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Preliminary Feasibility Study of a Sand-Clay Filter for treating Surface and Industrial Wastewaters in Trinidad

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Some physical, chemical and biological properties of raw water collected from Caroni River in Central Trinidad and raw wastewater from Angostura Distillery in North Trinidad were measured in the laboratory. In addition, the properties of the water effluent obtained by passing the raw Caroni River water through various sand-clay filter media that differed in the proportions of sand and clay by volume were tested in order to observe the efficacy of sand-clay mixtures as filter media. Hitherto, most filter media were made of sand placed in beds. In general, the pH from the effluents from the sand-clay filters increased while the turbidity and total suspended solids decreased in comparison with the raw untreated water. An optimal filter medium with a sand-clay combination of 70-30% was determined from the results. This optimal filter combination was used to treat raw industrial wastewater collected from the Angostura Distillery. Results showed that this filter medium decreased the total suspended solids, turbidity, 5-day BOD, total coliforms and phenol below the maximum permissible limits for discharge into the environment. The use of sand-clay filters for pre-treating industrial wastewater before discharge into the environment is encouraging but more testing would be necessary before it could be adopted as a commercial filter medium.

Keywords: Sand, Clay, Filter, Wastewater

1. Introduction

Many countries are looking into ways of recycling their industrial wastewater and re-using it in the industry for some medial task. The level to which the wastewater is treated will depend on the application it will be used for in the industry and such that if the water were to be discharged into the waterways or the environment generally, the flows through the settlement will be safe enough both environmentally and healthwise.

One method of treating the industrial wastewater is to use numerous chemicals to make it meet World Health Organisation (WHO) and Trinidad and Tobago Standards, currently set by the Environmental Management Authority (EMA) [1]. Another method for wastewater treatment is filtration process, which plays a key part in the removal of unwanted particles and ions from the water, making it harmless and uncontaminated [2]. Pre-treatment of water and wastewater like sedimentation could be done before filtration, but advancements in water treatment technology has indicated that the raw wastewater can pass directly from the point source to the filtration process [2, 3]. Filtration represents a natural method of treating industrial wastewater and bringing it to the required level for safe discharge into the environment.

The most common material that is used for water filtration is natural sand [2]. It makes a very efficient "strainer" for small colloids [4]. **Fair *et al*** [5] developed an accurate theory for predicting a head loss across a bed of clean sand. **Peavy *et al*** [2] listed the parameters of slow and rapid sand filters for water

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treatment. Although this method of filtration is successful, it is very costly in the sense that in Trinidad and many other developing countries, the sand used in this particular filtration process is mostly imported. Clay soil is very abundant in Trinidad and the cost of filtration would be reduced if different proportions of clay and sand were used as filter media.

The main dimension of a clay particle is usually less than 0.002mm and the different types of minerals have been created from the manner in which clay structures were stacked. There are three main groups of clay particles. Kaolinite is the most dominant part of residual clay deposits and is made up of large stacks of alternating single tetrahedral sheets of silicate and octahedral sheets of aluminum. Kaolinites are very stable with a strong structure and absorb little water and have low swelling and shrinkage response to water content variation. Illites consist of a series of single octahedral sheets of aluminum sandwiched between two tetrahedral sheets of silicon. Illites tend to absorb more water than kaolinites and have higher swelling and shrinkage characteristics. Montmorillonites have a similar structure to the Illites group but in the tetrahedral sheets, iron, magnesium and aluminum replace some of the silicon. They exhibit extremely high water absorption, swelling and shrinkage characteristics. Bentonite is a memebr of this mineral group and is usually formed from weathered volcanic ash. From literature search, only **Kapoor** and **Viraraghavan [6]** successfully used bentonite as clay filter media to remove heavy metals from aqueous solutions.

This paper concentrates its experimentation on using filter media made up of sand and clay in different proportions to treat raw water from Caroni River in Trinidad. The aim was to evaluate the efficiency of sand-clay filter media; to determine the optimal proportions of these mixtures as filters and to compare values obtained with those obtained using only sand filters. The optimal sand-clay filter medium obtained was used to treat wastewater from Angostura Distillery in Laventille, North Trinidad, in order to evaluate its effectiveness.

