EER ~C-081 MAGNETIC FILTRATION STUDIES OF RAW SEWAGE IN PUERTO RICO - RESULTS AND COSTS ANALYSIS

Final Report to:
PUERTO RICO AQUEDUCTS AND SEWERS AUTHORITY

Prepared by:
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CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

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ABSTRACT

Experiments using High Gradient Magnetic Filtration done by the Center for Energy and Environment Research are discussed. A brief introduction to this technology and a description of the mobile unit in which field studies were performed is presented. Studies to demonstrate the feasibility of the Process were carried out using sewage from two municipal treatment plants, EL Conquistador in Trujillo Alto and Guaynabo Treatment Plant. Highest Percent removal in terms of absorbance at 550 nm, Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Total Nitrogen (TN) and Total Phosphorus (TP) were 96.08%, 99.4%, 89.08%, 66.0% and 98.5%. Average ‘optimum concentrations required for HGMP treatment of this waste were 139 g/l of alum, 250 mg/l of magnetite and 25 ml/l of polyelectrolyte flocculant. Yet, concentrations were higher in the case of the El Conquistador Plant. Liquid and granular alum as well as a series of different types of polyelectrolytes were also tested. Electron microscopy studies done on flocculated sewage

showed no definite floc-structure as was expected. Cost estimate analysis for a 1 MGD HGMP plant fabricated by Sala Magnetic of Boston, Mass. is included along with operational and maintenance cost estimates. The advantages of this technique in terms of its low

Electricity and land requirements, added to the exceptional efficiency of the process in terms of solids and phosphorus removal, make HGP a highly attractive alternative for the treatment of the Island's municipal wastewaters.

Section 1.0

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INTRODUCTION

Description of the Technique

Magnetic Separation techniques are not new, they have been in use since the nineteenth century as a way to remove tramp iron and to concentrate iron ores. The technique depends on the application of a magnetic field to a waste stream, causing the material to migrate in the direction of the magnetic field gradient and not under the influence of hydrodynamic forces. Recent years have witnessed the development of a new magnetic filtration technology called High Gradient Magnetic Filtration (HGMF) which is capable of removing microscopic particles from a fluid stream at high flow rates. HGMF is capable of efficient filtration of very weakly magnetic suspended solids or precipitates for which conventional magnetic separation techniques are ineffective. These filters consist of a filamentary ferromagnetic filter bed (matrix) which is magnetized by a uniform magnetic field, producing very high local fields and very high local field gradients in the vicinity of the wire of the matrix. The combination of an efficient magnet and a high gradient matrix allows the economical generation of strong magnetic forces over a large surface area in the

Magnetic filter bed. Filtration then, 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/ft^2).

This magnetic filtration technique is not only intended to be used with wastewaters that normally contain magnetic particles, but also can be used to separate very weakly magnetic or nonferromagnetic solid components of the waste stream. The first step is a pre-treatment process in the case of non-magnetic effluents. This pre-treatment is to render the normally non-magnetic components weakly magnetic. Conventionally, this step consists of the addition of a finely powdered magnetic seed material, usually iron oxide, to the waste stream, followed by some means to associate the magnetic particles with the non-magnetic or dissolved impurities. The magnetic seed material utilized is generally magnetic black iron oxide (Fe■O■). The fact that Fe■O■ is strongly ferromagnetic (its induced magnetization being 408 that of pure iron), that it is reasonably cheap, that it can be milled to a fine powder, that its surface appears to be a good absorbent material and that it is quite inert in most systems makes magnetite the optimum material for conferring magnetic properties to non-magnetic wastes. The techniques used to associate magnetite particles with non-magnetic and dissolved materials include three steps: adsorption, coagulation, flocculation, and coprecipitation.

Adsorption: In the adsorptive mode, magnetite absorbs the non-magnetic particle or dissolved iron on its surface or alternatively, magnetite may be absorbed on the surface of the impurity particle.

Coagulation: Destabilization of the particles suspended in the fluid, as well as reduction of any repulsive forces between the seed and the impurity particles present is accomplished by the addition of inorganic coagulants such as aluminum sulfate (alum). Basically, coagulation is the process in which the particles suspended in a solvent are

Destabilization enables their transport to one another where they may coalesce into larger particles if the right conditions prevail. Colloid concentration, alkalinity, and pH are three factors which affect the process of coagulation during the pre-treatment.

