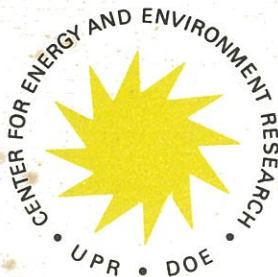


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AN ASSESSMENT OF MAGNETIC FILTRATION:
A NEW APPROACH TO PUERTO RICO'S
EFFLUENT POLLUTION PROBLEMS

*Report of a Select Panel
San Juan, Puerto Rico
March 21-23, 1979*

Coordinator: Dr. Ugur Ortabasi



CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
UNIVERSITY OF PUERTO RICO — U.S. DEPARTMENT OF ENERGY

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OF THE UNIVERSITY OF PUERTO RICO**

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LIST OF PARTICIPANTS

Members of the Select Panel

Dr. Arthur McB. Block
Scientist II
Center for Energy and Environment Research
Terrestrial Ecology Division
Caparra Heights Station
San Juan, Puerto Rico 00935

Eng. Rafael Cruz Pérez
President,
Environmental Engineering Consultant
Violeta No. 153
Urb. San Francisco
Rio Piedras, Puerto Rico 00927

Eng. John R. Harland
Seton, Johnson and Odell, Inc.
317 S. W. Alder St.
Portland, OR. 97204

Dr. John A. Oberteuffer
Vice-President,
Sala Magnetics, Inc.
247 Third Street
Cambridge, MA. 02142

Ms. María Beatriz Riesco
Scientist I
Center for Energy and Environment Research
Solar Division
Caparra Heights Station
San Juan, Puerto Rico 00935

Dr. James H. P. Watson
Sr. Res. Fellow
Dept. of Pure and Applied Physics
University of Salford
Salford, United Kingdom

Contributors

Prof. Ralph A. Mitchell
Division of Applied Sciences
Harvard University
Cambridge, Massachusetts 02138

Dr. Jorge Santiago
Department of Physics
University of Puerto Rico
Río Piedras, Puerto Rico 00931

EXECUTIVE SUMMARY

This report addressing the value of high gradient magnetic filtration to Puerto Rico's effluent pollution problems is the outcome of intense discussion among CEER personnel and a select panel. This panel consisted of experts from Puerto Rico, the United States and the United Kingdom assembled for a special 3 - day workshop.

This effort reflects our great concern as well as our determination to alleviate the effects of water pollution and potable water shortages on the health and welfare of the people of Puerto Rico. The present level of contamination of Puerto Rico's fresh surface water and ground water as well as of its aquatic recreational areas and beaches is already alarming. Increased population pressures are expected to aggravate the problem of pollution control.

At several locations on the island, hazardous water pollutants from industry, municipalities and communities are discharged to the environment with little or no treatment.

Increasingly strict application EPA regulations application, in response to the effluent treatment practices of the industrial sector are a subject of contention between the Agency and industry. In many cases conventional treatment methods have failed to provide significant water pollution control. If Puerto Rico is to meet zero discharge requirements by 1985, the development and demonstration of new water treatment technologies should be an urgent priority.

In a new program The Center for Energy and Environment Research of the University of Puerto Rico proposes to demonstrate a novel and powerful technology, called High Gradient Magnetic Filtration (HGMF) as an efficient,

flexible and cost effective means to remove pollutants from waste waters. The HGMF system utilizes "state of art" technology and its applications worldwide now include:

- Mineral Processing
- Sewage Treatment
- Paper Wastes
- Power Plant Water Purification
- Clay Purification

The advantages of this technology compared with conventional methods include overall cost savings, considerably smaller space and land area requirements, exceptionally high throughputs, reliable operation, low energy use and a very broad range of applicability.

Although the results of this investigation by the panel indicate that HGMF may provide a viable effluent treatment, a detailed systematic study of its application to a particular effluent is imperative. Research, development and pilot demonstration must be carried out prior to any successful implementation of the system. The Center for Energy and Environment Research has already initiated a comprehensive HGMF program to develop the technology to treat industrial wastes such as pharmaceutical plant effluents, distillery wastes (mostos) and sewage, in Puerto Rico.

The magnitude of the developmental task, however, calls for financial and technical help from appropriate government agencies, commercial organizations and industries which have an interest in finding solutions to Puerto Rico's waste effluent problems.

Section I

INTRODUCTION

Nearly all of the streams in Puerto Rico are heavily polluted. Only in the upper sectors of some isolated streams are the waters safe to drink without intensive treatment. A significant percentage of coastal waters show a persistent violation of dissolved oxygen (DO) requirements and coliform bacteria count restrictions. Some beach areas with recreational potential have been closed to public access due to the presence of polluted waters. Pollutants transported by the rivers into the sea create serious accumulation of sediments on coastal reefs and at the mouths of rivers. However, pollution problems in the island are distributed in such a way, that it is obvious that industries are not the only source of pollution. Sewage treatment is, in some cases, ineffective thus causing local water pollution problems throughout the island. Indeed, a direct relationship has been found between population density, industrial growth and the degree of water pollution in an area (1, 2, 3, 4).

The present pollution levels for both Puerto Rico's surface and ground water, and its aquatic recreational areas and beaches are already severe and increased population pressures will aggravate the problem of pollution control even further. The population density of Puerto Rico, an island 30 x 150 mi. in size, is rated the 6th highest worldwide with most of the population (ca. 90%) residing on a very narrow coastal plain. The large volume of waste generated by Puerto Rico's advanced industrialization programs, population density pressures and a fragile coastal zone environment have all combined to produce a grave challenge to the health, the welfare and the lifestyle of Puerto Rico's 3.2 million inhabitants.

At many locations on the island, hazardous water pollutants from industry, municipalities and communities are discharged to the environment with little or no treatment. In the past, a great number of community activities and projects aimed at minimizing adverse health conditions and at the social and esthetic effects associated with water contamination have been instituted but, in general, they have not been successful.

Suspended solids (SS) are a major problem, together with low oxygen levels and a high Biochemical Oxygen Demand (BOD) in most water bodies. A significant amount of pollution is traceable to agriculture, mining, construction and other activities associated with poor erosion control practices. The eutrophication of lakes and reservoirs is the direct result of the introduction of both sediments and pollutants identified with high BOD.

In the light of the existing conditions on the island it is evident that conventional treatment management methods have failed to significantly reduce water pollution. New methods and new technological developments appear to be urgent priorities for the reclamation of polluted water to meet Puerto Rico's industrial, agricultural and potable requirements by 1985.

Law #142, of May 1st 1950, provides the legal basis for a Water Pollution Control program in Puerto Rico. As originally adopted, that law gave the Secretary of Health the power to monitor, plan, regulate, and take measures to control water pollution. These legal powers were transferred to the Puerto Rico Environmental Quality Board (EQB) in 1970. In 1973, the EQB adopted Water Quality Regulations. Most of the present water quality controls have been established on the basis of the present National Pollutant Discharge Elimination System administered by the U. S. Environmental Protection Agency (EPA) with the concurrence of EQB (1).

Under this system, the responsibility for clean waters is divided between EQB and EPA. EPA controls effluent limitations based on available technology, and EQB deals with the quality of the receiving body of water. Any discharge permit mandates the concurrence of both agencies on the conditions of the permit.

Conventional treatment methods (5, 6) assumed to be the acceptable management practice for industrial wastes with high BOD and Total Suspended Solids (TSS) load include: anaerobic contact processes, a sequential combination of anaerobic followed by aerobic treatment; evaporation; and direct land application. In each case, ultimate disposal of the concentrated sludge residue remains as a follow-up step for complete treatment.

The anaerobic/aerobic contact process, is considered effective for the elimination of most pathogens if chlorination is subsequently carried out. BOD reductions of 90-95% of that of the influent are considered possible. A reasonably low level of TSS should also be possible with 90% removal considered achievable in most cases. Color and odor characteristics of the final products are acceptable, although if the anaerobic process is carried out in lagoons in contact with the atmosphere, offensive odors may be produced. For either process to remain energy efficient and not incur exorbitant operating costs, final aeration of wastes has generally involved lagooning which may impose unusual land space requirements on the process.

Anaerobic/aerobic sequential treatment is occasionally used and is traditionally associated with food processing industries. To avoid the spatial requirement of lagooning and odors, anaerobic treatment in closed tanks is a fairly acceptable alternative, although this step can introduce excessive capital and operating costs.

Direct land application of aqueous wastes may be effective for elimination of problem wastes if suitable land is available. Periodic surface flushing is generally a necessity to avoid salt build-up and soil deterioration although in some applications, the soil may actually benefit from the treatment in the short term (7). The long term effects of land application are not well established for high strength wastes where heavy metals and pesticides may accumulate in the soil.

Evaporation can be effective for drying relatively concentrated wastes. However sophisticated equipment with high maintenance costs and substantial energy requirements may be necessary. Evaporation is generally not cost effective for concentrating waste waters to a solid. Solar evaporation ponds may be used but a 5 day to 1 week holdup period may introduce a problem of unusual land area requirements.

Connection of waste stream conduits to sewer lines for municipal treatment can only be used for low strength wastes. Unless specific agreements with local treatment authorities, pre-treatment of high strength wastes is required by U. S. EPA regulations. Table 1 summarizes some observations on conventional treatment methods. It should be noted that each process separately has its weaknesses, but there are applications for which each is considered best available technology.

In recent years a new magnetic filtration technology, high gradient magnetic filtration, has been developed to remove micron size particles from a fluid stream at high flow rates. These high gradient magnetic separators or filters have been designed to maximize the magnetic forces on fine, magnetic materials. They are capable of efficient separation or filtration of even weakly magnetic suspended solids or precipitates for which conventional

TABLE 1

Treatment Technologies as Currently Practiced

<u>Treatment Technology</u>	<u>Comments</u>
Anaerobic Contact	Re-aeration of discharge required; Large investment for high BOD re- moval.
Aerobic Contact	Odor problem. May not treat chlorinated pesticide residues.
Aerobic Lagooning	Large land areas may be required.
Anaerobic/Aerobic Tank	May involve large land areas, high capital expenditures and require highly trained operators.
Direct Land Application	Monitoring of disposal area necessary. Not feasible if long sewerage lines are needed. Large, managed crop land area required.
Evaporation	Sludge transport and disposal management more urgent. Can be energy intensive. Can necessitate long hold up times.

magnetic separation techniques are ineffective. This capability is the result of the development of a filamentary ferromagnetic matrix and a large volume, high-field magnet. The combination of an efficient magnet and high gradient matrix permits the economical generation of strong magnetic forces over a large surface area in the magnetic filter bed. Filtration may be carried out economically, and at process rates of up to several hundred gallons per minute per square foot of fluid stream cross section (gpm/ft²).

Large scale industrial applications of this technology already exist for wastewater treatment in steel mills and steam condensate treatment in paper mills. Numerous large installations also exist in the clay industry for the separation of fine impurities from clay slurries.

For normally nonmagnetic colloidal material in polluted water, the addition of magnetic iron oxide powder (magnetite) along with a coagulant can form a combined particle sufficiently magnetic to be removed by high gradient magnetic filters. The machines provide a rapid filtration of many pollutants from water with a small expenditure of energy. They are more efficient than sedimentation because the magnetic forces on fine particles are many times greater than gravitational forces.

Municipal and industrial wastewater treatment by high gradient magnetic filtration with iron powder seeding is under active development in several countries. Applications include treating combined storm and sewer overflow, raw sewage and wastewaters from paper, petrochemical and other industries.

