to magnetize the iron. Much of the field produced by the coils in iron, however, never reaches the working volume but leaks around it through magnetic short circuits. The electromagnetic coils contribute nothing directly to the magnetic field of working volume since they are placed away from the working volume on the yoke of the magnet.

By contrast, in Figure 5b the magnetic circuit of the Sala design is shown superimposed on the prior art circuit. The electromagnetic coil is placed directly around the working volume where it contributes directly to the field within that volume as well as to the magnetization of the iron poles on either side of the working volume. A small iron return path around the Sala coil further increases the efficiency of the circuit. It is clear that considerable savings in iron have been achieved for the same working volume. In addition, the magnetic field produced in the new magnet is considerably more powerful for the same input of electrical energy than in prior art devices.



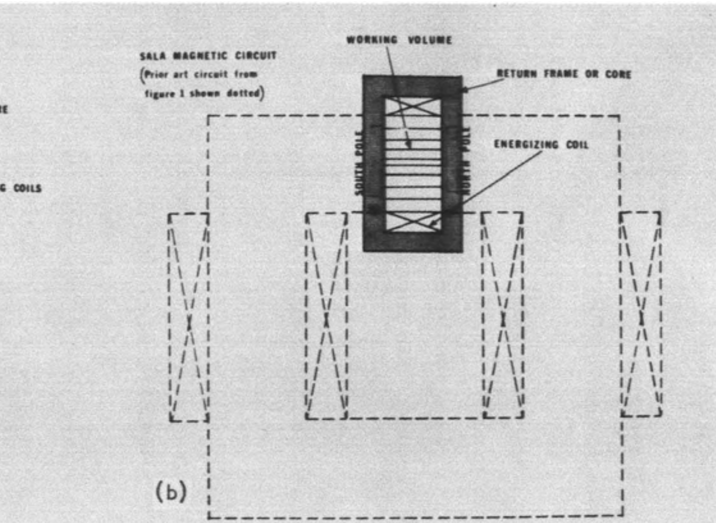


FIGURE 5a

Conventional high intensity magnetic circuit.

FIGURE 5b

Sala Magnetics circuit.

2.5 The Operating Variables of the Separator

The efficiency of magnetic particle trapping in a high gradient magnetic separator depends strongly on the operating variables of the separator as well as the size and magnetic susceptibility of the particles. The operating variables are the strength of the applied magnetic field, the velocity of the feed passing through the matrix, and the ratio of the feed material weight (percent of solids) to the working volume of the separator. In Figures 6 and 7, the effects of increasing magnet field, flow rate and matrix loading on the trapping of the magnetic particles is shown. The recovery of the magnetic particles increases with an increasing magnetic field because the magnetic forces are stronger. The recovery of the magnetic particles decreases with increasing feed velocity because the competing hydrodynamic drag forces are larger. The recovery of magnetic particles decreases with increased matrix loading since high gradient sites on the matrix become filled, leaving fewer trapped sites available. The effect of varying magnetic field, slurry velocity and matrix loading on the efficiency of a high gradient magnetic separator as a filter of magnetic particles varies approximately as the recovery indicated above. The optimization of the operating variables described here is important since these variables significantly affect the capital and processing costs in the practical use of high gradient magnetic separators.

3.0 HIGH GRADIENT MAGNETIC SEPARATORS

3.1 Cyclic Magnetic Separators

In its simplest form, the high gradient magnetic separator consists of a canister packed with a fibrous ferromagnetic material (such as stainless steel wool) and magnetized by a