2. Materials and Methods

2.1 Raw Water Sources

The raw water from the Caroni River was taken at its entrance pipe into the Arena Water Treatment Works, Piarco, Trinidad and used in the test. The East-West Corridor in Trinidad through which the Caroni River flows is the home of many industries like beverages, edible oils, soap, rum distilleries, agro-processing and these discharge their wastes into the river. Wastewater was collected at the outlet drain of the Angostura Distillery on the Priority Bus Route side in Laventille. The wastewater appeared black, had many colloidal particles suspended in it and could be smelt from a radius of approximately 100m. A day before the collection of the water samples from the two sources, the sample bottles were sterilised and incubated for 12 hours. Four (4) samples each were collected and taken to the laboratory for testing. In addition, some portions of the samples were passed through the filter media and their effluents were tested as well.

2.2 Materials of the Filter Medium

The type of sand medium used was 18-30 silica sand collected from the Sand Products Company in San Fernando, Trinidad. The particle-size diameters varied from 0.6mm - 1.18mm, making it a rapid sand [2]. The silica sand had a gritty feel to it when it was both dry and wet. Kaolinite clay, which was 95% pure, and had been hydraulically washed before packaging to remove as much impurities as possible, was used. It was collected from the Ceramic Design Company in Point Lisas, Trinidad. The diameter of the clay particles varied from 0.001mm to 0.002mm. The kaolinite was white and had a feel similar to that of chalk dust. As it was wetted, the material felt analogous to cream. However, the kaolinite when pre-packaged was clumped together. For the experiment, the clumps were broken up using a sieve of 1mm spacing. The clay particles now varied between 0.002mm and 1mm in size. The different proportions by volume used to mix the sand and clay components in the filter media are shown in **Table 1**.

TABLE 1: *Mean* Values of Water Properties in Raw Caroni River and Effluents through Sand-Clay Filter Media*

Water/Filter Code	Sand (%)	Clay (%)	pH	Turbidity (NTU)	Ammonia Nitrogen (mg/L)	Total Suspended Solids (mg/L)	Colour of water	Filtration Rate (m^3/h per m^2)
Raw Caroni River water	-	-	6.97	27.05	0.130	11.0	Brown	-
Effluents of Raw Caroni River Water through the Sand-Clay Filter Media								
A	100	0	7.24	286.50	0.155	58.5	Brown **	0.861
B	75	25	6.83	11.05	0.248	1.5	Clear	0.114
C (Optimal)	70	30	7.21	3.30	0.252	2.0	Clear	0.084
D	62.5	37.5	7.13	41.70	0.276	12.0	Whitish***	0.067
E	50	50	7.38	327.00	0.220	13.5	Very Whitish	0.003

* Mean of 3 replicates. Coefficient of variation ranged from 4 to 9%. This also applies for Table 2.
** Brown colour with suspended material from sand.
*** Whitish because of clay. Clay colloids took about 5 mins. to settle out.

2.3 The Filter Assembly

The filter assembly (**Figure 1**) consists of a $0.216m^3$ open tank with dimensions 0.6m x 0.6m x 0.6m placed on the stand with the open side facing upwards. A mounted cylinder 1m long and 0.303m internal diameter made of steel, acted as the filter bed and was fitted into the 0.3048m diameter hole made on the closed face of the tank. Thirty (30) centimetres of the cylinder was in the tank while the remainder of the cylinder protruded from the tank (**Figure 1**). A 3.18mm-thick mild steel circular plate had at its centre a 25.4mm female couple and was welded onto the base of the cylinder to seal it. One end of a 20cm-length and 25.4mm-diameter polyethylene pipe was fitted with a 25.4mm ball valve while the other end was formed into an L-shape and fitted with a 25.4mm PVC male couple and attached to the 25.4mm diameter female couple on the cylinder. Four (4) pieces of wire meshing were arranged in a staggered formation and placed over the opening of the orifice of the 25.4mm diameter pipe.

2.4 Experimental Procedure

Once a given proportion of a sand-clay filter had been thoroughly mixed, it was ready to be placed within the filter apparatus. The base of the 1m-long filter bed was used as the datum point. From this datum point to 20cm depth, a gradation of gravel sizes (1cm - 3cm) in diameter was placed to intercept any sand or clay particles that became suspended within the water as it reached the last stage of the filtration process. The filter material was placed from the 20cm to the 80cm mark. The 80cm to the 1m mark contained the influent sample to be filtered, which was continuously replenished during testing to maintain this constant 20cm head of influent liquid. Before the actual testing started, the cylinder was flooded with tap water to remove any