In addition to these industrial developments, the wide potential of high gradient magnetic separation and filtration has stimulated research efforts in oil refining, air filtration and the filtration of waters from nuclear power plants (8) at various companies and research centers throughout the world. In the light of severe environmental problems associated

with waste effluents in Puerto Rico and an apparent need for new technologies to deal with these problems it is the conviction of this Panel that high gradient magnetic filtration may be a useful alternative.

Section II

PRINCIPLES OF MAGNETIC FILTRATION

Physics of the Capture Process (9,10)

High gradient magnetic filters usually consist of a ferromagnetic wire wool filter bed (matrix), occupying 5-10% of space, magnetized by a uniform magnetic field so that high fields and high field gradients are produced throughout the matrix. These filters are so effective that even weakly magnetic particles of colloidal dimensions can be captured from a liquid containing the particles. As the thickness of particles captured in the matrix increases, the ability of the wire to further capture particles, decreases. At some point, usually determined by the process in question, the performance drops below acceptable limits. When this point is reached the feed to the filter is interrupted and the captured material is released from the matrix by switching off the applied magnetic field. The large demagnetizing factor of the wires in the matrix ensures that the residual magnetism in the matrix is small, facilitating the release of the particles. The cycle can then be repeated. Other systems have been developed where the matrix is continually moved through the magnetic field which allows fully continuous processing of slurries or liquids, an advantage in some applications.

A theory of capture for magnetic particles has been developed by considering the motion of magnetizable particles as if they are carried by a fluid moving in a uniform magnetic field applied perpendicular to the axis of a straight wire in the matrix. In all cases the field must be applied perpendicular to the axis of the wire in order to be effective.

In the analysis of the equations of motion of the magnetic particles near the wires and under the influence of the magnetic and drag forces, a

great simplification of equations of predictive value can be achieved by the introduction of a quantity called the magnetic velocity V_m (11). For ferromagnetic particles in a low magnetic field H_0 , V_m is given by

$$V_m = (4/3) \mu_0 b^2 H_0^2 / \eta a \dots \dots \dots (1)$$

where b is the particle radius, H_0 is the applied magnetic field (amp/meter), η is the viscosity of the fluid, a is the radius of the wire, and $\mu_0 = 4\pi \times 10^{-7}$ henry/meter. The magnetic velocity V_m is very important because if the slurry enters the separator at a velocity equal to the magnetic velocity, the separation is extremely effective.

For example, if the wires have a radius of $50\mu\text{m}$, if the particles have a radius of $2\mu\text{m}$ and if the magnetic field $H_0 = 1.59 \times 10^5$ (A/m) (2000 gauss) then $V_m = 3.4$ cm/sec. If the fluid enters the separator at a velocity of 3.4 cm/sec, the separation will be extremely effective. If the particles have a radius of $6\mu\text{m}$ then $V_m = 30.6$ cm/sec. These are roughly the velocities at which it has been found possible to treat steel mill effluent water, that is approximately 100-350 gal/min/ft².

In this low field region there is little to be gained by using a higher field as the processing velocity and power consumption both increase with the square of the field so that the power per unit volume of processed slurry is constant. However, additional field requires a greater amount of iron in the magnet circuit which increases the capital cost per unit volume of slurry processed.

Experimental observations have shown that as the material captured on the wire builds up, long strings of captured particles grow away from the wire. These strings act as additional capturing centers for particles and

consequently, little loss of performance is noticed for a wire, as the captured material accumulates. Beyond a certain length of particle string further growth is not possible due to the fluid drag. When this point is reached, the separating capacity of the wire drops abruptly. In practice, the filter is backflushed well before this occurs.

The wires in a separator are assembled in a matrix and placed into a canister through which the slurry is passed, as shown in Figure 1. When the interaction between the wires and the particles is strong, the separator fills up from the front and the feed part of the cycle ends before breakthrough of particles occurs. If a cyclic process, the field is switched off at this point and the captured particles can be removed from the system by flushing the canister with air, with an air-water mixture, a solvent or with water alone. The length of the feed cycle can be determined roughly by assuming that the wires can capture 3 to 4 times their own volume of material. This means that a loaded filter will contain about 20% by volume of captured particles.

The processing rate \underline{P} is given by

$$P = V_o AD \dots \dots \dots (2)$$

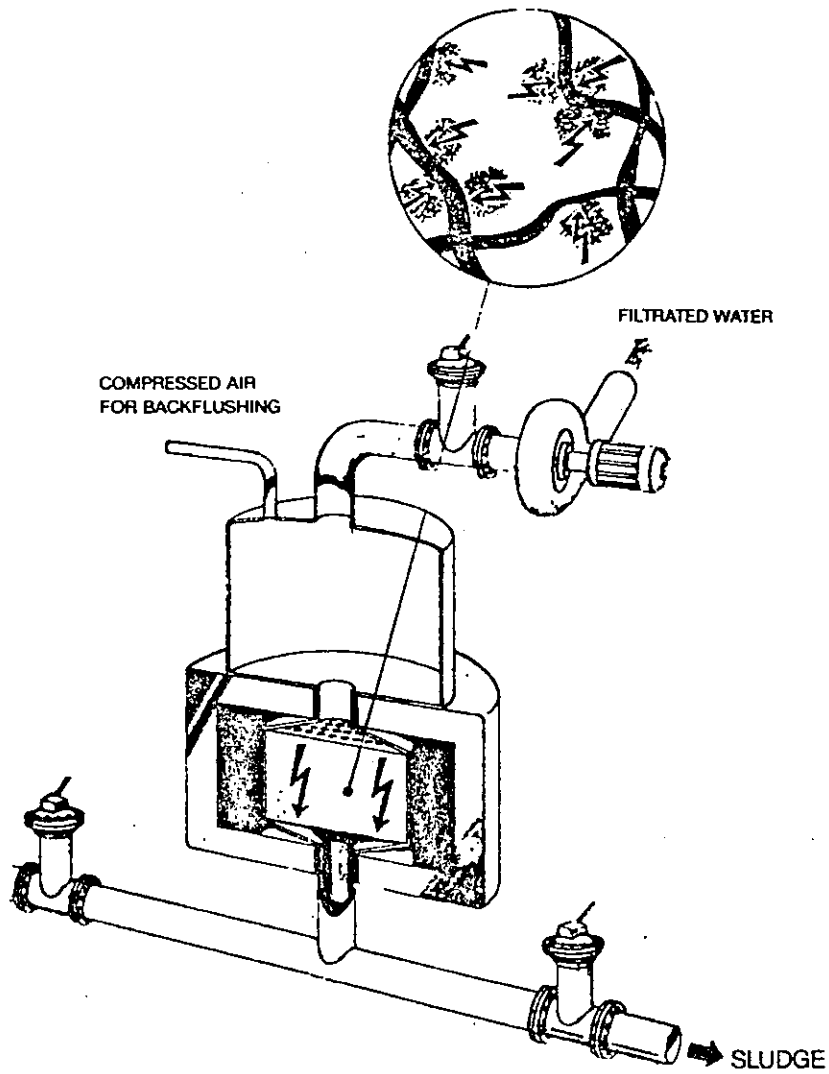
where $\underline{V_o}$ is the slurry velocity (approximately V_m), \underline{A} is the cross sectional area of the separator and \underline{D} is the duty factor. The duty factor is given by

$$D = \text{Feed Time} / (\text{Feed time} + \text{Dead time})$$

The dead time is part of the cycle when the feed is not flowing and may consist of time to switch the magnet on and off and the time to flush the magnetics. For efficient operation the feed time must be much greater than the dead time.

FIGURE I

**High Gradient Magnetic Separation Filter
Showing Section of Matrix Wire**



As an example, a typical filter will operate at 100 to 200 gpm/ft² and at a magnetic field strength of no more than 3 kG it can process 4000-8000 gpm of feed, consuming no more than 25 kW of electric power. Solids removal is typically 75%-95% depending on the particle characteristics, the flow rate per unit area and the magnetic field strength. The machine weight is approximately 70,000 lb. A more complete listing of capacity, weight and power consumption for magnetic separators in appropriate applications is shown in Table 2.

Features of the High Gradient Magnetic Filtration (HGMF)

The high gradient magnetic filtration process is based on the use of very strong magnetic forces to capture magnetic particles on the edges of filament wires that compose the matrix. The strength of the magnetic force generated allows even very fine particles of weakly magnetic materials to be trapped effectively.

The process may be used to effect separations between more magnetic and less magnetic particles (solid-solid separations) or to effect a filtration of magnetic particles from a liquid or gas (solid-liquid or solid-gas separations). An extension of the process to the filtration of nonmagnetic particles and even dissolved materials may be attained by a flocculation of these species with magnetic "seed" particles. This latter technique makes high gradient magnetic filtration applicable to a wide variety of liquid filtration problems.

High gradient magnetic filters include both cyclic and fully continuous devices. For most water treatment application, cyclic devices are utilized; but in certain cases where the density of solids in the feed stream is sufficiently large, fully continuous devices with a circular filter bed

TABLE 2

SPECIFICATIONS OF TYPICAL HGMF SYSTEMS

DIMENSIONS			APPROX. SYSTEM WEIGHT (lbs)	MATRIX AREA (ft ²)	FEED THROUGHPUT RANGE (gpm)	COOLING WATER		POWER INPUT (ACKVA)
WIDTH	LENGTH (inches)	HEIGHT*				VOLUME (gpm)	PRESSUE DROP (psi)	
162	206	126	170,000	77	5,900-19,650	9.2	54	75
120	147	112	70,000	37.8	2,900- 9,670	6.8	56	55.5
92	113	88	45,000	19.2	1,540- 5,130	8.0	26	42.5
71	91	69	18,000	9.3	720- 2,400	4.3	22	35.5
56	75	65	9,000	4.7	360- 1,200	3.5	36	28
44	63	60	5,900	2	200- 670	2.6	22	20
33	52	72	2,800	0.83	190- 300	2.3	34	18
27	37	38	750	0.06	5- 18	1.2	40	9.4

*Height measured flange to flange

Notes: The separators have a 15 cm axial matrix length and a maximum applied magnetic field strength of 5 kilogauss.

To estimate filter velocity, divide desired throughput rate by matrix area.

continuously moving through the magnet for loading and for subsequent flushing may be used. In either design filamentary matrices with high void volumes are used. Strong magnetic forces in the matrix are able to hold trapped particles against drag forces even at high process velocities. The high void volume of the matrix, permits both large retention of trapped solids and low pressure drop across the matrix even at high process velocities.

The design of the magnetic circuit used to magnetize the matrices is optimized to minimize power and capital cost. In most water treatment applications, magnet power is only a fraction of the total system power demand. The operation of high gradient magnetic filter at high process velocities permits high unit capacities and small space requirements.

Section III

PRINCIPLES OF MAGNETIC SEEDING FOR FILTRATION OF NON-MAGNETIC SUBSTANCES: ORGANIC AND NON-ORGANIC PARTICLES AND DISSOLVED MATERIALS

High gradient magnetic separation and filtration techniques may be extended to non-magnetic particles (organic and inorganic) and even dissolved materials. This is possible in high gradient magnetic filters because of the strong trapping forces which permit the capture of aggregations of non-magnetic particles which contain fine, strongly magnetic seed particles.

Basic Concept

The magnetic seeding technique involves the addition of a finely powdered magnetic seed material (usually magnetic iron oxide) to the stream to be filtered and some means to associate the magnetic particles with the non-magnetic or dissolved impurity.