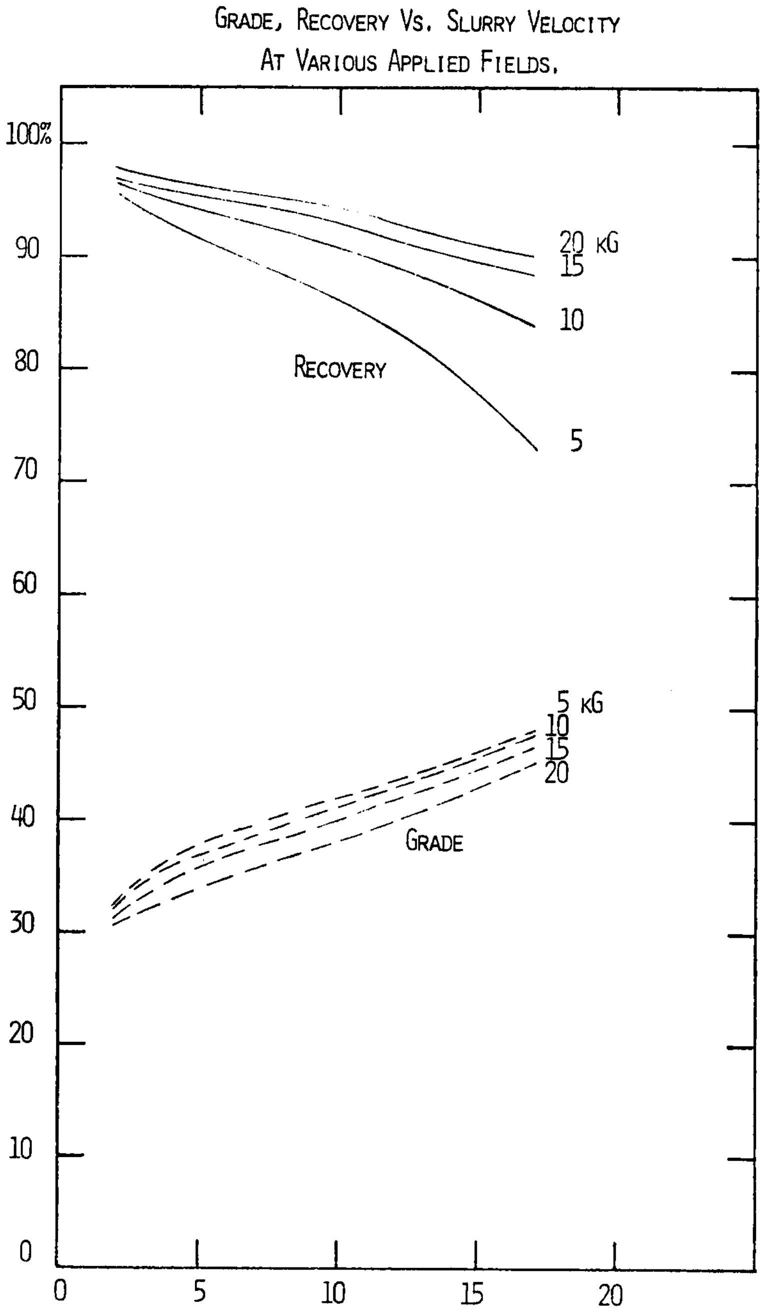


FIGURE 6

Influence of slurry velocity on the grade and recovery of magnetic material at various applied fields.

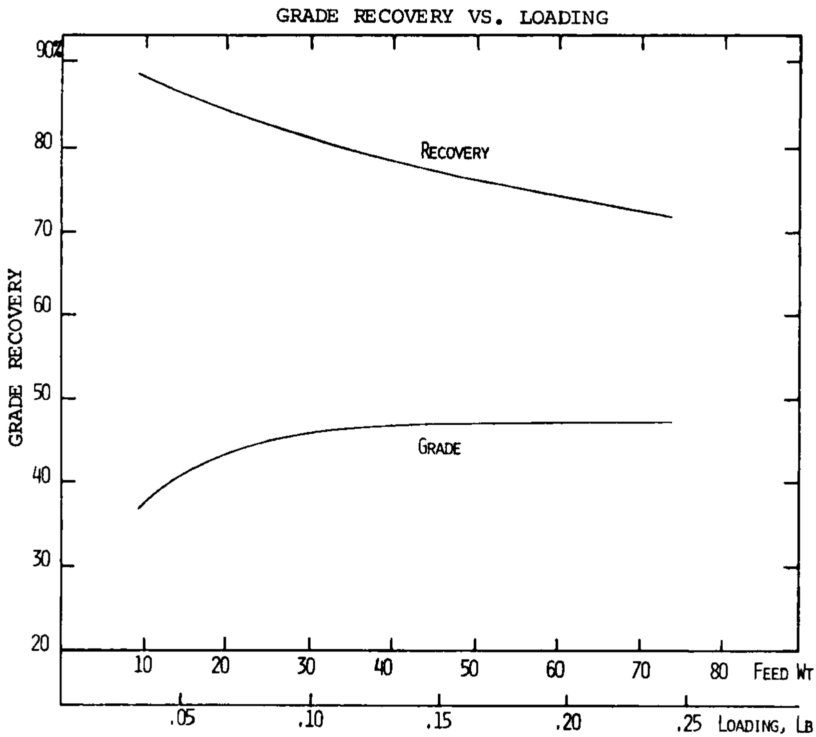


FIGURE 7

Decrease in magnetic material recovery with matrix loading.

strong external magnetic field. A schematic cross-section of a static high gradient magnetic separation device is shown in Figure 8. The magnetic matrix shown at the center is magnetized by the coils (indicated by crosses) which surround the canister. An iron frame (indicated by cross-hatching) increases the efficiency of the electromagnetic coils. The device operates in a sequence of feed and flush modes. A feed slurry containing the particles to be separated is passed up through the device with valves 1, 3 and 5 open. The magnetic particles are trapped on the edges of the magnetized fibers while the non-magnetic particles and slurry fluid pass easily

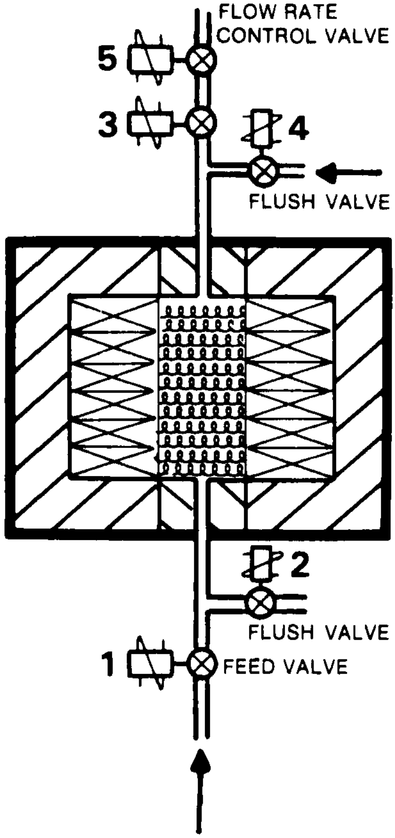


FIGURE 8

Schematic of a high gradient magnetic separator.

through the canister. The matrix offers only a small hydraulic resistance to the feed material. When the matrix has become loaded with magnetic particles, valves 1, 3 and 5 are closed and the magnetic particles are easily washed from the matrix by reducing the magnetic field to zero and opening valves 2 and 4 to permit backflushing. High gradient magnetic separation devices of this type, termed "static," "batch," or "cyclic" devices are used to process fluids and minerals containing a low percentage of magnetic impurity. Cyclic devices may be operated automatically and quasi-continuously by use of feed surge tanks. These devices are useful for water treatment and certain mineral processing applications such as kaolin purification. A small cyclic device is shown in Figure 9.