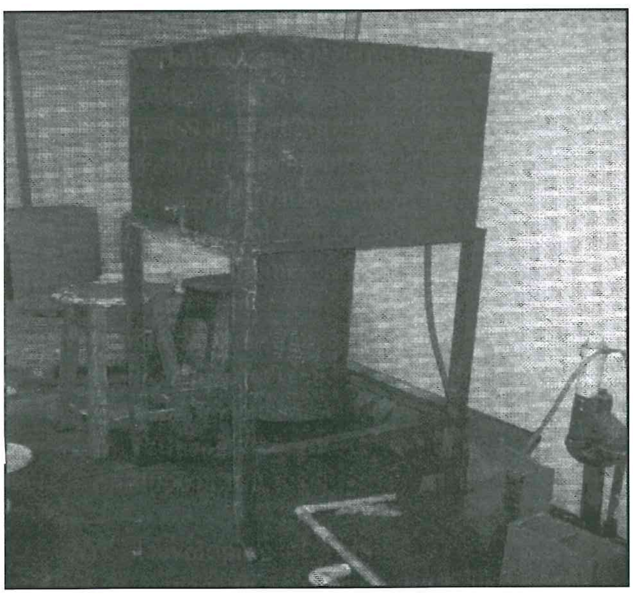

FIGURE 1: *The Filter System Apparatus*

dust or very fine colloids and to pre-wet the filter mixture so that the influent water would not be absorbed into the surrounding particles. This meant that the filter materials were pre-coated with a thin film of water, which ensured that the influent water flowed through. After the cylinder had been flooded, the ball valve was left open for about two (2) hours to allow excess water to drain out. Timing began when the influent samples were poured into the filter and the experiment stopped when a pre-determined 3.5 litres of effluent had been collected through the 25.4mm pipe outlet. The total flow rate of water through the media was computed.

From the collected effluent, one (1) sample was taken and placed into a sterile bottle and sent to the Laboratory for testing. Testing was done for two (2) more runs on the same sand-clay filter medium. The experiment was then repeated for the other sand-clay filter media after backwashing. Backwashing was carried out after each filter medium was tested in order to determine the efficiency of the process, in particular, to make sure that during backwashing of a particular filter medium, clay particles did not stick to the sand particles, preventing the water from passing through the filter media to unclog it.

2.5 Laboratory Testing of Samples

Testing of the raw Caroni River water and its effluents through different filter media was carried out at the Civil Environmental Engineering Laboratory using standard procedure. pH was measured using a pH meter. Total suspended solids were determined using the standard filtration procedure. The free ammonia nitrogen was determined by adding Nessler's reagent to the sample and then measuring the absorbance value using the spectrophotometer at the wavelength of 4.15nm. Turbidity of water was measured using a turbidity meter.

Apart from the turbidity and pH tests which were carried out in the Civil Environmental Engineering Laboratory for the raw wastewater from the Angostura Distillery, and effluent from a sand-clay filter, five (5) additional tests were carried out in the Caribbean Industrial Research Institute (CARIRI) Environmental Engineering Laboratory located on the campus. They include the 5-day biochemical oxygen demand (BOD) measured using the CARIRI micro method number 009; ammoniacal nitrogen using the EPA 350.2 method [8]; total suspended solids using SMEWW2540 A, B.2, C.2, D method [7]; total coliform count adopting the CARIRI Micro method No: 008 and the test for the presence of phenol compounds using the SMEWW 5530C method [7].

3. Results and Discussion

Table 1 shows the values of the physical and chemical properties of the raw Caroni River sample as well as its effluents (treated water) after passing through the filter media. The filter codes A - E represent different combinations of sand and clay arranged in increasing clay content by volume. For instance, medium A represents only the sand filter while medium E represents a combination of 50% each of sand and clay. Results showed that, as expected, the filtration rate of raw Caroni River through the filter media decreased with increasing clay content. The filtration rate for the 100% sand filter (0.861m^3/h per m^2) refers to that of a rapid sand filter. This value decreased ten-fold to the filtration rate of 0.084m^3/h per m^2 for the 70% sand and 30% clay filter medium, which is about 65% of the lower rate for the slow sand filter [2]. This value further decreased when the proportion of clay increased. Clay soils have lower infiltration rates than sandy soils because they have fewer large pores when compared to sandy soils [9].