Flocculation: High molecular synthetic polymers such as Aerofloc and Betz are used as flocculants to create bridges and bind together slurry flocs, thus enhancing the strength of inorganic flocs against shear forces during filtration. Depending on the charge on the ionizable group of a polyelectrolyte, they can be classified as being anionic (negatively charged), nonionic (no ionizable group present), or cationic (positively charged). This characteristic - the ability to ionize - along with the molecular weight and degree of branching affect the polyelectrolyte's qualities and usefulness in any particular application. With the formation of large, uniform, and strongly bound agglomerates, the waste is ready to be passed through the high gradient magnetic filter.

Trailer Description: Evaluation of this novel technique in Puerto Rico was done using a Mobile Pilot Plant rented from Sala Magnetics Inc., Cambridge, Massachusetts. Figure 1 shows the pilot plant as it was stationed at Guaynabo Treatment Plant for on-site research. This trailer was constructed by Relco Corporation of Billerica, Massachusetts, and was fitted with pilot plant components and laboratory facilities by SALA. The dimensions of this pilot plant are 2.4m W x 8.5m L x 3.3m H with a gross weight of 3,000 kg, a filtering flow capacity of 380 l/min, and a sludge production of 0.5 kg/hr. This mobile laboratory unit was in Puerto Rico for a period of approximately eight months.

Description of the Pilot Plant system: Wastewater was pumped into the trailer by a submersible pump and passed through a wedge wire screening device (where waste was screened to a 35 mesh size) to prevent clogging of the system lines. The pre-screened waste was collected in a 55-gallon drum.

Gallon barrel, where it was constantly agitated to prevent any settling of suspended material. A feed pump forced the waste stream through a rotameter for process plan monitoring and discharged it into a chemical mixing tank. Before entering this chamber, however, alum was dosed into the stream by means of a metering pump. Once in the chemical mixing chamber, the pH of the alum-treated waste was monitored and the dosing rate was adjusted from time to time, as necessary. Magnetite was added to this tank also using a metering pump. As the seeded alum-flocs passed into the next treatment tank (flocculating unit), polyelectrolyte was added to bind the flocs together. In the flocculating tank, slow agitation further increased floc formation.

The flocculated feed waste was then ready to be drawn through the magnetic separator using a filtering pump. The magnetized flocs as they passed through the separator were attracted and adhered to the matrix. The filtered waste passed via a flowrate monitoring device and into the disposal line which was provided with an open-funnel to allow sample collection of the filtered waste. Periodically, as the filter cycle was completed (i.e., when flocs no longer adhered to the filter matrix), the filter pump and the magnet were shut off and the matrix was backflushed with high pressure air-water. This backflush water containing the flocs washed from the ferromagnetic fibers was collected into a surge tank from which it slowly drained into a thickener. The sludge which settled at the thickener was manually collected and discarded while the supernatant was pumped back into the flocculating tank. Except for the manual adjustment of flowrate made at the beginning of a run, pilot plant operation was automatically controlled. Figure 1 shows a picture of the inside of the trailer in which the mixing tank, the flocculating unit, the dark-colored flocculated waste, the electromagnet, the filtered waste, and the control panel are clearly evident.

MATERIALS AND METHODS

Preliminary

Testing Preliminary

Jar testing for the determination of optimal concentrations of magnets, alum, and polyelectrolyte was conducted before any filtration was attempted. In general, the "criterion" for optimum was based upon the rapidity of formation and precipitation of stable, large, non-stringy flocs and the clarity of the supernatant. Turbidity was measured in terms of absorbance at 550 nm. Bench studies or "jar testing," as these preliminary studies are frequently designated, were done at the laboratory facilities at CEER or at the trailer during given filtration. Occasionally, during onsite experiments, the quality of the waste being treated would change during filtration and additional jar testing was necessary to determine the new optimum concentrations. Usually, 100-ml samples were utilized for jar testing and optimum concentrations were determined by varying one additive over a wide range of concentrations while keeping the other two constant and adjusting the pH. Alum concentration was the most critical parameter in the municipal sewage treatment undertaken and the pH of the alum-treated waste usually was optimal between 6.3 and 7.0.

Pilot Plant Studies

Pilot plant studies were conducted on waste produced at two different sewage treatment plants: El Conquistador and Guaynabo Treatment Plant. Laboratory-derived data was applied to the pilot plant operation after deciding on a reasonable flow rate (i.e., 11-19 l/min) of the waste to be treated. If, for example, the optimized alum concentration was determined to be 500 mg/l, a suitable delivery rate of the premixed alum stock solution was assigned. The alum stock solution concentration could then be approximately determined by the equation:

USC = FW x OC / DR

In which:

USC = Unknown Stock Concentration (g/L)
FW = Flow rate of Waste (l/min)
OC = Optimized Concentration (mg/l)
DR = Delivery Rate of USC (l/min)

The stock concentration of the two other additives, magnetite and the polymeric flocculant, was also determined.