3.2 Continuous Magnetic Separators

Continuous high gradient magnetic separation devices have also been developed.[13] These devices are useful for separation problems where the magnetic fraction of the feed slurry is large and the duty cycles of cyclic devices would be too short for efficient separation. Many mineral separations require such devices.

4.0 HIGH GRADIENT MAGNETIC FILTRATION TECHNIQUES IN WATER TREATMENT

The use of high gradient magnetic separation or filtration in water treatment may be accomplished in two ways depending on the nature of the contaminants of the water. For waters contaminated by magnetic suspended solids, such as those found in steel mills and the corrosion products of boiler waters, high gradient magnetic filtration may be used alone to effect a highly efficient removal of these particles.

Alternatively, if these suspended solids or other impurities in the water are non-magnetic, a magnetic seeding technique may be used to bind the non-magnetic contaminants to magnetic particles which may then be filtered magnetically in high gradient magnetic filters. Such a technique for magnetic separation of solids from a liquid medium was outlined in Czechoslovakian patent No.: 132624 in which a coagulant is used to attach particles to a coarse iron seed.[14]

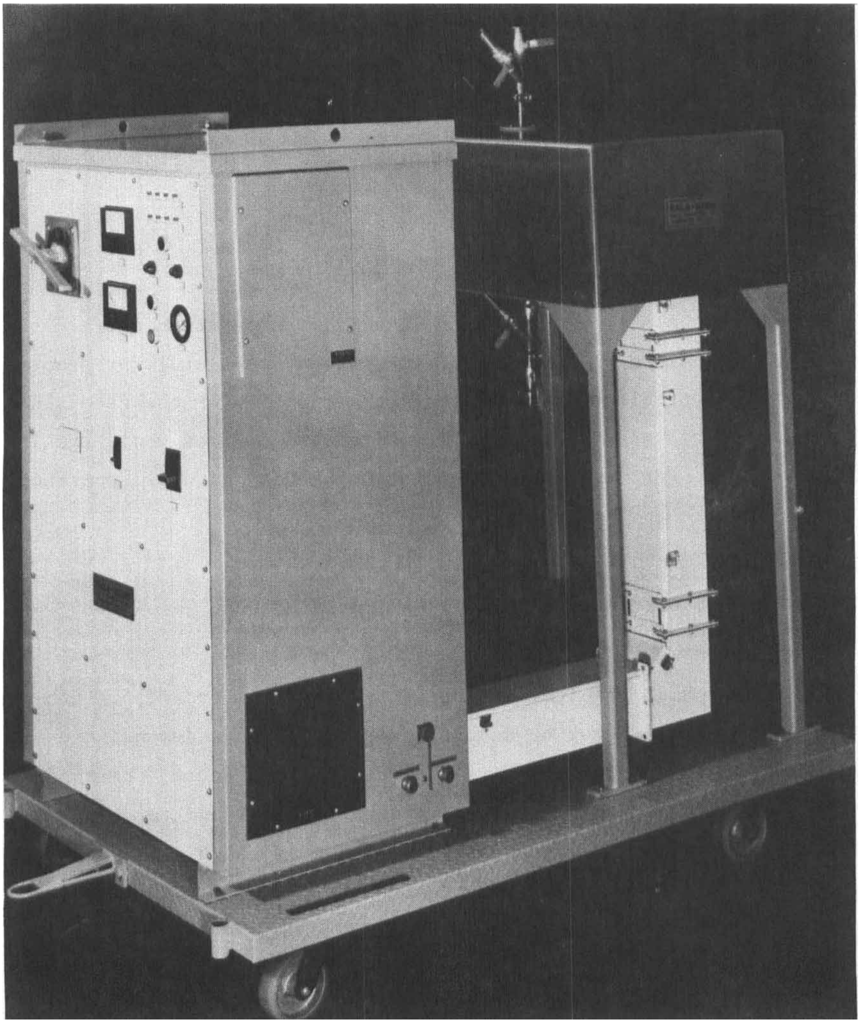


FIGURE 9

10 cm bore skid mounted cyclic magnetic separator.

Colloidal pollutants in water which may be removed by this technique include algae, bacteria, viruses, and non-biogenic suspended solids. In addition, some finely divided precipitates remain in the water after phosphates are precipitated. The addition of a magnetic seed in the form of very finely divided magnetite (1 to 30 μ) serves to make these pollutants magnetic.[14,15] The magnetite both adsorbs to the larger particles and acts as an adsorbent for the smaller particles in the water. In addition, a portion of the soluble organic material in solution is adsorbed to the magnetite. The seeded water is filtered rapidly on a high gradient magnetic separator yielding water almost free of insoluble pollutants. A portion of the soluble organic matter is also removed. The concentrated pollutants and magnetite are easily removed from the separator's matrix by washing in the absence of the magnetic field.

In some cases it is necessary to use chemical flocculating agents to stimulate the formation of flocs around the magnetite seed particles. As it is unnecessary to develop large flocs, the long contact periods used in conventional flocculation and sedimentation procedures are not necessary prior to high gradient magnetic filtration.