Magnetic Seed

The magnetic seed material is generally magnetite, Fe_3O_4 , magnetic (black) iron oxide. While other magnetic materials may be used in certain cases, magnetite is the obvious choice for several reasons. First, it is strongly ferromagnetic; its induced magnetization is about 40% that of pure iron. Second, the type of magnetite required is relatively inexpensive (about \$25 per ton). Third, it is quite inert in most systems of interest. Finally, the surface of magnetite appears to be a good absorbent material. Viruses, for instance, have an excellent affinity for the surface and in general the particles are easily incorporated into flocs formed by inorganic flocculants. Other possible seed materials include other less oxidized forms of iron, ore iron, cobalt, and nickel as well as oxides of these and other well-known relatively strong magnetic substances.

Association of Seed and Impurity

The techniques used to associate magnetite particles with non-magnetic and dissolved materials include:

Adsorption

Coagulation and Flocculation

Coprecipitation

Adsorption: In the adsorptive mode magnetite adsorbs the non-magnetic particle or dissolved ion on to its surface or alternatively magnetite may be adsorbed on the surface of the impurity particle. The process is governed by the usual dynamics of coagulation and the adsorptive forces include one or more components in the double-layer force system. To enhance the adsorptive mechanism, pH changes in the candidate stream may be used to produce opposite surface charges on the magnetite and the particulate impurity.

Coagulation and Flocculation: Inorganic coagulants (alum, ferric chloride) added to a waste slurry, act both to neutralize surface charge and reduce any repulsive forces between the seed and the impurity particles so that the particles may agglomerate. Organic flocculants create bridges between particles and enhance the strength of inorganic flocs against shear forces.

Coprecipitation: Coprecipitation of certain dissolved materials and ions to produce insoluble compounds is a third means of effecting association. The coprecipitation generally involves a change in pH to create particulates sufficiently magnetic to be filtered directly in a high gradient magnetic filter. In addition to coprecipitation, dissolved materials (organic

and inorganic) may be removed by adsorption. Hydroxides formed by flocculation produce large surface areas available for adsorption of ionic species and the capacity for adsorption of ions by oxide surfaces is well known. Indeed, it appears that even the small natural layer of hydroxide existing in naturally occurring iron oxides in boiler water can adsorb calcium and magnesium ions sufficiently. It is observed that hardness is reduced when these waters are treated by high gradient magnetic filters without any addition of chemicals. An obvious extension of these methods to dissolved material removal is precipitation followed by flocculation of the resulting suspension with magnetic seed.

Combination materials: In addition to the flocculants mentioned above several promising flocculant-seed natural combinations have been developed for high gradient magnetic filtration. These include an aluminum sulfate-containing fine particulate magnetite and a magnetite suspension in which the particles have been treated so as to produce coatings of organic polymer material.

Application Procedure

In practice, the seeding procedure is relatively straight-forward. A generalized procedure will allow for pH adjustment of the influent to optimize coagulation. The next steps are the addition of an inorganic coagulant in a flash mixer, addition of the magnetite seed to the flash mixer and finally the addition of the polyelectrolyte. The resulting dosed influent is allowed to grow flocs under slow speed agitation. The detention time for flocculation is 2-4 minutes. The flocculator overflow passes directly to the high gradient magnetic filter. The operation of the filter is similar to that for direct magnetic filtration. The sludge is backflushed either periodically in a cyclic device or continuously, in a carousel device. The

sludge is generally a small fraction of the feed stream.

Sludge

Treatment of the sludge will depend on the particular application. An intermediate step of settling to increase solids content, direct vacuum filtration or immediate disposal are alternatives. In most applications magnetic seed usage is of the same magnitude as that of the alum and does not require recovery. Indeed allowing the magnetite to remain with the sludge can enhance the density and further treatability of the sludge.

Seed recovery may be required to meet EPA standards for solid wastes disposal. If magnetite seed recovery is desirable it may be accomplished in several ways:

chemical dissolution

magnetic stripping

incineration

washing

Chemical dissolution of magnetite is similar to the currently preferred process for alum recovery. Magnetic stripping involves a solid-solid separation in a second high gradient magnetic separator. Incineration involves burn-off of organic material to recover the regenerated seed. Washing at different pH's may be appropriate for certain applications where impurity disposal and/or sludge dewatering is not a problem.

Section IV

PRESENT WORLD-WIDE APPLICATIONS OF HIGH GRADIENT MAGNETIC FILTRATION

The first high gradient magnetic filter was installed in the clay industry in 1969. Since that time the technology has become fully accepted by the clay industry with numerous large scale installations of magnetic filters in the United States, Britain, and Czechoslovakia. Application developments since 1969 have focussed on the processing of minerals and water treatment. This development work has led, at the time of writing, to additional full scale installations now functioning, in the steel and paper industry. Many other potential applications exist for water treatment and chemical processing. The current status of high gradient magnetic filtration is summarized in Table 3.

In the water treatment applications, the largest industrial units are employed for the filtration of steel mill process water. At Kawasaki Steel in Japan a 2 meter diameter device filters 4000 gpm of water from a gas scrubber. The system requires only a small space in the plant, uses low power (50 kW), and operates fully automatically with little maintenance. Figure 2 shows the Kawasaki HGMF plant after installation.

The use of magnetite seeding and high gradient magnetic filtration for treatment of waste water containing dissolved and nonmagnetic solids has been demonstrated on a small scale in the United States by Sala Magnetics under sponsorship of the EPA (11), on a pilot plant scale and, more recently, in Sweden on a larger scale. The demonstration plant in Sweden mounted in an 8 by 25 ft. container includes chemical dosing, flocculating equipment high gradient magnetic filter and a small backflush settling tank. This system has a capacity of 250 gpm and has been demonstrated for tertiary and secondary-tertiary sewage treatment.

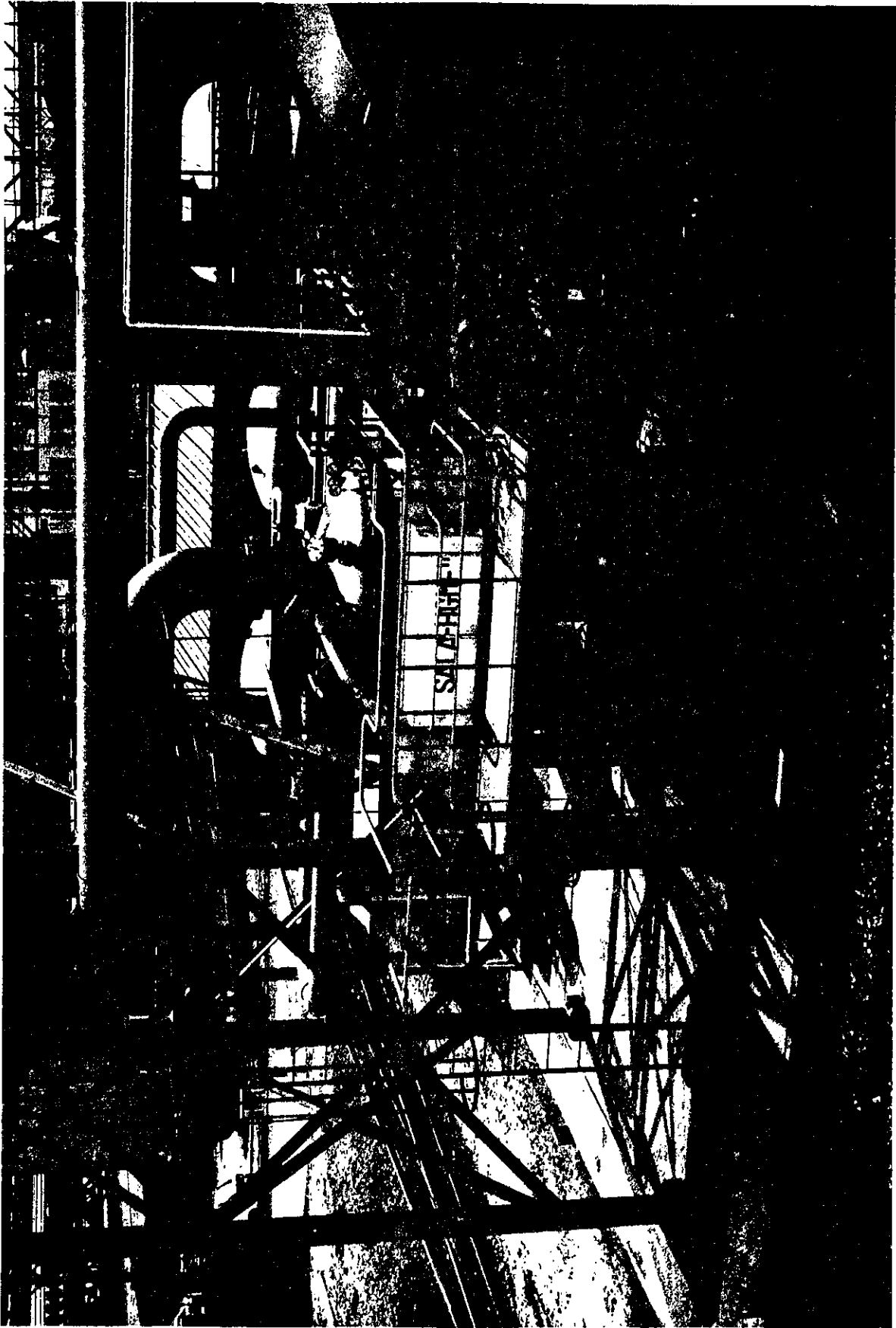
TABLE 3

High Gradient Magnetic Separation and Filtration Applications

State of Development Application	Full scale Application Operating	Full scale Planned	Development	Research	Country
Boiler Water treatment	X	X	X	X	USA, Japan, USSR
Clay	X	X	X	X	USA, UK, CZ
Resource Recovery	X	X	X	X	USA
Steel Mill Wastewater	X	X	X	X	Japan, USA, UK, Sweden
Mining		X	X	X	USA, S. Africa Sweden, Canada Japan
Nuclear		X	X	X	USA, UK, Japan
Brewery*			X	X	UK
Sewage*			X	X	USA, Sweden, Japan
Storm Water* Overflow			X	X	USA
Water Reclamation (Purification)			X	X	USA, Sweden
Coal Desulfurization				X	USA
Medical Applications				X	UK
Virus Removal*				X	USA

* Process in which magnetite seeding is used.

Figure 2



SALA-HGMF® HIGH GRADIENT MAGNETIC FILTER MODEL 214-15-5
INSTALLED AT KAWASAKI STEEL COMPANY IN CHIBA, JAPAN

Section V

ECONOMICS OF MAGNETIC FILTRATION

The costs of installed high gradient magnetic filters will obviously vary from plant to plant, and be dependent upon, among other factors, the relative concentration of the waste to be treated, the flow rate of waste, and other site-specific conditions. The most thorough economic analysis of the process published in the literature is for a 25 million gallon per day (mgd) plant for treatment of combined sewer overflow and sewage (CSO). The cost accounting was based on the results of detailed pilot plant tests (11). Because of the importance and detail of this analysis the complete text is reproduced in Appendix A and is summarized below.