In the same fashion, water quality parameters such as absorbance at 550 nm, total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), and total phosphate (TP), were measured in all samples before and after filtration to determine the percent removal of sewage components during the magnetic filtration process. All the chemical determinations were done following the procedures described in Standard Methods (1975). However, there was a slight variation in the digestion step for TKN analysis. For the first three TKN determinations done, digestion was carried out with a prepared digestion agent and glass granules. The rest of the TKN determinations were done by adding the digestion chemicals separately and using Hengar granules.

224 Unfiltered samples from on-site experiments at Guaynabo were a composite of influent collected at the beginning and at the end of the filtration period. Filtered samples were always collected in the middle of the filtration cycle (i.e., at 1 minute for a 2-minute cycle). If no change in the filtration parameters was done during a given filtration, samples were collected every 30 minutes and a composite was used for analysis. When a change in concentration of a given additive was made in the course of filtration, additional filtered samples were collected to measure

absorbance and check if the variation had produced a noticeable effect. For these cases, water quality parameters were done on the best filtration obtained for a given date.

El Conquistador treatment plant is an activated sludge treatment plant situated in the municipality of Trujillo Alto, having a capacity of 0.5 MGD and an actual process rate of 0.1 MGD. Raw sewage from this treatment plant was collected on several occasions for magnetic separation while the trailer was stationed at CFER parking facilities. A maximum of 346 liters of raw sewage was filtered on any given occasion. It was unfortunate that in only three cases complete.

The text was collected and stored for later analysis to determine the relative success of the filtration process at a time. However, extensive jar testing of the wastes was performed. The maximum filtering flow rate tested was 11 L/min with filter cycles lasting one minute. The total filtering time was approximately 30 minutes. Water was used in all cases. Granular alum and Hercofloe 631 were utilized in all the filtrations. Optimum concentrations of alum, magnetite, and polyelectrolyte were of the order of 50 mg/l, 400 mg/l, and 3 mg/l, respectively, for all. No attempt was made to vary these concentrations during the filtrations.

Onsite filtrations were done at the Guaynabo Treatment Plant for a period of two months, starting March 21, 1980, and ending on May 22, 1980. Guaynabo is a trickling filter treatment plant with a total filtering capacity of 1.9 MGD but with an actual average flow of 2.5 MGD. There is also present at this treatment plant an activated sludge package treatment facility which treats part of the incoming waste.

Table I gives the pilot plant parameters used for the 18 filtration runs made at Guaynabo. It can be observed that two types of waste were used: raw sewage and the waste after it had gone through the preliminary clarifier. Filtering flow rates were of the order of 11 L/min, 15 L/min, and 19 L/min, and the magnet delay time was varied from 4 to 6 seconds. The longest continuous filtering operation was of 2.5 hours. A 2.5 kg magnetic field was used for all tests.

Two types of alum were utilized, granular and liquid. A number of different polyelectrolytes ranging from anionic to nonionic and cationic were also tested to determine their effectiveness. The high molecular synthetic polymers tried during actual filtrations were the following: 1420, 1120, 1129, and 1140; Hercofloc 618, 827, and 831; and Percol 720, 720, 126, and 776. Testing of these polymers was done after the pilot plant system was.

The text was standardized in terms of the optimum concentrations of alum, magnetite, and Hercofloc 831. After testing of a given polymer was completed, the system was again brought back to its conventional operational configuration using Hercofloc 831. This was done in order to recheck the system and be sure that the concentration requirements for the waste had not changed during the testing period. Each testing period lasted about 30 to 45 minutes at the end of which samples were collected for absorbance determinations.

Polymer concentrations tested ranged from 1.0 to 1.5 mg/l, with the highest concentration giving the best results. Efficiency of any given polymer was rated by the absorbance reduction at 550 nm which, in most cases, was related to the type of flocs formed. Granular and liquid alum concentrations were varied from 63 mg/l to 190 mg/l, with 130 mg/l giving, on average, good results.