5.0 DIRECT APPLICATION OF HIGH GRADIENT MAGNETIC SEPARATION TO WATER TREATMENT

5.1 Suspended Solids Removal

5.1.1 Steel Mill Waste and Process Waters

Treatment of steel mill waters involves the direct filtration of finely divided, strongly magnetic suspended solids. Non-magnetic suspended contaminants such as tramp oil are naturally seeded by the magnetic particles. As a result they are also removed without the addition of further seed or chemical media.

Table I presents some of the results obtained in treating steel mill process and waste waters.[16,17] Signficant reductions in suspended solids content are achieved for a variety of feeds. In most cases over 90% suspended solids reductions are obtained in a single pass through a high gradient magnetic filter at very high flow rates. For example, 1,500 mg/l suspended solids in mill scale is reduced to only 53 mg/l in a single pass at a flow rate of about 9 m/min and a magnetic field intensity of 19 kG (1.9 T). To some extent, a trade-off between magnetic field strength and flow rate may be seen by comparing this result with those for blast furnace scrubber and rolling mill effluents where in a single pass the suspended solids are reduced from 521 mg/l to 3.1 mg/l at the much slower flow rate of 0.72 m/min but at a magnetic field of only 2 kG (0.2 T). Since the flow rate is slower, the process capacity of

TABLE I

Results Obtained Using High Gradient Magnetic Separation To Treat Steel Mill Process and Waste Waters

	Suspended Feed mg/l	Solids Treated mg/l	Magnetic Field kG	Flow Vel. m/min	Number of Passes
BF Scrubber Water	1340	13	10	3.4	2
	582	1.2	5	1.32	2
Vacuum & Electric Furnace	309	2.5	10	2.1	2
BOF Scrubber Water	4500	<1	9.6	2.5	1
	4500	10	4.6	5	1
Mill Scale Pit Overflow	150	13	19	2.7	2
Cold Rolling Mill Water	47.6	14	11.5	0.74	1

the device would be lower but since the magnetic field is also lower in this case, the operating costs for power, and to some extent capital costs, would also be reduced. The particular characteristics of a given effluent would determine the optimum operating conditions for a high gradient magnetic separator.

5.1.2 Boiler Feed Waters

Heitmann has reported the effectiveness of magnetic filters for the removal of iron oxide in boiler feedwater.[18] Iron oxides, magnetite and hematite are the principal corrosion products in these waters. They occur as 10-20 μ particles. High field magnetic filters are able to reduce iron content from 200 ppb to 4 ppb at high process rates. Devices with capacities of up to 5,000 gpm are presently under construction.

High gradient magnetic filters also have been used successfully to effect a single-pass removal of over 90% of the radioactive corrosion product from nuclear reactor primary coolant loop.[19]

5.2 Heavy Metals Removal

The release of heavy metals into the environment by industry or in agricultural practice poses both a health hazard to humans and causes extensive ecological damage. The hazard is especially great because the microflora are unable to degrade these pollutants which are consequently concentrated up the food chain.[20] The efficient removal of heavy metals from point sources is of prime concern for the maintenance of pollution-free natural waters.

Okamoto has proposed a new process using ferrous and ferric hydroxide gels to eliminate heavy metals from wastewaters.[21]

This process is applicable to a wide range of heavy metals such as those found in smelting plants, incinerator smoke flushing, plate process and from surface treatment of metals.

A related process developed by Nippon Electric Company of Japan and described by Okudo, Sugano and Tsuji,[22] consists of treating the waste water with ferrous sulfate, neutralizing with sodium hydroxide and oxidizing with air under specific conditions. As a result, a ferrite sediment in which the heavy metals and iron have been co-precipitated, is obtained. This magnetic sediment is separated by magnetic filtration. The performance of this process is shown in Table II.

The removal of heavy metals by precipitation and direct high gradient magnetic filtration has also been observed. Table

TABLE II

Concentration of Metal Ions in Influent and Effluent

Metal	Concentration Influent mg/1	Concentration Effluent mg/1
Hg	7.4	0.001
Cd	240	0.008
Cu	10	0.01
Zn	18	0.016
Cr	10	>0.01
Ni	1000	0.2
Mn	12	0.007
Fe	600	0.06
Bi	240	0.1
Pb	475	0.01

III shows the removal of Ni and Cu from precipitated plating waste waters by direct high gradient magnetic filtration.

6.0 APPLICATIONS OF HIGH GRADIENT MAGNETIC SEPARATION

6.1 Bacteria

Finely divided magnetite adsorbs well to bacterial cells. When raw sewage, secondary treated effluent, or polluted water is seeded with magnetite, the microbial cells are amenable to removal by high gradient magnetic separation. De Latour[5] described the almost total removal of coliform bacteria from polluted river water seeded with magnetite using a high gradient magnetic separator operating at a background magnetic field intensity of 10 kG (1.0 T).

Tests conducted by Sala Magnetics for the Boston Metropolitan District Commission also used the addition of a flocculant to remove close to 100% of coliform bacteria from polluted Charles River water.

Mitchell et al.,[6] described the removal of between 90 and 97% of the bacteria from polluted water seeded with magnetite and passed through a high gradient magnetic filter. More recent

TABLE III

Treatment of Plating Waste Water

Sample	Cu mg/l	Ni mg/l	Treatment	pH
Feed	3.0	5.3	--	--
S-5	0.30	1.5	100 mg/l $FeCl_3$	8.5
S-7	0.23	2.8	200 mg/l Magnetite	8.5
S-8	0.16	0.85	No Additives	10.1

studies in Mitchell's laboratory have yielded 99% removal of bacteria from seeded raw sewage.