The installed capital cost of the plant including chemical addition, sludge dewatering, effluent chlorination equipment and magnetic filters was estimated at \$5.187 million for the 25 mgd plant. Operating and maintenance costs were estimated at \$0.175 per 1000 gallons of treated water. It is interesting to note that of the total power cost of \$0.024 per 1000 gallons only 13% is used to operate the magnets and this is less than one third the power to pump water through the entire system, (45 ft head loss). Combining the capital, operating and maintenance costs, the total cost of treated effluent would be \$0.234 per 1000 gallons (depreciating capital over a plant life of 20 years at 8% annual interest rate by the capital recovery factor method).

The cost per 1000 gallons of water treated will vary inversely with the size of the treatment plant. Hence, to treat mostos from an averaged sized distillery will cost more than the values estimated for the

25 mgd plant. However, a superficial analysis of the major cost components, such as chemical costs which will remain approximately constant regardless of plant size, indicate the costs will not vary significantly from those shown. It should be noted that in Appendix A the operating costs at 5.7 mgd flow are the costs to operate a 25 mgd plant intermittently and do not necessarily reflect the cost to treat water with a plant designed specifically for lower throughput rates.

Section VI

POLLUTED WATER EFFLUENTS IN PUERTO RICO

The following is a summary of information regarding general industrial groups on the Island, and the problems associated with their effluents. More detailed information can be obtained from the studies conducted by EQB under the 208 programs (13).

Point Source

Pharmaceuticals - High BOD, COD, low DO, and high organics. High amounts of rinsing water and biologically active components.

Treatment lagoons, sludge incineration and chemical treatment are commonly used in these industries.

Chemical Industries - High BOD, COD, low DO and toxic components.

High amounts of cooling water are common in this type of industry.

Diverse combinations of treatment are found.

Distillers - Extremely high BOD, suspended solids, biologically active components and significant coloration characterize these effluents. Except for land disposal in one case, no treatment is given to these wastes at present.

Breweries - High BOD, suspended solids, biologically active components and high turbidity characterize these effluents.

Food Processing - High BOD, residual proteins, oils, solids and odors are the typical waste from these industries.

Sugar Industries - High BOD, solids, organics, coloration and odors are the characteristics of these wastes. Treatment consists of oxidation and sedimentation lagoons. At best treatment is not

complete.

Petrochemicals - High COD, low DO, solids, oil, organics and coloration are typical pollutants in these waters. Treatment is varied, consisting of biological treatment, oxidation lagoons, chemical treatment, and raw discharges in some cases.

Refineries - Characteristic wastes and treatment are very similar to the ones associated with petrochemical industries.

Textiles - The main problem associated with the textile industries in the island is the coloration of the waste streams. Main treatment, when any is given, is chemical in nature, consisting of absorption by activated charcoal or by resins.

Electroplating - The principal pollutants associated with this activity are metals, such as mercury, chromium, lead, zinc, copper, etc. and some toxic agents such as cyanide and acid leachate. Treatment consists of pH adjustments, some chemical absorption, or principally terminal disposition of wastewaters into the nearest stream or sewer.

P. R. Aqueducts and Sewers Authority

Sewage - Public treatment plants in Puerto Rico handle primarily domestic wastes. However, the wastes include also a significant fraction of wastes from industries and commercial establishments. A significant number of treatment plants offer inadequate treatment to the wastes.

Storm Sewers - Storm Sewers and combined sanitary - storm sewers present special pollution problems in Puerto Rico. Storm sewers collect wastes from the streets and surface areas and, because of

illegal sewerage line connections, untreated sanitary wastes as well. Combined sewers then discharge without treatment, both street runoff and pollution wastes.

Area Sources

Agricultural Wastes - Wastes from dairy farms, feedlots, agriculture and other associated activities are considered a serious water pollution problem in Puerto Rico. Significant pollutants are solids, nutrients, fertilizers, herbicides, pesticides and leachate. Very little control or treatment is associated with these activities.

Construction run-off

The main problem associated with the construction industry is the lack of erosion control. During construction, sediment laden run-off is allowed to reach water bodies without any treatment.

Mining Activities

In a larger measure than with the construction industry erosion is the main pollution result associated with mining activities. In a few isolated cases, some controls such as sedimentation lagoons are used.

Urban run-off

High solids and coliform counts are associated with urban run-off. Normally, the initial run-off after a storm is where the main concentrated fraction of pollutants is found. After a period of time has elapsed, pollutants tend to decline in concentrations.

Rural Communities

These sources were, up until very recently, not considered

as significant sources of pollutants. Recent studies have provided data indicating that sediments and organic pollutants in significant amounts are generated by these communities, without any control or treatment given to these wastes.

Water Supplies

Small quantities of potentially toxic materials, are not removed by standard drinking water treatment plants. In the case of well waters, some metals are found to be present. In surface waters, the pollutants found in the source stream are composed of a variety of products, ranging from exotic chemicals to viruses; not all are removed by treatment. After these waters are used, evaporation can concentrate the pollutants in the waste stream.

Section VII

RUM DISTILLERIES PROCESS WASTE (MOSTO)

Molasses from sugar production is the principal raw material utilized in the fermentation process for the production of rum. After fermentation, the product is distilled to the required alcohol concentration. The fusel oils, and heads from the distillation, fermenter bottoms, yeast from fermenter beer and other sources are mixed together to form what is known as "mosto". Analyses of typical mosto samples indicate BOD's of about 33,000 mg/l and TSS of about 18,000 mg/l, pH from 4.0 to 5.5, high coloration and viscosity. Such high concentrations of BOD and TSS tend to eliminate conventional treatment processes as cost effective alternatives.

In Puerto Rico the main sources of mosto are the three principal RUM producers of the island.

Bacardi Corp. at Palo Seco, discharges its mosto without treatment into Boca Vieja bay by means of a pipeline in amounts from 300,000 to 1,000,000 gpd.

Puerto Rico Distilling Corp. at Arecibo discharges mosto by a short pipe to the coast without treatment.

Destilería Serralles in Ponce, P. R., mixes its mosto with its own sugar cane field irrigation waters and disposes of it by land application. Regulatory agencies have reported some reservations (1) about this system due to its possible long term effects on soil conditions and underground water contamination.

Other rum producers on the island do not distill, and limit their production to the blending of selected alcohols.

Environmental Protection Agency Regulations

The U. S. Environmental Protection Agency (EPA) has promulgated regulations aimed at returning water bodies to a condition it considers safe for recreational and commercial use by the U. S. public. According to its schedules, ocean dumping of untreated wastes will be unacceptable by 1985. Consequently, concentrated sludge separation from aqueous wastes will be necessary. The purified water will be reclaimed or be pumped into water bodies with its temperature precluding possible thermal pollution of the water body.

The dewatered sludge may be incinerated, land dispersed, accomodated in sanitary land-fills, or composted and used for agricultural purposes. Generally, in the latter case, liming must be carried out to limit heavy metal uptake from the sludge into the agricultural produce. In the case of aqueous wastes with high BOD, pre-treatment reduction may be demanded by municipal sewage plants before accepting industrial wastes for treatment.

The historical sequence of EPA regulations provides for the best practicable treatment by July of 1977. The Congressional Act upon which this compliance time frame was established was set forth in 1972; as part of this act, a permit issuance system entitled National Pollutant Discharge Elimination System (NPDES) was established. During the interim period 1972-1977, dischargers which received NPDES permits were expected to comply with EPA regulations on a programmed basis arranged between recipients and EPA-the so called compliance schedule. More recently promulgated EPA regulations aim at resource recovery and the so-called "zero discharge", meaning that all wastes are to be treated to the extent that any discharge to the environment must meet as a minimum, locally established water quality criteria, and, moreover,

must remove from the discharge any pollutant that is not present in the receiving water body.

Distillation Industry Waste Treatment in Puerto Rico

Distilling industries in Puerto Rico have been obliged to face the problem of high BOD in their waste-mostos. With one exception, none of Puerto Rico's rum distilling industries is currently in compliance with EPA rulings. In one case an NPDES has been accepted but a schedule has not been followed. It is not certain how long the present situation can continue before EPA compels the industries to install pollution control equipment and there are reasons to believe that even those treatment systems considered and proposed by several distilling companies to EPA will not bring them into the NPDES compliance. For these industries, in particular, zero discharge would appear to be an extremely difficult goal to meet.

Conventional Treatment Methods

A recent report by the Water Resources Research Institute of Mayaguez A & M Campus of the University of Puerto Rico (13) indicates that in the case of 2 local distillers, reduction of daily average BOD load by 90%, and daily average TSS load by 99% would be necessary to comply with provisions of the NPDES permit issued to one of them. Standard treatment methods proposed by the distilling industries include: conventional anaerobic contact process, sequential anaerobic/aerobic treatment, evaporation and direct land application. It is unlikely that conventional anaerobic treatment alone would be able to treat mosto sufficiently to achieve the reduction in BOD required since typical BOD removal in this step is only about 80%. Aerobic lagoon treatment alone would probably not be practical because the high oxygen demand of mosto could not be transferred by the most efficient surface aerators.

For example with a BOD of 30,000 mg/liter -typical of mosto- and a

flow rate of 300,000 gallons of mosto per day (200 gal./min) a transfer of 37 tons of oxygen per day would be required. Using surface aerators to achieve this transfer would necessitate 1,540 horsepower - in surface aerators rated at 2 lbs of oxygen transfer per hour per horsepower. At an electric power cost of \$0.03 /kwhr, it would cost about \$2.75 /1000 gal treated, an exorbitant treatment expense.

While activated sludge aerobic processes should not be discounted out of hand, the volume of solids might make the process unwieldy and difficult to manage routinely.

Sequential anaerobic/aerobic treatment may be useful but suffers from possible requirements of extensive land areas, heavy capital investment and may necessitate permanent employment of highly trained operators.

Evaporation is an energy intensive process which would necessitate development of large sludge dumping areas, disposal management systems and a large primary holding area.

Direct land application is already in use by one distilling company, apparently meeting the NPDES criteria. Land application may be a viable short term solution provided that the distillery is located near a sufficiently large area of agricultural land. Monitoring both salt build-up in soils and possible perfusion to aquifers must be undertaken for this alternative to be considered for routine disposal. Long sewerage lines with accompanying maintenance problems and control of sewerage line right-of-way can make this method - unfeasible in Puerto Rico. Finally, land application requires a year-round commitment to uninterrupted irrigation.

The excessive operating costs and land use requirements implied by the expansion of one of the current treatment technologies mentioned above could lead to operating difficulties of P. R. distilling industries which

traditionally have contributed significantly to the economic infra-structure of the Island.

It seems to us that there is a growing body of evidence indicating that a new technique or an original approach could yield the answer to the problem of land area and operating expense without an inordinate capital investment. At present, technologies available for the control of this problem are not going to provide a final solution compatible with the environmental and economic needs of the Island. We feel that provision of necessary additional time needed to evaluate promising magnetic filtration technology would benefit both the natural and economic ambient of the Island. Magnetic separation has been presented as a possible technique or an essential component of a hybrid system which will be capable of treating large volumes of low-nutrient, high BOD wastes produced as by-products of the rum distilling industry.

Applicability of High Gradient Magnetic Filtration to Mostos Treatment

The applicability of high gradient magnetic filtration to the mostos problem is based on successful tests on mostos and related effluents. First, in tests carried out on a wide variety of organic and inorganic waste waters the magnetite-seeding-high gradient magnetic filtration technique has been shown to be highly effective in the removal of suspended solids, BOD, color, bacteria and other criteria substances. Second, in tests carried out by Sala Magnetics and the University of Salford on mostos samples, total suspended solid reduction and a corresponding decrease in sample turbidity and color were observed.

