CHAPTER III

THEORETICAL CONSIDERATIONS

Wastewater Reclamation and Reuse

Wastewater reclamation is the advanced treatment of wastewater using advanced methods and processes that will remove contaminants so much so that it may be reused satisfactorily. It is aimed to relieve the problems of provision of new sources of supply to meet the ever increasing demands of water due to growing population and at the same time to minimize environmental pollution which is aggravating urban communities. To determine the feasibility of wastewater reclamation, it is necessary to decide its intended uses whether for agricultural irrigation, industry or municipality. The treatment processes needed and relative costs as well as the quality and quantity of other source must also be considered.

Reuse of reclaimed wastewater is subject to many factors additional to purely technical one of meeting public health standards. The consumer must be fully informed of the source, understand the need to reclaim and find such reclamation and reuse acceptable. Without such social acceptance, the program can never be successful. The introduction of reclaimed wastewater should be done step-wisely starting from "low level" uses, such as recreational lake supply for swimming pleasure, boating, sport fishing and municipal street cleaning, with the ultimate target to gain social acceptance as a potable supply.

As far as industry is concerned, reclamation and reuse of its effluent is not uncommon but is most often confined to within factory recycling. On agricultural side, reuse of wastewater is unintentional. Some part of water diverted for irrigation returns to the stream and is available for subsequent reuse by downstream irrigators. Such practice has led to the accumulation of dissolved salts in the soil which can be hazardous if they are transported in the drainage water to the main streams.

Another form of reuse is the return of treated wastewater to ground water aquifers, either by percolation or well injection, where depletion or salt water intrusion has occurred.

Wastewater Reclamation by Filtration

1. Introduction

Filtration is the process of separation of suspended or colloidal impurities from liquids, in which the liquid passes through network of wires, threads or fibers, or some kinds of porous membrane, such as woven fabric or filter paper, of through porous beds of granular materials like sand. During the passage of the liquid, the solids are arrested mechanically, either directly by the medium itself or indirectly by solids already held or matted on the medium.

The history of filtration can be dated back to as early as 1804, when the first so - called "slow sand filter" was used successfully (SKEAT and DANGERFIELD, 1969). Afterwards, more development had been done on slow sand filters, but due to scarcity of land and drastic growth of population "rapid sand" filtration became more popular in early twentieth century.

A slow sand filter is usually rectangular in shape having the depth of 2.5 to 4 m, built below the finished ground level in an area of about some hundred square meters. The sand of effective size of 0.15 to 0.35 mm with uniformity coefficient of 1.5 is suitable for efficient filtration with rates ranging from less than 0.1 to about $\overset{\approx 10}{0.4}\ m^3/m^2/\overset{/d}{hr}$. Some thickness of sand is placed on gravel size of 8.53 to 19.05 mm ($\frac{3}{8}$ to $\frac{3}{4}$ in.) having depth of about 30.48 cm (12 in.) (HUISMAN, 1970; FAIR, GEYER, and

OKUN, 1968; and AZIZ, 1971)

Slow sand filters can handle as much as 100 - 200 mg/l of turbidity for a few days but best results are obtained when the average turbidity is 10 mg/l or less (as silica). Under ideal conditions, they can reduce total bacterial counts by 99.9 to 99.99% and E. coli by 99 to 99.9%. Viruses reduction is effective when lower filtration rates are used. According to FAIR, et al (1968), general features and design parameters of slow - sand filters are given in Table 2.

Slow sand filtration is more advantageous to developing countries since land and low - skilled labour requirement are not the problem. Slow sand filters can be built of local materials, hence the construction costs are low and the operation and maintenance are simple. Safety and reliability of the filters can be secured without any requirements of complicated mechanical electrical and electronical equipment that are indispensable in rapid sand filters.