6.2 Algae

Algae are removed by high gradient magnetic separation as efficiently as bacteria. In batch experiments all of the algal cells in contaminated water were caught on the high gradient magnetic filter. The high degree of efficiency in removing algal cells probably reflects their large size and therefore the high concentration of magnetite adsorbed to their surfaces.

6.3 Viruses

Viruses are important agents of human diseases, and during the past decade considerable attention has been paid to their fate in the aquatic environment. Water is known to be an important carrier for animal viruses and especially the agents of infectious hepatitis and poliomyelitis. These infectious particles occur generally at very low concentrations in water and research has been focused on the development of water treatment processes to remove them efficiently.[23]

In general, virus particles may be removed from water by chemical treatment such as chlorination or ozonation, or by physico-chemical processes such as flocculation, filtration or adsorption to surfaces.[23,24] The adsorption of viruses onto surfaces has been reviewed by Bitton,[25] who reported that iron oxides may act as good adsorbents for the removal and concentration of viruses. Viruses are known to be adsorbed to hematite[26] and magnetite iron oxide.[27]

Bitton and Mitchell[28] have carried out an extensive study of magnetic separation of viruses from water. Ninety-five percent of the viruses were removed by high gradient magnetic filtration following ten minutes of contact time with magnetite. A concentration of 250 ppm of magnetite was sufficient to yield maximal removal. The addition of calcium chloride as a bridge between the virus and magnetite improved separation. The process removed as few as 30 and as many as 14,000 virus units per ml of water.

Magnetic separation techniques could be used as a pre-treatment of water before disinfection to lower the concentration of viruses. Because of their small size and the difficulty of culturing them, the concentration and detection of viruses in potentially contaminated water is a serious problem. High gradient magnetic separation offers a technique for rapid concentration of small numbers of viruses from large volumes of water. This makes it particularly attractive for use in routine testing of drinking water.

6.4 Dissolved Phosphorus

Eutrophication is the enrichment of natural waters with nutrients. A result of this process is the excessive growth of algae, and ultimately the development of anoxic conditions in the water. Phosphorus is an important nutrient controlling algal productivity in rivers and lakes. The major source is sewage and agricultural wastes. Several methods are available for the removal of phosphorus from sewage or from receiving waters.[29,30,31,32,33] They depend on the coagulation of the phosphates with lime or alum. The coagulated phosphates are usually sedimented in ponds. Disadvantages of the sedimentation process include the requirement of time and space and the inability to remove finely suspended particles. By comparison, high gradient magnetic separation of phosphates is very rapid and removes even very finely suspended phosphate precipitates with devices requiring a small area.

The process for removal of phosphates by high gradient magnetic separation requires seeding with magnetite at the same time as the phosphate-rich water is treated with a coagulant.[6,34,35] Typical data are shown in Figure 10. Only 250 ppm of magnetite were necessary to remove coagulated orthophosphate by magnetic separation. When montmorillonite clay was used as a flocculant, magnetic removal efficiency was higher than 90% at levels of phosphate as low as 250 μg P

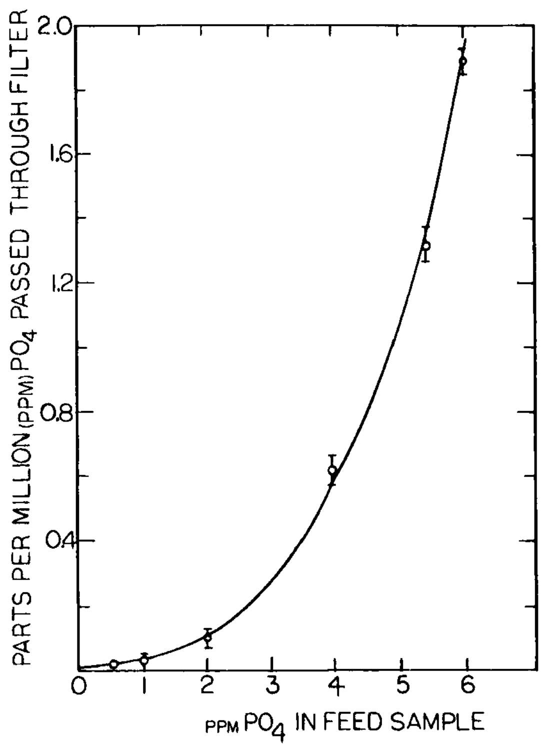


FIGURE 10

Reduction in phosphate concentration obtained by passing a phosphate-contaminated sample through a high gradient magnetic filter.

$liter^{-1}$. The increased efficiency is probably related to the adsorption of phosphates to the edges of the clay particles.[36]

When the water contains high phosphate concentrations, removal efficiencies greater than 90% require a second passage through the high gradient magnetic separator or the addition of higher concentrations of magnetite. Flow rates ranging from 30 to 150 gpm/ft^2 were used in these studies.

6.5 BOD_5 Removal

A high level of BOD_5 indicates water containing a large concentration of organic contaminants. The quality of such water is considered poor. Magnetic seeding and flocculating techniques combined with high gradient magnetic separation decrease the BOD_5 content of water. Decreases in BOD_5 for samples of kraft paper mill effluents including primary clarifier overflow and for Charles River samples are shown in Table IV. These results were obtained at the Sala Magnetics laboratory.[15]

TABLE IV

BOD_5 Reductions Using High Gradient Magnetic Filtration

Source	Feed	Treated	% Reduction
Pulp & Paper Mill Primary Effluent	414	130	69
Stabilization Basin Overflow	51	9.8	80
Charles River	40	16	60

6.6 Color and Turbidity

The quality of natural waters is adversely affected by color and suspended solids. Both colored materials and suspended solids associate well with magnetite making them amenable to removal by high gradient magnetic separation. De Latour[5] describes the removal of 95% of the color and turbidity from water by this process.