Magnesite was changed from 1000 mg/l to 100 mg/l, with a concentration of 250 mg/l giving as good results as higher concentrations. Concentrations of Hercofloc 831 were varied from 20 mg/l to 1 mg/l, with 1.5 mg/l giving as good or better results as higher concentrations.

The filtering cycle period of 2 minutes was selected on the basis of the quality of the filtered waste produced through experimentation. Figure III shows the effect of time into cycle versus absorbance at 550 nm. As can be deduced from this graph, a 2-minute filtering cycle was most adequate if a good filtrate quality was desired.

After about three minutes into the filtering cycle, the matrix began to saturate with trapped material and was unable to attract more. Consequently, the filtration efficiency deteriorated rapidly. Experiments done by increasing the concentration of magnetite with the hope of increasing the 2-minute filtering cycle were frustrated by the quantity of solids which the matrix was called upon to process.

Maintain magnetically bound. The volume of backflush produced was measured in order to obtain an estimate of the volume backflushed per volume treated. The backflushed volume for a 2-minute cycle at a filtering rate of 19 1/min was found to be of the order of 3 liters. So, the ratio of backflush volume to treated volume was about 0.1. With increasing filtering rates, the ratio of backflush volume to treatment volume increased proportionately. Unfortunately, the amount of the supernatant being returned to the flocculating tank after the backflush went to the thickener was not measured. This will undoubtedly make this concentration ratio much more favorable.

Electron Microscopy studies were conducted to investigate the structure of the flocs formed and the relationship between floc morphology and removal of suspended material using electron microscopy. Due to the characteristics of the materials under study, the samples had to be agar-embedded to facilitate their handling during the preparation process. Since flocs are the result of the interaction of different components such as alum, magnetite, polymer, and the flocculated material, it was found necessary to look at each individual component in order to get a clearer picture of the floc's morphology. Alum (granular and liquid), magnetite, and Hercofloc 831 were processed for analysis. These filtration additives were prepared in concentrations equal to the ones used under normal flocculation as well as in more concentrated forms.

Centrifuged samples of primary treated sewage and of raw sewage were also analyzed. Flocs formed by the addition of alum and Hercofloc 831 in the presence of water and in the presence of raw sewage were also created.

Preparation of Samples: Centrifuged waste and flocs containing raw sewage were fixed at room temperature in either 2.5% or 3.0% glutaraldehyde (prepared in water or 0.1 M phosphate buffer). The pH of the glutaraldehyde solution was kept around pH 7.0. Fixation varied from 1 to 2 hours. This procedure was... [Text ends here]

The text was followed by three rinsing periods of five minutes each. Rinsing was done with water or phosphate buffer. At this point, the organically fixed material, as well as the non-fixed inorganic samples, were embedded in a 4% agar solution (in phosphate buffer). The blocks thus formed were allowed to harden. A block containing just agar was also included in the process. All the blocks were sliced into pieces measuring 1 mm or less and post-fixed in 1.8% osmium tetroxide (prepared in 0.1 phosphate buffer at pH 7.0) at room temperature for 1 to 2 hours. Dehydration was done after post-fixation with ethanol and was accomplished by the use of a graded series of alcohols (50%-70%-80%-95%-100%) followed by 100% propylene oxide.

Dehydration was also done at room temperature. Following dehydration, the samples were placed in a 1:1 solution of propylene oxide and resin and were left overnight uncapped to allow the propylene oxide to evaporate. Infiltration was done by placing the samples in the resin mixture for a period of 2 to 6 hours. Two types of resin mixtures were most commonly used as the embedding medium. The first resin mixture consisted of 100 parts of a resin (LK 112), 89 ml of a hardener (NADIC methyl anhydride), and 1.5% of the accelerator (benzyldimethylamine). The other resin mixture used followed the same formulation except that another resin (Epon 812) was utilized. Once infiltration was completed, each piece of infiltrated material was placed in a gelatin capsule which was then filled up with the resin mixture. The capsules were placed in an oven at 60°C for 2 to 5 days to allow the embedding mixture to polymerize. Blocks thus formed were allowed to cool and the gelatin cover was removed in warm water. Trimming and sectioning of the blocks was done using an ultramicrotome. Sections of about 100 A thickness were placed on 300 mesh size copper grids and stained for five minutes in 1% uranyl acetate, rinsed in water, and placed for 5 extra minutes in an alkaline solution of lead acetate. Once dried, the grids were ready to be viewed with a microscope.