It seems that once the clay had been saturated and then left to drain, it was observed that once it came into contact with water, it became "fluid-like" again. This indicates that the clay could be continuously re-used, as impervious layers were not formed. Another observation was that after backwashing and the filter was being emptied for the next experiment, the clay particles acted as a binding agent for neighbouring sand particles. Thus, it reduced the size of the voids for water to pass through. During backwashing, which was carried out for each filter medium after three (3) continuous tests, it was found that for the sand only filter, the medium remained intact and no filter material came out into the tank. For filters with 25% and 30% clays, very little clay particles were seen in the tank during backwashing but the proportion of clay particles dislodged was very large for the filter media with 37.5% and 50%, suggesting that the optimum clay content for a sand-clay filter is about 30%.

High value of the nephelometric turbidity units (NTU) indicates the large amounts of insoluble particles that are present in the water. Turbidity is a measure of the extent to which light is either absorbed or scattered by suspended materials in water [2]. The raw Caroni River water had a turbidity of 27.05 NTU. Turbidity of raw Caroni River increased to 286.50 NTU when it was passed through the only sand filter (filter medium A). This was because of the loose nature of sandy soils, which added its dusty particles to the water effluent. The dusty nature of sand persisted despite pre-washing before testing. This made the water from the Caroni River retain its brown colour and also had suspended material from sand. However, turbidity decreased to 11.05 NTU when clay was introduced at 25% content. This was because the small pore openings created by smaller particles like clay increase filtration efficiency by straining and other removal mechanisms [2]. Also, the sand particles which were trapped by the wet clay got adhered to the surface of the clay particles. The head loss through the filter medium, however, increased resulting in diminished filtration rate. Larger medium-like sand increases pore size, reduces head loss and increases flow rate, but sacrifices filtration efficiency [3]. A mixture of clay and sand as a filter medium may then be desirable to improve filtration efficiency.

It could be speculated that the addition of the clay to the filter medium acted as a compensator for the lack of depth needed by the 100% sand medium. An additional reason why the 100% sand filter medium had a much higher turbidity reading than the other sand-clay media is that the 100% sand filter may not have had sufficient filter depth. **Peavy *et al*** [2] suggested that the depth of a rapid sand filter could go up to 0.75m unlike the 0.6m depth used in this study. Moreoever, the operation of most rapid sand filters requires the pre-treatment of chemical coagulation in order to destroy the charges of colloids. The implication of reducing the levels of turbidity in the effluents with sand-clay filters is advantageous as any microbes present in the effluent could now be exposed to the sunlight at greater depths because of the ability of the sunlight to reach further depths. The effluents from water treatment plants are normally exposed to sunlight in order to kill about 90% of bacteria present in the water [2].

However, when the clay content in the filter medium was increased to 37.5% and 50% (filter media D and E), the turbidity increased again from values obtained with the 25% clay content and increased above the values of the raw water sample (**Table 1**). This was a result of the whitish clay particles being in suspension in the effluent samples. The water flow rates also dropped dramatically, particularly in the filter E medium with 50% clay content. These results suggest that while clays may be desirable in filter media, their proportion in relation to sand is important. In this experiment, it would seem that the optimal clay content to achieve adequate filtration lies between 25% and 37.5% by volume. An optimal filter medium (filter medium C) with 70% sand and 30% clay was therefore chosen and tested along with the others. This optimal filter medium gave turbidity values (3.3 NTU), which were much lower than that for the 25% clay medium.

The total suspended solids (TSS) indicate the amount of solids that remain suspended in the solution, once it had been left to settle for a while. The 100% sand filter had the most suspended solids in solution followed by the 50% sand- 50% clay filter. The filter medium, which had the least suspended solids in solution, was the 75% sand- 25% clay mixture. It is suggestive that the introduction of clay into the filter medium greatly reduced the amount of TSS, once settling had occurred, relative to the Caroni River's suspended solids. This will have a positive impact in the sizing of the treatment facility and indirectly the cost of setting up such a facility. With the use of the optimal filter bed media, there was a vast decrease in the amount of suspended solids present in the effluent as opposed to the influent sample.

The pH indicates the level of hydrogen ion concentration. The raw Caroni River water sample showed a pH of 6.97, which is almost neutral. As the water was passed through the sand-clay filter, there was an increase in pH, relative to the value obtained for the influent sample. This means that the filtration process made the raw river water less acidic, which is desirable for environmental purposes.