Results obtained in tests made on polluted Charles River water by Sala Magnetics show a 97% reduction of the color and a 99% reduction in turbidity.

Sala has carried out a series of bench tests on several pulp and paper mill effluents for a major U.S. paper company with excellent results. These results show significant reductions in color and turbidity. In the kraft paper mill tests no attempt was made to optimize the seed or flocculant concentrations. Color and turbidity reductions in Charles River water, sewage and pulp and paper mill effluent are displayed in Tables V and VI respectively.

TABLE V

Color PCU

Source	Feed	Treated	% Reduction
Charles River Top	105	3	97
Charles River Bottom	3700	1	99
Deer Island Sewage	150	20	87
Pulp and Paper Primary Effluent	3700	110	97
Stabilization Basin Overflow	2680	135	98

TABLE VI

Source	Feed	Treated	% Reduction
	Turbidity JTU		
Charles River Top	20	2	90
Charles River Bottom	1700	1	99
Deer Island Sewage	50	3	94
Pulp and Paper Primary Effluent	750	<25	>96.6
Kraft Mill Stabilization Overflow	250	<125 (clear)	50

Preliminary cost studies based on the full set of results obtained in testing pulp and paper mill effluents indicate that these effluents can be treated at a total cost of a few cents per cubic meter.

A 4 liter per minute continuous operation pilot plant that includes a flocculation train and a seed recycling system is shown in Figure 11 and is now operating in the Sala laboratory in Cambridge, MA and will provide further engineering data for a larger pilot plant and for full-scale SALA-HGMS™ magnetic filter installations.

6.7 Oil Pollutants

There are a number of applications for which preliminary test results are of sufficient interest to be mentioned here. These involve the removal of emulsified oil from refinery wastes. Table VII shows some results obtained at one of our laboratories on refinery waste water.

Magnetite adsorbs oil well. Turbeville[15] prepared bouyant ferromagnetic particles to spread on oil spills. The magnet-

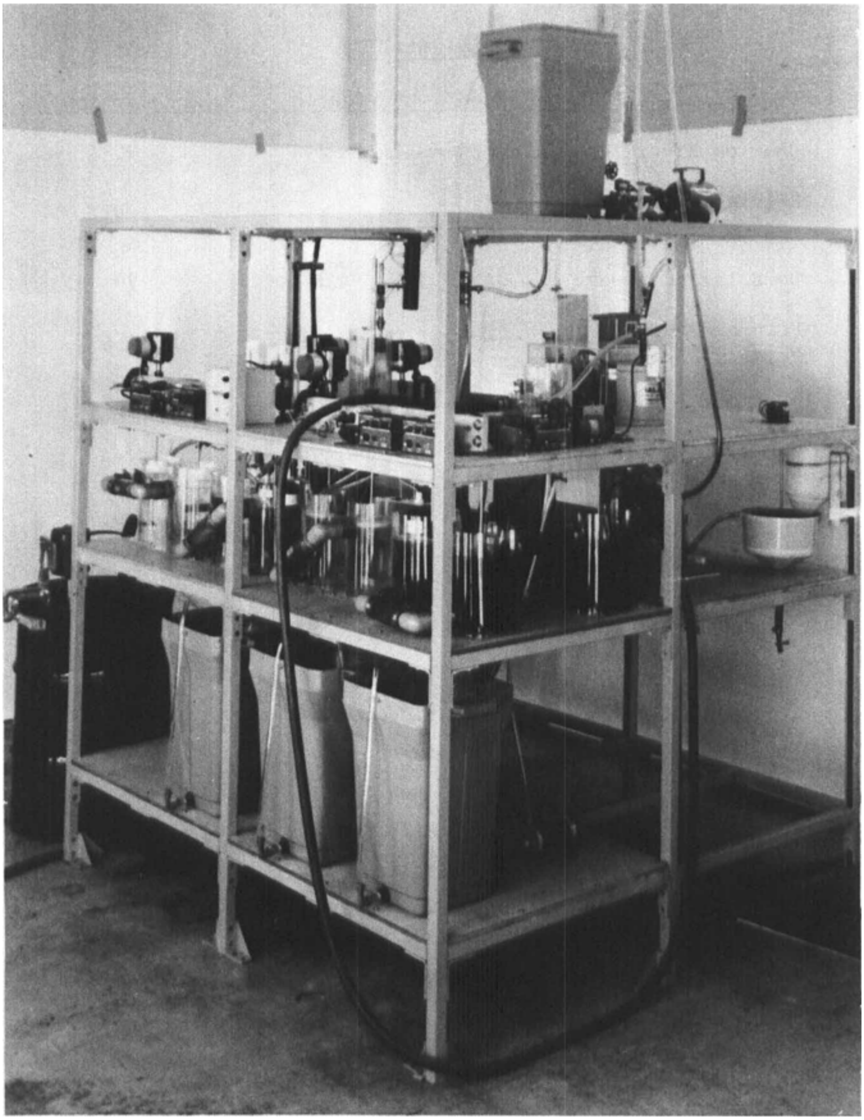


FIGURE 11

A 4 liter per minute continuous operation pilot plant for treating magnetically-seeded waters.