Sala Magnetics has carried out tests with a wide variety of waters using the magnetite seeding techniques, some results of these tests are

summarized in Tables 4 and 5. These results include laboratory tests as well as continuous pilot plant studies. In addition to the striking visual results of clarity increase in the streams tested, a virtual absence of odor in treated organically contaminated samples is often noted. Although the mosto waste as described above, in general, have higher concentrations of suspended solids and BOD they are similar in many respects to waste and polluted waters successfully treated by magnetite seeded-high gradient magnetic filtration techniques.

Direct evidence of the treatability of mostos by the mag-seed high gradient technique has been obtained in recent tests at Sala Magnetics Inc. and at the University of Salford. In a brief series of unsponsored tests of mosto carried out by Sala Magnetics in early 1978 for Schenley Distilleries no positive evidence of suspended solids or BOD reduction was obtained. However in a later more extensive effort for the CEER more appropriate coagulation and flocculation conditions were used.

In laboratory tests carried out to determine treatability of an unknown effluent, the possible range of experimental conditions--coagulant type and concentration, magnetite seed concentration, polymer type and concentration, and flocculation type--is very broad. Although some general experimental methodology to determine appropriate conditions has been developed, these efforts remain largely a trial and error procedure which may require considerable time, particularly if the range of appropriate conditions within the parameters available is relatively narrow, as it often is for more difficult effluent streams such as mostos. Given this reality, it is understandable why preliminary tests yielded no positive results but later, more extensive trials, showed several promising combinations. A sampling of results from the Sala Magnetics tests is shown in Table 6. The chemical

TABLE 4

RESULTS OF HGMF LABORATORY TESTS PERFORMED AT SALA MAGNETICS INC., CAMBRIDGE, MASS.			
Water Type	% Removal		
	Suspended Solids	Turbidity or color	BOD or COD
Sewage	91	88 (turbidity)	60-75 (COD)
Combined storm and sewage	95	93 (turbidity)	90-98 (COD)
Paper Mill (Aeration Stabilization Basin)	93	95 (turbidity)	81 (COD)
Spent Beer	89	87 (turbidity)	--
Surface Water	99	99	--

TABLE 5.** CONTINUOUS PILOT PLANT: OPTIMIZED RUN

CSO COLLECTED ON 3/17/76	SUSPENDED SOLIDS (mg/l)	APPARENT COLOR (PCU)	TURBIDITY (FTU)	FECAL COLIFORM (cells/100 ml)	TOTAL COLIFORM (cells/100 ml)	BOD ₅ * (mg/l)
FEED AVERAGE (1 sample only)	460	650	230	3.6×10^7	6.3×10^7	>79
(# of Tests)	(3)	(3)	(3)	(4)	(4)	(2)
Range	400 - 520	600 - 800	200 - 250	$2.0-5.0 \times 10^7$	$5.1-7.0 \times 10^7$	>75-83
TREATED SAMPLES (Continuous Run)						
Average	6.0	47	8	5.3×10^4	1.1×10^5	6.0
(# of Tests)	(9)	(10)	(10)	(6)	(6)	(4)
Range	4.1 - 9.1	41 - 53	8 - 11	$1.5-13 \times 10^4$	$0.70-2.2 \times 10^5$	5.2-7.0
% REMOVAL						
Average	98.7%	92.8%	96.3%	99.85%	99.83%	>92%
Range	98.0-99.1%	91.8-93.7%	95.2-96.5%	99.64-99.96%	99.65-99.88%	>91-93%

TEST CONDITIONS

Magnetic Field: 1.6 KG
 Flow Velocity: 56 m/hr
 Alum Conc.: 100 mg/l
 Polyelectrolyte Conc.: 2.4 mg/l
 Magnetite Conc.: 420 mg/l
 PH: 7.3
 Residence Time: 10 min
 Cycle Length: 4 min

Samples collected between 1 and 4 minutes into cycle/Continuous stabilized Cycling of 50 minutes.
 *Feed BOD₅ shown is not accurate as inadequate dilution (1:9) was used. Value is only a minimum BOD₅ possible. The actual undetermined value is expected to be much higher. Likewise the % removal figures are underestimates.

** See reference No. 12.

TABLE 6

Results of HGMF of mostos by Sala Magnetics as affected by test conditions				
Test Conditions			Results	
pH	Alum (mg/l)	Por E	Description	Suspended Solids Reduction
3.8	1000	Betz 1120 - 100 mg/l	no flocs	not measured
7.2	5000	Betz 1160 - 2500mg/l	small flocs	not measured
7.0	5000	Hercofloc 818 250mg/l	no flocs	not measured
4.0	5000	Hercofloc 849 250mg/l Betz 1120 - 100mg/l	large flocs	72%

concentrations are clearly not optimized but the reduction of suspended solids in one trial gives a good indication of the feasibility of the approach. The tests at Sala are supported by the earlier tests carried out at the University of Salford.

Section VIII

CEER EFFORTS IN THE FIELD OF HGMF

Work Objectives and Scope of the HGMF Program

High Gradient Magnetic Filtration is receiving increasing attention from various industries as a means for reducing the levels of contaminants from plant effluent streams. Although the problems are different in each particular system, the water quality of most of them appears to benefit from the magnetic filtration approach.

In accordance with this increasing awareness and pressing environmental needs CEER/UPR has established a magnetic filtration program to meet the following objectives.

- . To provide a comprehensive state-of-the-art review of HGMF and its application with emphasis on the needs of the people of Puerto Rico, the Puerto Rican Government and industry in general.
- . To help to provide specific HGMF system designs for demonstration plant applications.
- . To test and help monitor the demonstration plants.
- . To evaluate the demonstration plant applications on a cost -benefit basis.
- . To make specific recommendations to government and industry.

HGMF Program Outline

The HGMF program at the CEER will encompass a large number of activities ranging from basic research at the molecular level to process development and demonstration applications. The elements of this broad research

program are listed below:

Program Elements

1) Chemistry of selected effluent stream

- Surface chemistry of particles.
- Interaction with coagulants and flocculants.
- Particle seed interaction ; floc stability.
- pH control.
- Seed material and chemistry of separation of magnetic seed materials from flocs for reuse.

2) Magnetic separation studies

- Matrix design.
- Flow rate, magnetic field, loading.
- Operational modes (continuous, intermittent).
- Backflushing and cleaning of matrix.

3) Sludge treatment

- Properties of the resulting sludges.
- Thickening and dehydration methods.
- Seed recovery.
- Ultimate disposal.

4) Demonstration or Testing

- System automation advantages testing.
- System design.
- System installation and operation.
- Sludge treatment.
- Cost/Benefit analysis.

The Center is committed to the short and long term implementation

of HGMF and is presently in the process of developing the time schedule and resources needed for the above outlined program. An effort of this scale will require substantial economic support from the local and federal government and industry. Preliminary experiments presented in this report have been funded by CEER's own developmental resources.

Current Research and Development Efforts

Preliminary Experiments at the University of Salford, U. K. and Sala Magnetics, Cambridge, Mass, U. S. A.

At the University of Salford rum slops containing 0.09% mercuric chloride as a preservative were received. The surface chemistry of the suspended particles was examined. It was found that at the mostos pH = 4.6 the particles were close to the zero point of charge. With addition of HCl the pH was adjusted to 4 and the particles became slightly positive. With a further adjustment to pH = 3, the mobility of the particles was measured as 5 um/sec/volt which is a low value, indicating a small positive surface charge. Using potassium hydroxide, the pH was increased to 7 where the particles have a weak negative surface charge. The seed having a strong positive charge would therefore be effective at pH = 7. Since the particle surface charge is not a strong function of pH it was concluded that the system was not charge stabilized but stabilized perhaps by hydrophilic natural polymers, such as dextrans and cellulose. This indicated that in order to use the seed at pH = 4.6, it must be added to the mostos with a cationic flocculant in low concentration. Another possibility is to pre-coat the seed with a suspected look-alike polymer, before magnetic separation.

An attempt was made to seed the mostos with the addition of magnetite at 3% by volume without the addition of any other chemical or

coagulant. The absorbances of both the treated and untreated waste were measured as a function of wavelength throughout the visible spectrum (Figure 3). In general, the absorbance of the untreated sample had three times the absorbance of the treated samples at all wavelengths, with absorbance generally higher at shorter wavelengths.

Magnetic filtration tests were performed by Sala Magnetics, Inc., Cambridge, Mass on three typical but different potential sources of pollution from the Island: domestic raw sewage, rum slops and pharmaceutical wastes (spent beer). Preliminary unoptimized results obtained for raw sewage, rum slops and pharmaceutical waste yielded reductions of suspended solids of 92.3% 72.0% and 89.0%, respectively. The batch processing data, as well as the results from Sala for these effluents, are summarized in Tables 7, 8, and 9. Turbidity measurements of the untreated versus the treated spent beer are summarized in Figure 4. In general absorbance was higher for both untreated and treated samples at lower wavelengths, but on the average, treatment by magnetic filtration reduced the absorbance by a factor of more than 7, the average absorbance of the treated spent beer waste actually measuring only 13% of that observed for the untreated spent beer. Analysis of Kjeldahl nitrogen on untreated and treated samples of pharmaceutical waste showed a reduction of 52.3%. When analysing the data given above, it should be kept in mind that these numbers represent only preliminary results and that these can be substantially improved by varying some of the filtration parameters. The results of this preliminary evaluation tend to indicate a good potential for application of this technology to the water pollution problems of Puerto Rico.

Figure 3

Comparative Graph of Light Absorbance in Untreated Mosto (M) and Magnetically Filtered Mosto (MMF)