However, the filtration process increased the level of ammonia nitrogen in the raw Caroni water. Ammonia nitrogen indicates the level of bacteria in water available to convert organic nitrogen into ammonia. The results (**Table 1**) show that with the introduction of the clay medium, the level of ammoniacal nitrogen in the effluent doubled. The possible explanation that could account for the phenomena is the presence of bacteria already in the clay medium and when it became fluidised, the bacteria now became mobile as it probably used the water influent as a mode of transport. Results from this chemical test lead to the suggestion that the effluents need to be disinfected to remove the bacteria. In some cases, a high concentration of disinfection needs to be added to the effluent of the varying filter media where necessary. Future work should involve the measurement of the total Kjeldahl nitrogen (TKN) and heterotrophic plate count of the influent and effluent in order to verify whether the increase in ammoniacal nitrogen was due to bacterial conversion of TKN and whether bacteria present in the influent or in the clay contributed.

Table 2 shows the values of the measured physical, biological and chemical properties for the raw Angostura Distillery wastewater and the effluent after the raw samples were passed through the optimal filter combination (70% sand and 30% clay) derived above for the Caroni River water sample. This clay ratio was chosen in this experiment because as the clay content further increased, the data values became "unfavourable." The assumption here is that optimal filter combination derived for the Caroni River water sample would also be optimum for the Angostura distillery wastewater. The Caroni River had the same type of contaminants as the industrial wastewaters since most wastewaters flow into its distributaries.

Results show that apart from the ammoniacal nitrogen and phenol compounds where the method used could not detect differences between the wastewater influents and effluents, the measured properties of the effluents were reduced to levels that were in almost all cases, safe for discharge into the environment, according to the standards set by the EMA in Trinidad (**Table 2**). For instance, the turbidity of the industrial wastewater influent, relative to the Caroni River water influent, was high (48.8 NTU). However, when the industrial influent was passed through the filter with 30% clay content, the turbidity reading was as low as 2.9 NTU. Also, the overall microbiological quality of the industrial waste efflluent

TABLE 2: *Mean Values of Measured Properties of Raw Angostura Distillery Wastewater And Its Effluents through the Optimal* Sand-Clay Filter Medium*

Property	Raw Wastewater	Treated Effluent	EMA Standards for Inland Water [1]
Total Suspended Solids (Mg/L)	68.0	2.0	50
Ammonia Nitrogen (mg/L)	<1**	<1	10
5-Day BOD (mg/L)	984	244	300
Total Coliform (Cfu***/100ml)	2.15×10^6	None detected	35
Phenol (μ g/L)	<5**	<5	10
pH	5.67	5.36	6 - 9
Turbidity (NTU)	45.90	2.90	5.00
Colour	Black	Clear	-
Filtration Rate (m^3/h per m^2)	-	0.086	-

* 70% Sand and 30% Clay.
** Detection limit for ammonia nitrogen is 1mg/L and 5μ g/L for phenol.
*** Colony forming units.

greatly improved as was indicated by the nil total coliform count result.This could be as a result of the initial pH of the industrial influent as certain microbes cannot survive in acidic solutions.

The results of filtration of industrial wastes using the optimal filter medium are encouraging. The rate of filtration ($0.086m^3/h/m^2$) was almost same as that of the raw Caroni water using this optimal sand-clay filter. One major achievement when the optimal sand-clay mixture was tested was that the effluent of the industrial wastewater came out clear and odour-free. The odour of the raw Angostura wastewater emanates at a 100m radius from the source industry. This is a definitive plus in treating this particular wastewater, in that supposing the industrial effluent had no changes chemically or biologically, then at least the horrific smell, often compared to that of rotten eggs, will be eradicated from the discharge. This would reduce the sickening effects to the inhabitants in and around that source location and also to the motorists travelling through that area. It could be possible that sulphides that usually cause odours were removed by filtration.

The clarity of the industrial effluent is another achievement, especially since it was a one-stage treatment, which is, from the point source to the filtration system using only the optimal 70% sand-30% clay mixture. The overall improvement in the microbiological quality of the effluent is also positive. The use of this sand-clay filter medium is therefore promising.

The 30% clay filter medium, clay particles sufficiently filled the inter pores of sand and acted as an efficient slow sand filter. The efficiency of this optimal filter was tested using three (3) continuous filtrations which lasted approximately 35 mins. each and the filtration rates remained more or less constant, showing that the pores were not clogged. The good results obtained for this filter during backwashing were also encouraging. However, for a better evaluation of this sand-clay filter, it needs to be operated on a continuous basis for at least one (1) month. It is supposed to maintain a reasonable flow rate without choking as well as good effluent results for that period. The backwashing operation cycles and its residual management are also critical in its evaluation. These would form the focus of a further research before the sand-clay filters can be fully accepted as a filter medium. The preliminary results obtained in this study are, however, very encouraging.

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