TABLE VII

Bacterial Removal

Source	Feed #/100 ml	Treated	% Reduction
Charles River Top	16,000	0	100
Charles River Bottom	16,000	300	98
Deer Island Sewage	2.8×10^6	1.8×10^4	99

ized surface film adsorbed the oil pollutant and was recovered using magnetic equipment. Oil in more confined spaces might be removed by high gradient magnetic filtration. Refinery effluents would be amenable to this type of treatment.

6.8 Radionuclides

Magnetic adsorbants have been used to remove radionuclides from water. Starke and Quecke[37] discussed decontamination of radioactive wastes by adsorption of radionuclides of strontium, cobalt and cesium onto magnetic materials. High gradient magnetic separation may provide a means for the removal of low concentrations of radionuclides in nuclear power plant waste waters.

7.0 TREATMENT PROCESSES

7.1 Treatment Plant for Blast Furnace Scrubber Water

Removal of suspended solids from blast furnace scrubber water is a problem common to all steel mills. Clarifiers are generally used to treat these process waters because deep bed filters are unable to cope with the high load of suspended solids. Clarifiers require large areas and the addition of chemical flocculants to produce high quality, low suspended solids effluents. The costs of high gradient magnetic filtration are highly competitive with conventional treatment while offering the advantages of high purity effluent and much smaller space requirements.

A possible flowsheet for a 57,000 m^3/day plant consisting of feed pump, high gradient magnetic separation filter, a thickener and a vacuum filter with a small pump to return the thickener and filter overflow to the feed line is indicated in Figure 12. The wide solid line indicates the flow of the

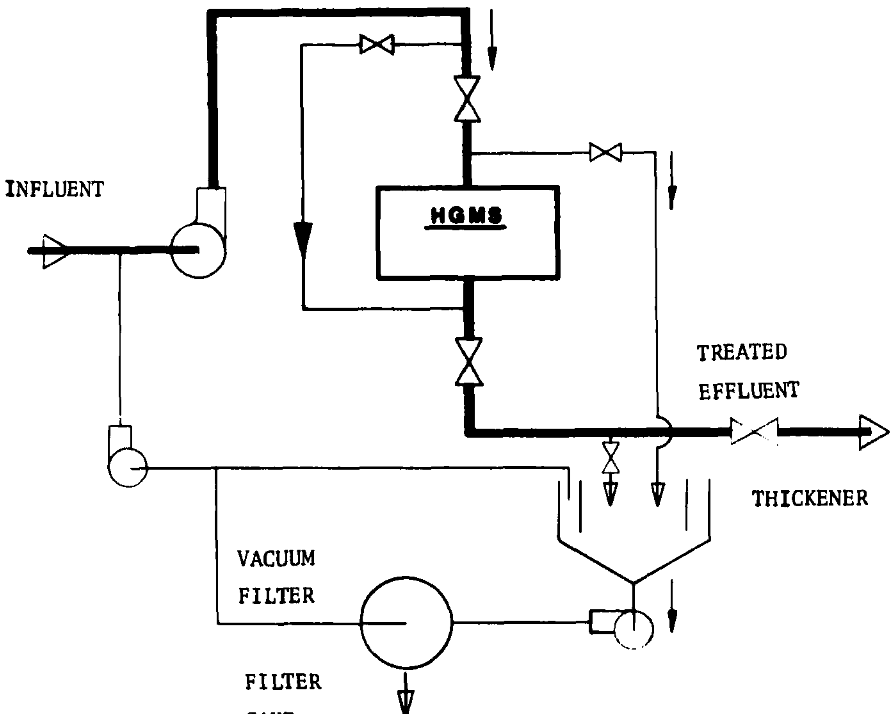


FIGURE 12

Flowsheet for a 57,000 m^3/day water treatment plant.

treated effluent through the high gradient magnetic filter during the operating portion of the cycle. The influent is diverted and used to backwash the high gradient magnetic filter with the magnet de-energized. The 1 to 2% solid density sludge removed from the filter goes to a thickener with sufficient capacity to take a full three minute influent flow, thereby serving as a surge tank as well as thickener. The 30% solids underflow from the thickener is pumped to a conventional vacuum filter to produce filter cake. At the end of the wash cycle, a flow diversion valve is closed and the flow resumes through the filter with the magnet energized. The first few seconds of flow may have higher suspended solids content than conventionally treated water and may be diverted into the thickener if necessary. The duty cycle for the system based on a 2 kG (0.2 T), 3 m diameter magnet would be approximately 77%, ten minutes on and three minutes off for backwashing when flow velocity is 60 gpm/ft^2 and the initial suspended solids concentration is 2000 to 3000 MGD.

The total estimated, installed cost of such a device would be U.S.$843,000.00. The cost per liter per second of capacity for this sytem is approximately U.S.$5.30. The estimated operating cost per cubic meter is U.S.$0.013. The area required for this installation would be approximately 2,040 square meters; the area covered by the clarifier alone to treat this flow would be 12,400 square meters. It is anticipated that the typical performance of this device would be to reduce the suspended solids in the influent from 2000 to 3000 mg/l to an effluent containing 5 to 15 mg/l.

An engineering sketch of a 3 m ID, 2 kG (0.2 T) SALA-HGMS^{TM} magnetic filter is shown in Figure 13. This figure shows the scale of the device and gives an idea of its physical appearance.