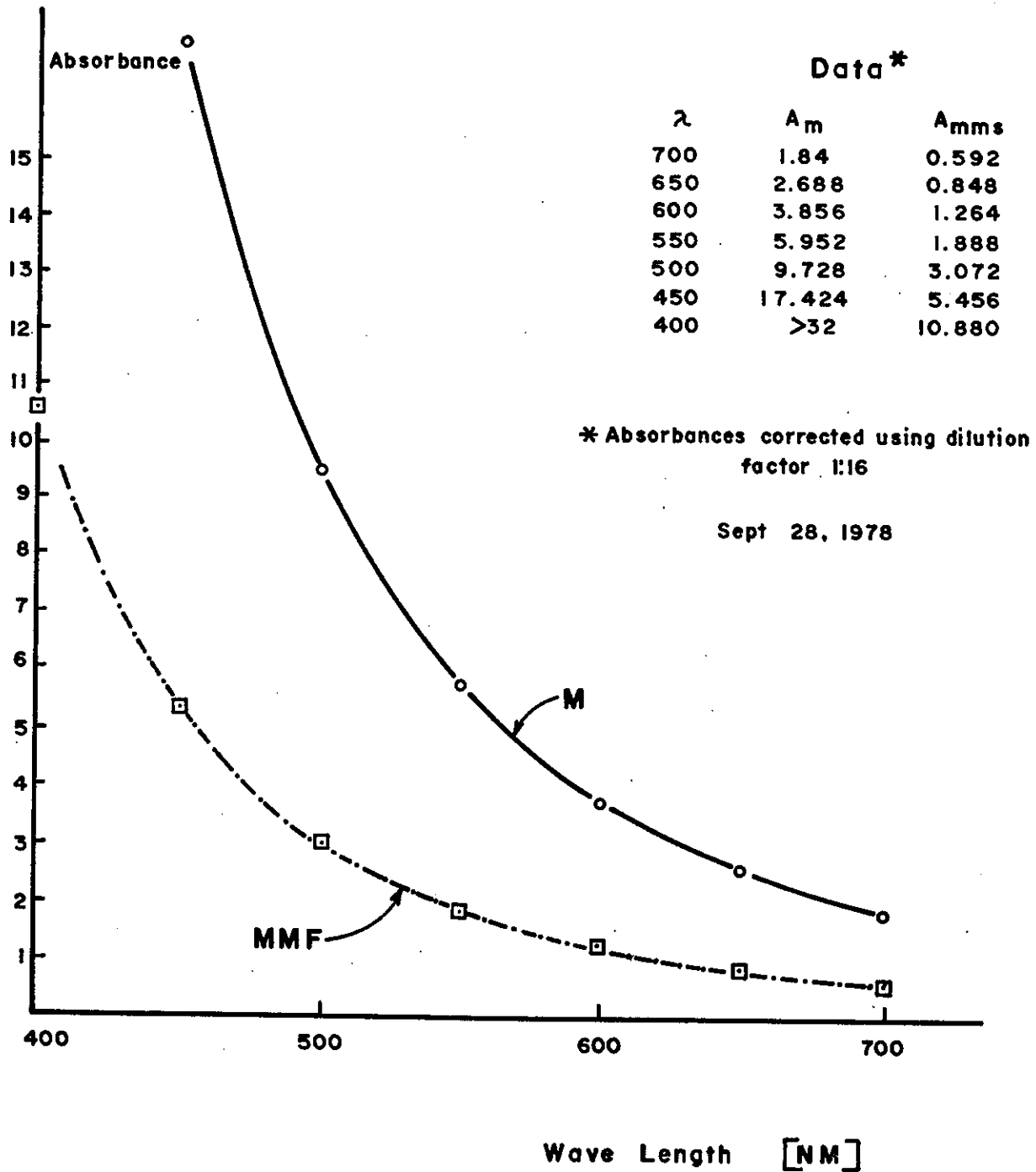


TABLE 7

HMGF Results on Raw Sewage from Puerto Rico obtained by
Sala Magnetics, Inc., Cambridge, Mass.

CONDITIONS

Alum	:	140 mg/1
Magnetite	:	200 mg/1
Polyelectrolyte	:	Hercofloc 831, 0.5 mg/1
Magnetic Field	:	2 KG
Flow Velocity	:	82 gpm/ft ²
Residence mixing	:	2.5 minutes
Matrix	:	(#57) expanded metal, R-type, 45 mil spacing
Sample Volume	:	2 liters

RESULTS

There were two separate runs done for this particular waste

Analysis of Suspended Solids in run #1 in:

Feed	:	137 mg/1
Magnetically filtered	:	11.7 mg/1
Reduction in Concentration of Suspended Solids	:	91.5%

Analysis of Suspended Solids in run #2 in:

Feed	:	166 mg/1
Magnetically filtered	:	12.7mg/1
Reduction in Concentration of Suspended Solids	:	92.3%

TABLE 8

HCMF Results on mostos from Puerto Rico obtained
by Sala Magnetics Inc., Cambridge, Mass.

CONDITIONS

Alum	:	0
Magnetite	:	5 g/1
Polyelectrolyte	:	Hercofloc 849; 250 mg/1 Betz 1120, 100 mg/1
Magnetic Field	:	2.5 KG
Flow Velocity	:	82 gpm/ft ²
Residence mixing	:	4 minutes
Matrix	:	expanded metal, 45 mil spacing
Sample volume	:	1 liter

RESULTS

Analysis of Suspended Solids in:

Feed	:	7415 mg/1
Magnetically Filtered	:	2050 mg/1
Reduction in Concentration of Suspended Solids	:	72%

TABLE 9

HGMF Results on Spent Beer from Puerto Rico obtained by
Sala Magnetics, Inc., Cambridge, Mass.

CONDITIONS

Alum	:	200 mg/l
Magnetite	:	20 g/l
Polyelectrolyte	:	Hercofloc 831; 50 mg/l
Magnetic Field	:	2 KG
Flow Velocity	:	82 gpm/ft ² (initial)
Residence mixing	:	4 minutes
Matrix	:	expanded metal with 45 mil spacers
Sample volume	:	250 ml

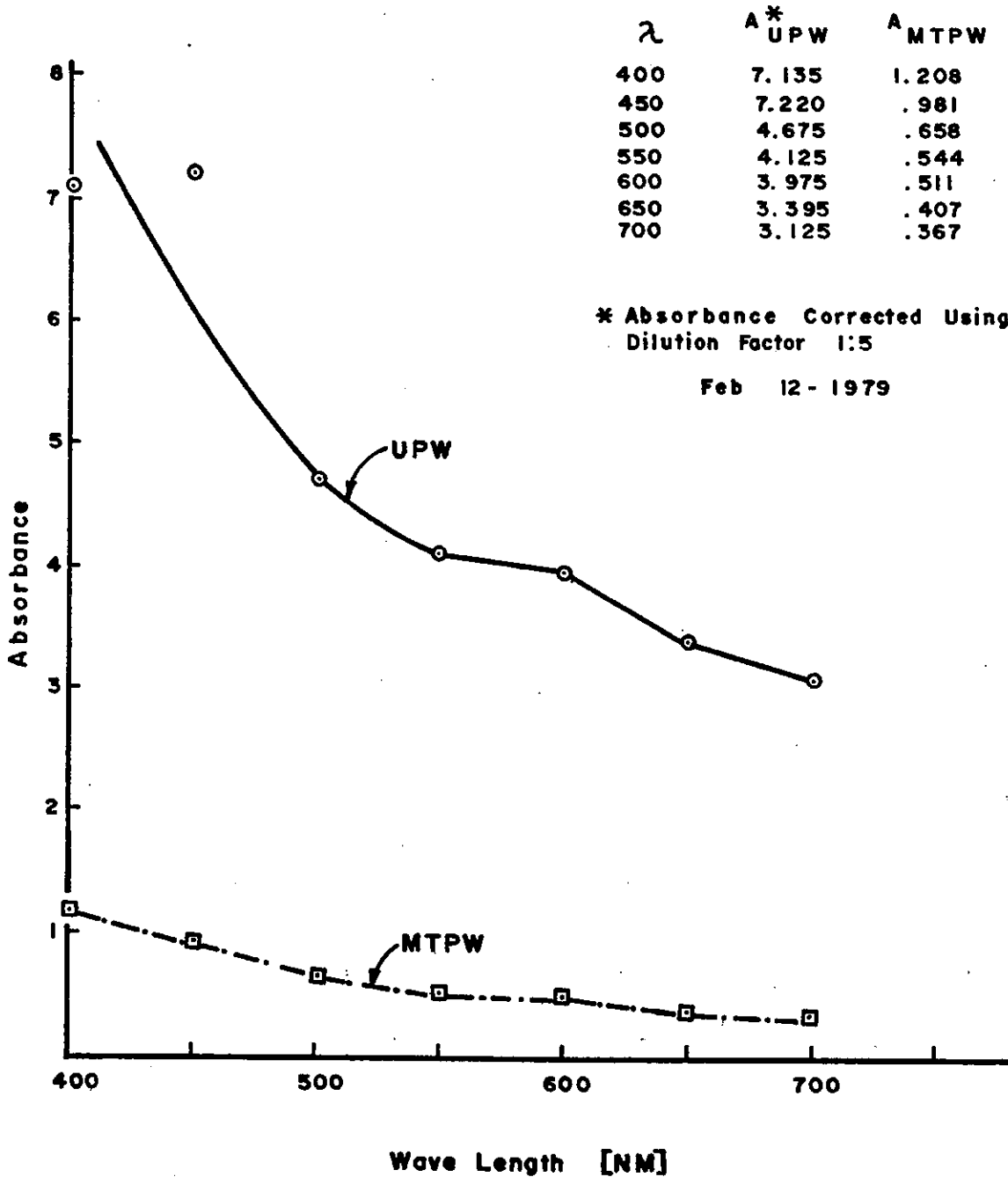
RESULTS

Analysis of Suspended Solids in:

Feed	:	29.3 g/l
Magnetically Filtered	:	3.1 g/l
Reduction in Concentration of Suspended Solids	:	89%

Figure 4

Comparative Graph of Light Absorbance in Untreated Pharmaceutical Waste (UPW) and Magnetically Filtered Pharmaceutical Waste (MTPW)



Mobile Magnetic Filtration Trailer

Magnetic filtration is a developing technology and on-site demonstration of its potential for pollution control of many effluent streams has not yet been carried out. To bridge the information gap from bench test to full demonstration plants CEER is planning the use of a small capacity (10gpm) mobile magnetic filtration laboratory to be leased from Sala Magnetics. The primary objective of this 12 month project is the on-site testing of various effluent streams. To accomplish this, the trailer will be stationed at selected sites of discharges in Puerto Rico for a period of one week. During the testing period various parameters each, including seed, polyelectrolyte concentration, matrix loading, residence times, magnetic field and flow rates will be changed to assign effectiveness of filtration parameters to each type of waste. Influent and effluent will be analyzed continuously with respect to suspended solids, pH, apparent color, turbidity, settleable solids, BOD, CO coliform bacteria and heavy metals. The data obtained from this trailer will then be utilized to develop the criteria for the applicability of HGMF to treat industrial waste streams surveyed, to form the basis for pilot plant design studies and to chart future research and development directions.

Section IX
CONCLUSIONS

The High Gradient Magnetic Filtration is a new technology to treat industrial, domestic and commercial waste effluents. Data from presently operating and full scale HGMF plants indicate a cost effective and reliable performance. Although HGMF has not yet been fully tested for treatment in Puerto Rico enough evidence has been collected to suggest that it be considered as a viable new process to complement and/or replace some of the conventional methods.

In particular this Panel concludes that HGMF is potentially a cost effective and practical method to treat mostos. It should be stated however, that a rigorous research development and demonstration program must be assembled to implement this method successfully.

The Center for Energy and Environment Research has already initiated the first phase of this program and has demonstrated the feasibility of mostos treatment on a bench scale. For a full scale development of the program other resources from the government and industry will have to be allocated.

HGMF can be developed into a powerful new method that will permit a large fraction of the industries in Puerto Rico to comply with the zero discharge EPA regulations by 1985.

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APPENDIX A

Economics of Magnetic Filtration

Cost Estimate for a 25 Million Gallon Per Day High Gradient Magnetic Filtration Unit For Combined Sewer Overflow and Treatment Facility.

The data generated in this and previous of seeded water treatment have provided considerable information useful in the formulation of design and size presented the estimated capital, operation and maintenance-related costs for a proposed integrated wet and dry weather flow treatment plant capable of processing 25 million gallons per day at peak flow. The design of this treatment facility has been upgraded considerably from the one outlined in the earlier report (EPA-600/2-77-015), and includes high-quality system components throughout, with reserve capacity and/or spare units as integral parts of the design.

CAPITAL COSTS

Capital costs for the 25 MGD combined wet and dry weather flow treatment plant are summarized by sub-system in Table VII-1. The total estimated capital cost for this seeded water treatment system is just under 5.2 million dollars. Not included in the capital cost estimates are systems for seed recycling and alum recovery. These systems are contemplated for a fullscale facility, but at this time too little process information is available for a determination of what should be included. It is hoped that a demonstration size plant will be able to generate sufficient quantities of seeded sludge, in the near future, for proper evaluation of various process alternatives in the recovery and reuse of the magnetite seed and/or the aluminum sulfate incorporated therein. The cost of land has not been estimated because of its site-specific nature.