The Electron Microscope

3.0 19 El Conquistador Treatment Plant Data

The extent of elimination of contamination by magnetic filtration on raw sewage coming from El Conquistador Treatment Plant in Trujillo Alto is given in Table TZ. The optimum average removal for this waste in terms of absorbance, 785, 800, and TP was of the order of 95.98%, 91.7%, 71.98% and 87.38% respectively.

The highest percent reductions for this waste in terms of absorbance, 785, 800, and TP were as follows: 96.2%, 95.4%, 88.1%, and 98.5%. Concentrations of alum, magnetite and Hercofloc 931 needed on this waste for filtration were of the order of 550 ng/l, 400 ng/l and 3 mg/l, respectively.

Suayrabo Treatment Plant Data

Table III gives the measured water quality values of raw sewage and land primary treated sewage before and after magnetic filtration treatment and the percent improvement achieved by the process.

Average treatment values for raw sewage in terms of absorbance, 755, BOD, TN and TP removal were 88.2%, 59.2%, 71.7%, 53.9% and 69.9% respectively. The best separation obtained for this waste was characterized by a decline in the parameters measured of 96.09% of absorbance, 99.48% of TSS, 89.0% of BOD, 66.0% of TN and 98.5% of TP.

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26 Average % removal for primary treated sewage in terms of absorbance,

BOD, COD, TN, and TP were of the order of 85t, 55.38, 52.3%, 51.5% and 96.68 respectively. For the primary treated sewage, the highest percent removal in terms of absorbance, TSS, BOD, COD, TN, and TP were of the order of 90.88, 87.08, 68.9%, 66.4%, 52.68 and 99.67 respectively. Visual observations of the sewage entering the plant on dry, sunny days were strikingly different from that entering on rainy days. This change in effluent could also be noticed in a change in the requirements of alum for good floc production. Alum proved to be the most critical and variable of the chemicals used for magnetic filtration, the quantity required for a good, rapid precipitation of curdy flocs, varied from as low as 90 mg/l to as high as 190 mg/l. On average, for Guaynabo, alum concentrations of 130 mg/l gave positive results. Granular versus liquid alum made no difference in the requirement of alum needed for filtration. However, liquid alum was much easier to handle than the granular form. Magnetite concentrations as high as 1000 mg/l and as low as 100 mg/l were tried; but it was shown that 250 mg/l was enough for a good filtration to take place. Concentrations higher than 250 mg/l did not improve the filtration and did not lengthen the cycle as had been expected a priori. Concentrations of 160 mg/l and lower resulted in a lot of flocculated material escaping the attraction of the magnetic matrix. This was probably due to the decreased incorporation of the magnetic particles in the flocs. It is interesting to note, however, that on average a magnetite concentration equal to 1.6 times the concentration of suspended solids present was sufficient for an acceptable filtration. This is far lower than the conventional recommended dose rate which is about 3 times the concentration of TSS. Hercotac 31, a synthetic polymer, was the polyelectrolyte utilized in all filtration experiments conducted over an extended period. A number of other polymers were also tested, but always for periods of time shorter.

The duration was one hour. Concentrations of this moderately anionic polymer ranged from as high as 20 mg/l to as low as 1.0 mg/l. It was observed that a concentration of 1.5 mg/l yielded results as good as higher concentrations, while at concentrations as low as 1.0 mg/l the agglomerations formed were not large and easily yielded to disruption from hydrodynamic forces. Of the rest of the polymers tested, only two produced good-sized flocs and the filtrate in each case showed a generally higher absorbance value than did the filtrate using Hercofloc S91. With the highly anionic Setz 1120, a reduction in absorbance of 97.38 was observed and a percent reduction in BOD of 77.8 was obtained. The moderately anionic Betz 1110 produced a reduction of absorbance of 72.28 and large flocs. It should be pointed out that all these polymers were tested at pH levels which did not require adjustment (i.e., between 6.3 - 6.5).

Electron Microscopy Studies: Electron microscopy work was hindered from the beginning by a series of problems related to the incomplete polymerization of the resin mixture, which in turn made the task of sectioning the blocks almost impossible. To correct this problem, a number of changes were made during the research, such as increasing the polymerization time, using one anhydride - nadic methyl - instead of two, and trying two different epoxy resins, LX 112 and Epon 612. These changes made no significant difference in the quality of the blocks produced and therefore, in most instances, few good sections or none at all were obtained for viewing under the electron microscope. Also, samples containing magnetite had to be discarded due to the fact that the magnetite present on these blocks tended to rupture the sections as they were cut. Samples that could be examined under the electron microscope were those of agar, alum, polyelectrolytes, centrifuged raw sewage, and flocculated raw sewage. Samples of the additives that were analyzed showed no particular or repetitive pattern that could be attributed to their presence.