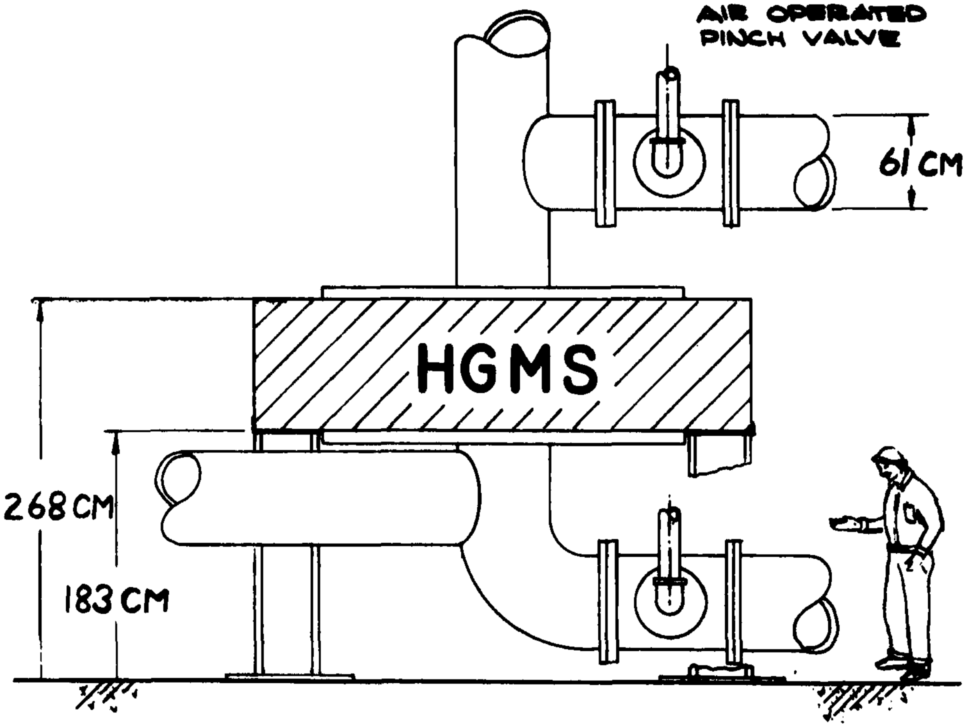


FIGURE 13

3 m ID, 2 kG (0.2 T) high gradient magnetic filter.

7.2 Municipal, Sewage and Non-Magnetic Contaminant Treatment

Figure 14 is a simplified flowsheet proposed for the treatment of municipal waste waters. It is similar to that used in tests on Charles River water performed by Sala Magnetics, Inc., for the Boston Metropolitan District Commission. This flowsheet includes a preliminary screen to remove coarse particles greater than 200 μ from the water prior to further treatment. The water then passes through a seeding and flocculation train in which magnetic seed and appropriate floccu-

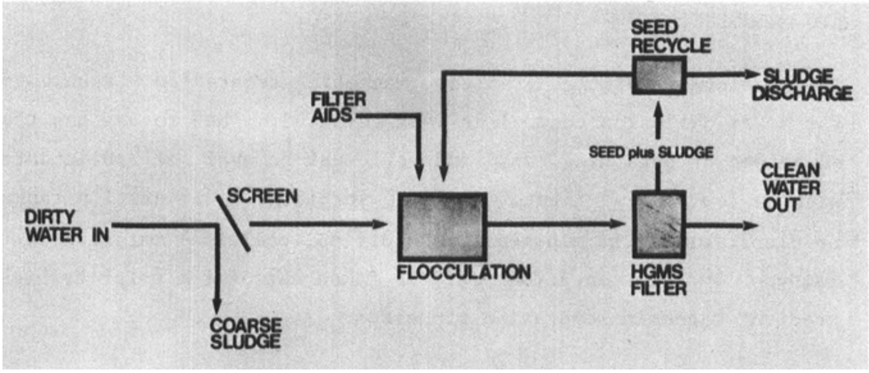


FIGURE 14

Simplified flowsheet for water treatment applications requiring magnetic seeding techniques.

lating agents are added and mixed thoroughly with the water. The seed provides a nucleus to which such contaminants as coliform bacteria and viruses adsorp and around which other contaminants such as suspended solids and the materials contributing to BOD_5, color and turbidity are flocculated. A 2 MGD facility embodying such a flowsheet costs an estimated U.S.$545,000. Maintenance and overhead for such a system are estimated at U.S.$0.26/1000 gallons. Some typical results from these tests are shown in Table VI and VII. These results display the effectiveness of high gradient magnetic separation in the removal of contaminants such as BOD_5, color, turbidity, fecal and non-fecal coliform and phosphorus that prevent these waste waters from being used for recreational purposes in the case of municipal waters.

Sewage has been treated by high gradient magnetic separation with similar success.

8.0 CONCLUSIONS

The development of high gradient magnetic separation techniques for water pollution control is well advanced. The process has the advantage of obtaining rapid and efficient removal of pollutants with a low energy input. The need for large sedimentation tanks or clarifiers is eliminated. In addition, colloidal material not removed by sedimentation may be taken out of the water by high gradient magnetic separation processes.

The high gradient magnetic separation process is highly versatile and offers possibilities for use either as a replacement for small sewage treatment facilities or in large facilities as an advanced treatment process. In the latter capacity high gradient magnetic separators could be used to remove phosphates and polish effluents following secondary treatment.

High gradient magnetic separation has strong potential in eutrophication control. High process rates and low energy requirements make it economically feasible to pass a pond or river reach through a high gradient magnetic separator to remove algae and phosphates.

High gradient magnetic separation technology offers enormous potential in the field of water pollution control. As demonstration and full-scale plants are built in the next few years, this technology will find increasing use in reducing contamination of our natural waters.

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