TABLE VII-1 CAPITAL COST ESTIMATES FOR A HIGH GRADIENT MAGNETIC FILTER BASED
25 MGD CSO/SEWAGE TREATMENT FACILITY.

Part 1

<u>Subsystem</u>	<u>Estimated Installed Cost</u>
De-gritting and Pre-screening	\$ 394,900
Feed Pumping	297,600
Flocculation Train Y Chemical Feed	510,500
High Gradient Magnetic Filters	990,000
Backflusing	141,300
Filter Piping and Valving	527,400
Thickening and De-watering	265,600
Disinfection	86,900
Electrical	137,100
Automatic Process Control & Monitoring	258,700
Physical Plant Construction	<u>490,000</u>
Subtotal:	\$ 4,100,000
Construction Contingency 10%	<u>410,000</u>
Subtotal:	\$ 4,500,000
Engineering and Administration 15%	<u>677,000</u>
TOTAL ESTIMATED COSTS:	\$ 5,187,000

Part 2

A breakdown of the subsystem components on which the above cost estimates were made is given below.

De-gritting and Pre-screening System

- . influent flow meter (Parshall flume);
- . coarse bar screen;
- . rotary wedge wire screens (6);
- . entry pipe to plant;
- . bypass piping and valving;
- . concrete troughs and pits;
- . influent flow distributors;
- . conveyor system; and
- . grit hopper.

TABLE VII-1 CAPITAL COST ESTIMATES FOR A HIGH GRADIENT MAGNETIC FILTER BASED
25 MGD CSO/SEWAGE TREATMENT FACILITY.

Part 1

<u>Subsystem</u>	<u>Estimated Installed Cost</u>
De-gritting and Pre-screening	\$ 394,900
Feed Pumping	297,600
Flocculation Train Y Chemical Feed	510,500
High Gradient Magnetic Filters	990,000
Backflusing	141,300
Filter Piping and Valving	527,400
Thickening and De-watering	265,600
Disinfection	86,900
Electrical	137,100
Automatic Process Control & Monitoring	258,700
Physical Plant Construction	<u>490,000</u>
Subtotal:	\$ 4,100,000
Construction Contingency 10%	<u>410,000</u>
Subtotal:	\$ 4,500,000
Engineering and Administration 15%	<u>677,000</u>
TOTAL ESTIMATED COSTS:	\$ 5,187,000

Part 2

A breakdown of the subsystem components on which the above cost estimates were made is given below.

De-gritting and Pre-screening System

- . influent flow meter (Parshall flume);
- . coarse bar screen;
- . rotary wedge wire screens (6);
- . entry pipe to plant;
- . bypass piping and valving;
- . concrete troughs and pits;
- . influent flow distributors;
- . conveyor system; and
- . grit hopper.

TABLE VII-1, Part 2 (continued)

Feed Pumping System

- . variable speed pumps;
- . single speed pumps;
- . support frames;
- . piping for feed flow; and
- . sump well.

Flocculation Train and Chemical Feed System

- . flocculators (3);
- . flash mixers (6);
- . static mixer (3);
- . alum storage and delivery system;
- . polyelectrolyte make-up and delivery system;
- . magnetite slurry and delivery system; and
- . support structures.

Magnetic Filters

- . High gradient magnetic filters (5);
- . Power supplies;
- . Indirect cooling systems;
- . instrumentation; and
- . support structures.

Blackflush Equipment

- . screw compressors (2);
- . piping;
- . valves (5);
- . air receivers (5);
- . stands and concrete pads; and
- . instrumentation.

Filter Piping and Valving

- . filter piping and valves;
- . chemical rinse piping, tank and valves;
- . air line piping and valves;
- . structures for piping; and
- . test component.

Thickening and De-watering Systems

- . thickener and rake;
- . sludge pumps (2);
- . surge tank;
- . vacuum belt filters (2);
- . conveyor;
- . sludge hopper;
- . piping for sludge;
- . sump pump for thickener overflow; and
- . overflow piping.

TABLE VII-1, Part 2 (continued)

Disinfection System

- . hypochlorite storage tank;
- . chlorine diffusers;
- . metering pumps;
- . residual chlorine analyzer;
- . chlorine piping;
- . contact chambers (3); and
- . outfall piping.

Electrical System

- . motor control centers;
- . wiring and conduit;
- . transformer and accessories;
- . electrical boxes, etc.

Automatic Process Control and Monitoring Systems

- . micro-processor controller, including:
 - flow metering;
 - alarms;
 - differential recording; and
 - interface capability;
- . sampler;
- . analyzers; and
- . monitoring system.

Physical Plant Construction

Building of approximately 16,500 ft², including:

- . piping;
- . electrical system;
- . lighting;
- . office facilities;
- . control room;
- . laundry;
- . crane;
- . etc.

Installation costs were based on estimates from equipment suppliers, the Chemical Engineer's Handbook (Perry), and the Richardson Rapid System. Capital costs are represented at an Engineering News Record (ENR) index of 2700. Labor was figured at \$13/hour, based on an ENR of March 9, 1978.

No provisions have been made for the equipment and operational costs associated with the disposal of either the dried sludge cake or the grit removed from the waste water.

OPERATION AND MAINTENANCE COSTS

Operation and maintenance costs for the 25 MGD facility are estimated in Table VII-2 in dollars per 1000 gallons of water treated using an assumed average flow of 5.7 MGD and a continuous flow of 25 MGD over the course of a year.

The chemical and electrical costs shown are approximate, current local prices for the Cambridge, Massachusetts area. Operator labor is based on 24 hours/day monitoring of the facility plus an 8 hours shift for routine maintenance. The freight costs for the chlorine are included in the chemical costs; polyelectrolyte freight costs are considered insignificant.

From the table it will be seen that total estimated operating costs for seeded water treatment range from \$.23 per 1000 gallons of treated water.

No costs have been included for final disposal of sludge and grit, or for sludge treatment chemical conditioning (should the latter prove necessary). The chemical demand and net operation costs could change significantly if seed recycling or alum recovery are incorporated into the flowsheet.

Power consumption for a system running at 5 MGD and at 25 MGD is shown in Table VII-3. The magnetic filters specified for this system are

more efficient than those units previously specified, and will therefore require only about 12 percent of total plant energy consumption.

DESIGN CONSIDERATIONS

The treatment plant will include three main flow streams for waste water purification, although there will be one flow as they enter the facility (pre-treatment) and as they leave (chlorination and de-watering). The actual water/suspended solids separation occurs in one five high gradient magnetic filters (the fifth is considered a spare). The first filter is available to handle normal dry weatherflow, estimated in this instance at 5 MGD, and the remaining four filters operating at a maximum flow rate of 125 gpm/ft² are available to handle the 25 MGD peak storm flow. When all five filters are activated, the maximum capacity of the system will be 32 MGD, and average annual through put is assumed to be 5.7 MGD. Figure VII-1 is a system design schematic.

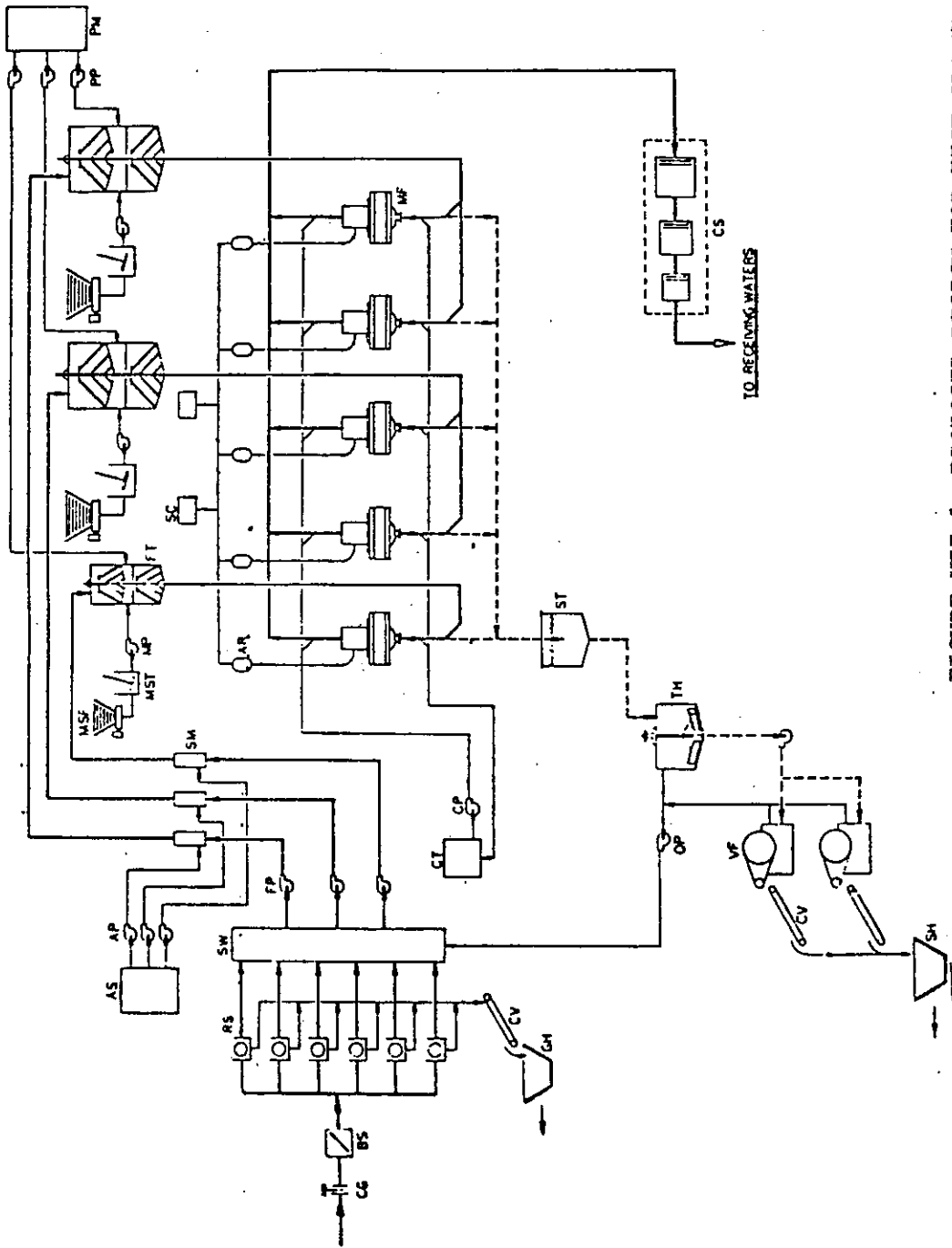


FIGURE VII-1 PROPOSED DESIGN FOR HIGH GRADIENT
MAGNETIC FILTER BASED 25 MGD/
SEWAGE TREATMENT FACILITY

KEY TO FIGURE VII-1

<u>No. of Units</u>	<u>Symbol</u>	<u>Description</u>
5	AP	Alum Delivery Pump (2 spare)
1	AS	Alum Storage Tank
5	AR	Air Receiver
1	BAS	Bar Screen
1	CG	Control Gate
1	CP	Caustic Rinse Pump
1	CS	Chlorination System
1	CT	Caustic Storage Tank
6	CV	Conveyor
5	FP	Feed Pump (2 spare)
3	FT	Flocculator Tank System
1	GH	Grit Hopper
5	MF	Magnetic Filter
3	MP	Magnetic Delivery Pump
3	MSF	Magnetite Screw Feeder
3	MST	Magnetite Slurry Tank
1	OP	Over-flow Pump
1	PM	Polyelectrolyte Make-up System
1	PP	Polyelectrolyte Delivery Pump (2 spare)
6	RS	Rotary Strainer
2	SC	Screw Compressor
1	SH	Sludge Hopper
3	SM	Static Mixer
2	SP	Sludge Pump (1 spare)
1	ST	Surge Tank
1	SW	Sump Well

KEY TO FIGURE VII-1 (continued)

1	TH	Thickener
2	P	Vacuum Filter

TABLE VII-2 OPERATION AND MAINTENANCE COST ESTIMATES FOR A HIGH GRADIENT MAGNETIC FILTER BASED 25 MGD CSO/SEWAGE TREATMENT FACILITY.