In other words, the work done made it impossible to distinguish the three different additives from one another. As was expected, a great number of microorganisms, believed to be bacteria, were present in the centrifuged raw sewage as shown in Figure IV. A close-up of the microorganisms present in raw sewage is seen in Figure V. Bacteria were also present in samples of flocculated raw sewage, but these organisms were randomly distributed and not within a structural floc-type form as was envisioned by the investigators. An example of this is seen in Figure VI.

2. Cost Analysis

Capital costs: The estimated installed capital costs for a High Gradient Magnetic Filter based on a 1 MGD Sewage Treatment Facility were calculated by staff engineers of Sala Magnetics and range between $660,000 and $725,000. This plant would be a fully-automatic, self-contained wastewater treatment unit. It would incorporate pre-treatment (screening and gritting), sludge dewatering, and magnetite feed recovery subsystems in addition to the basic magnet-seed process. The solids operation, i.e., sludge dewatering and magnetite reclamation, would function during a single shift only and chemical storage facilities would permit a 20-day uninterrupted operation period. The control systems would allow continuous operation requiring only a daily operation inspection. This plant would have a backup system for units critical to process function. The estimated cost includes standard instrumentation and data logging equipment but the cost of land has been excluded due to its site-specific nature.

Operational and Maintenance Costs: Table IV shows operational and maintenance costs for the 1MGD seeded water treatment plant. Estimates are in dollars per 1000 gallons of water treated. From this table, it can be seen that the total chemical, electrical, and maintenance and operator labor costs per 100 gallons are on the order of 0.20, 0.13, 0.08, and 0.12 respectively.

Respectively, it should be noted, however, that electrical costs can be reduced up to 50% by judicious means.

Table 1: Operation and Maintenance Cost Estimates for a High Gradient Magnetic Filter Based on a 1 MGD Sewage Treatment Facility.

COSTS IN $ PER 1000 GALLONS:

Chemicals:
- Alum (Liquid, 508) 1308g/l = $126.50/day.
- Ton $0.141/kg (delivered price)
- Magnetite (commercial grade, -225 mesh) 250mg/2 = $90.00/ton
- $0.100/kg (approx. delivery price)
- Polyelectrolyte (Hercofloc 831 anionic) 2.50g/1 = $1.57/pound
- $3.47/kg. (delivered price)
- Chlorine 0.0859/gallon = $0.17/pound
- $0.37/85 (delivered price)

Total Chemical Costs: $0.202

Operational costs:
- Electrical Power = $0.096/KWh
- Magnet 0.023
- Other Equipment $0.08
- Maintenance $0.083
- Operator Labor 8 man-hours = $15/hr

Equipment selection is based on power utilization efficiency. Also, the maintenance cost may vary considerably depending on plant operation practice.

Conclusions:

The High Gradient Magnetic Filter (HGMP) was shown to be more efficient when used to treat raw sewage than in applications involving treatment of primary-treated sludge. The highest percent reductions of absorbance, TSS, BOD, Tt, and TP obtained with this technique during on-site filtration were 96.2%, 99.4%, 89.7%, 66%, and 98.5% respectively. In most cases, optimum concentrations of additives for treatment were 130 mg/l of alum, 250 mg/l of magnetite, and 2.5 mg/l of polyelectrolyte. Anionic polymers such as Hercofloc 831 and Betz 1120 proved to be the best synthetic polymers tested for treating sewage. A continuous monitoring system for adjusting optimum alum levels is necessary for treating this waste, which was found to vary in quality as a function of weather conditions. Results of the pilot plant studies demonstrate that HGMP is a viable method for the purification of raw sewage in terms of the efficient removal of suspended solids and TP. Even though seed reclamation studies were not attempted, the cost-effectiveness of this technique versus conventional methods is evident.

The methods were not conducted by CFER. However, 'the economic viability of this process as described by Oder and Horst' shows that HOMF units of 10 MoD or better are economically competitive. Moreover, HGH has significant advantages including low power requirements and low real-estate costs due to its high processing rates and the compactness of the filtering machinery. The ever-increasing cost of power and the high cost of available land in Puerto Rico, coupled with the demonstrated effectiveness of the technique, should make HOM a highly attractive treatment alternative for the island's municipal wastewaters.

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