<u>Item</u>	<u>Costs in \$ per 1000 gallons</u>	
	<u>5.7 MGD</u>	<u>25 MGD</u>
<u>Chemicals:</u>		
. <u>Alum</u> (liquid, 50%) 100 mg/1 \$100/dry ton \$.110/kg \$.27/gal. \$.071/l	.042	.042
. <u>Magnetite</u> (commercial grade, -325 mesh) 200 mg/1 \$35/ton \$.018/lb \$.039/kg	.030	.030
. <u>Polyelectrolyte</u> (Hercoflocc 831, anionic) 1 mg/1 \$1.36/lb \$3.00/kg	.011	.011
. <u>Chlorine</u> (15% Sodium Hypochlorite, WilChlor 2) 1 mg/1 \$.30/gal \$.079/l \$.529/kg available Cl ₂ (delivered price)		
<u>Total Chemical Costs:</u>	<u>.087</u>	<u>.087</u>
<u>Chemical Freight Costs:</u>		
. <u>Alum</u> for 50 mi or 80 km \$.05/gal \$.013/l	.007	.007
. <u>Magnetite</u> for 200 mi or 322 km \$10/ton .011/kg (estimated)	.008	.008
<u>Total Freight Costs:</u>	<u>.015</u>	<u>.015</u>

TABLE VII-2 (continued)

Cost in \$ per 1000 gallons

<u>Item</u>	<u>Cost in \$ per 1000 gallons</u>	
	<u>5.7 MGD</u>	<u>25 MGD</u>
Electrical Power \$.055/kWh	.032	.024
. <u>Magnetic Filter</u> (5) 15 kW ea.		
. <u>Other Equipment</u>		
125 kW 5 MGD		
404 kW 25 MGD		
Operator Labor:		
32 man-hours/day \$15/hr	.039	.039
Maintenance Costs:		
. Mechanical Equipment and Physical Plant (3% of equipment cost)	.042	.008
. Electrical Equipment, Instru- mentation, and Piping (2% of equip- ment cost)	.011	.002
<u>Total Labor and Maintenance Costs:</u>	<u>.092</u>	<u>.049</u>
TOTAL OPERATION AND MAINTENANCE COST PER 1000 GALLONS:	<u>.226</u>	<u>.175</u>

TABLE VII-3 POWER CONSUMPTION FOR A 25 MGD FACILITY

<u>Item</u>	<u>Energy Consumed in kWh</u>	
	<u>5 MGD</u>	<u>25 MGD</u>
De-gritting and Pre-screening	8.2	18.7
Feed Pumping 45 ft. head	40.0	200.0
Chemical Makeup and Delivery	2.4	6.5
Flocculator Chain Mixing	9.0	39.0
Magnetic Filters	15.0	60.0
Compressors	12.0	45.0
Dewatering System	31.0	42.0
Control Instrumentation and Bldg. Service	12.0	23.0
Miscellaneous	<u>10.0</u>	<u>30.0</u>
TOTAL:	140.0	464.0

TABLE VII-4 ASSUMED PARAMETER VALUES FOR A 25 MGD SYSTEM

<u>Item</u>	<u>Design Value</u>
<u>Magnetic Filters</u>	
. Bore	84 in (214 cm)
. Length	6 in (15 cm)
. Magnetic Field Strength	0,3 kG
. Maximum Flow Rate through Matrix	125 gpm/ft ² (18 m ³ /min) (4800 gpm)
<u>Waste Water Characteristics</u>	
. Maximum Storm Flow	25 MGD (1.1 m ³ /sec)
. Nominal Dry Weather Flow	5 MGD (.22 m ³ /sec)
. Average Flow over 1 Year	5.7 MGD (.25 m ³ /sec)
	100 mg/l
<u>Backflush Parameters</u>	
. Backflush Flow Flux Rate through Matrix	500 gpm/ft ² (73 m ³ /min) (19,300 gpm)
. Backflush Duration	8 sec
. Backflush Volume	2600 gal (10 m ³)
. Maximum Pressure Drop before Backflush	10 psi
. Caustic Rinse Flow Rate through Matrix	20 gpm/ft ² (2.9 m ³ /min)
<u>Mixing and Residence Times</u>	
. G Factor for Flash Mixer	300/sec
. G Factor for Flocculator	100/sec
. Reynolds Number for Static Mixer (21 in)	7.5 x 10 ⁵
. Total Mixing Residence Time	5 min
<u>Chemical Dosages</u>	
. Alum Concentration	100 mg/l
. Magnetite Concentration	200 mg/l
. Polyelectrolyte Concentration	1.0 mg/l
. Chlorine Concentration	2 mg/l
. Chemical Storage	6 days at peak flow; 30 days at dry weather flow
<u>Other Parameters</u>	
. Pumping Head for Feed Pumps	45 ft. (33 psi)
. Pre-screening size	20 mesh (.84 mm)

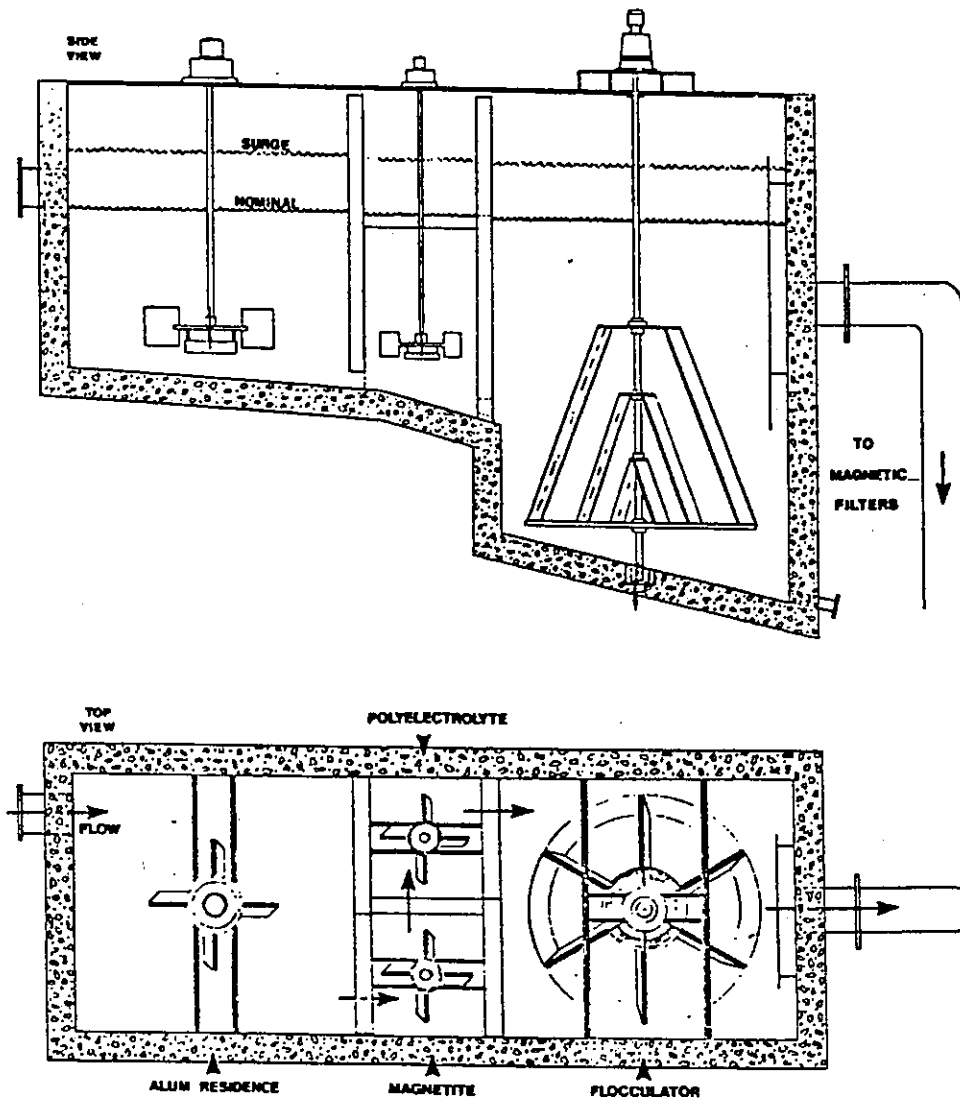


FIGURE VII-2 TOP AND SIDE VIEWS OF ALUM RESIDENCE/FLASH MIX/
FLOCCULATOR RESIDENCE TANK CHAIN FOR THE 25 MGD
SEEDED WATER TREATMENT SYSTEM

Table VIII-4 gives the parameter values used in obtaining magnetic filter and operational cost estimates for a 25 MGD facility. These values were chosen on the basis of the experimental data, previous experience in the field, flow requirements, and equipment design limitations.

A combined wet and dry weather flow treatment plant has an inherently large reserve capacity which remains unused for a major portion of the year. For the 25 MGD peak flow system in question, it was arbitrarily assumed that in the course of a year there would be 30 storms producing a 25 MGD flow for an average of 10 hours each, or a total of 300 hours of CSO at a 25 MGD through put rate, compared to 8460 hours of dry weather flow at 5 MGD. Although these are assumed values, and may not be representative for a given location, the fact remains that in this type of treatment facility, a large amount of equipment must be regularly maintained for only sporadic use. As a consequence, operation and maintenance costs are relatively high in proportion to the number of gallons treated.

The system shown in Figure VII-1 is similar to the seeded water treatment flowsheets presented in the past (i.e., the Mobile Pilot Plant Trailer design and the 25 MGD system outlined in Figure X-1 of EPA publication EPA-600/2-77-015), with a few design changes. For example, static mixers have been added for initial alum dispersal prior to the large alum residence tank. The floc chain, consisting of an alum residence tank, two flash mixers for polymer and magnetite addition, and a larger flocculator for final residence are sized for a total of 5 minutes mixing time. A detail of this system is shown in Figure VII-2. The pressure head created by the alum mix/flash mix/flocculator tank unit is now designed to be used in place of the filter pump suction head used in previous designs to draw the chemically pretreated water through the magnetic filters. Thus, there is no longer a need for filter pumps in the

system.

Another change is with the magnetic filter design which affects the backflush system; each magnetic filter now has its own hydrotank for backflushing incorporated as an integral part of the magnetic filter canister (forward flow) plumbing. In this way, much extra plumbing and valving have been eliminated, as well as the extra control provisions for filling the hydrotanks with filtered water. This latter operation is now accomplished automatically, in a passive manner, with each filter cycle.

Other features have been included in the design to make the system both dependable and foolproof. The design is conservative, and spare pumps assure adequate back-up; the process control system is versatile and completely automatic; and a bypass system has been included for emergency situations.