2. Mechanisms of Filtration

According to HUISMAN and WOOD (1974), the overall removal process in slow sand filter is the combination of mechanical straining, sedimentation, adsorption, chemical and biological activities. They described the physical process of filtration in the following ways.

i) Mechanical Straining In this activity large suspended matters removal takes place entirely at the surface of the filter and is independent of the filtration rate. Its efficiency is developed by the formation of a "schmutzdeck" at the surface layer of the filter bed. However, bacterial and colloidal matters cannot be removed since they are too small for the pores among the grains to retain.

Table 2 General Features and Design Parameters of Slow-Sand Filters

Feature Considered	<u>From FAIR, et al (1968)</u>
1. Rate of filtration	0.1 $m^3/m^2/hr$ (2-6 in/hr) as secondary filter: 0.2 - 0.3 $m^3/m^2/hr$.
2. Size of Bed	large, 2000 m^2 or more
3. Depth of bed - sand and gravel	sand : 0.6 - 0.9 m gravel : 30 - 60 cm
4. Effective sand size	0.3 mm
5. Uniformity Coefficient	1.7 - 2.0
6. Gravel size	18 cm : 20 mm 7.5 cm : 8 mm 5.0 cm : 2-3 mm
7. Underdrains	(a) Split- title laterals laid in coarse gravels discharging to tile or concrete main drain (b) no fines concrete floor

Table 2 (Continued)

Feature Considered	From FAIR, et al (1968)
8. Head Loss	
Initial	5 - 7.5 cm (.2 ft)
Final	60 - 90 cm (4 ft)
9. Length of run between cleaning	2 weeks - 3 months Avg - 2 months
10. Penetration of suspended matter	Surface layers
11. Method of cleaning	(a) Surface layer scraped by hand, washed and replaced (b) Mechanical surface washed
12. Costs - Initial	
Capital	High
Operating	Low
Depreciation	Low
13. Bacterial removal efficiency	as high as 99.9%
14. Water Quality	Reduce tastes and odor, reasonable amounts of suspended and settleable matter

ii) Sedimentation Particulate suspended matters are removed by precipitation on the sides of the sand grains. Sedimentation efficiency is a function of the ratio between surface loading and the settling velocity of the suspended matters. Particles with diameter of 4 microns are most vulnerable to the process. However, truly colloidal matters cannot be extracted in this way.

iii) Adsorption When suspended matters collide with sand grains previously coated with gelatinous deposited bacteria and colloidal matters, they adhere to the sand grains and thus are removed. Physical attraction between particles (Van der Waals force) and electrostatic attraction between opposite electric charges (Coulomb force) increase the adsorption efficiency.

iv) Chemical and Biological Activities On filtering, not only suspended impurities but also the bacteria present in the raw water are adsorbed on the sand grains. Here the bacteria consumed the organic deposit as food for their metabolism and growth. Next, the metabolized products are transported further down to be consumed by other bacteria at greater depth. In this manner the organic solids are degraded and finally convented into dissolved inorganic salts like water, carbon dioxide, nitrates, phosphates, etc.

These bacterial activities are most pronounced in the upper part of the filter bed and gradually decrease with depth where food is limited. Thus, with each scraping off of filtering medium a big portion of bacteria are removed.

Unfortunately, chemical parameters on the filtration process have not been firmly established until now. Several hypotheses have shown disagreement among themselves and have been unable to predict filter performance (STANLEY, 1955; CLEASBY and BAUMANN, 1961; MACKRLE, 1961; and JORDAN, 1963).

3. Factors Affecting the Filtrate Quality

i) Filtration Rate

Several investigators have reported that the higher the filtration rate is, the worse the effluent quality will be. At slow rate, not only can turbidity be effectively removed but also can viruses be reduced (BAYLIS, 1956; HUDSON, 1958; CLEASBY & BAUMANN, 1962; and HUISMAN, 1970). However, SEGALL & OKUN (1966) contradicted this report by stating that filtration rate has less effect on the filtrate quality than do the grain size and porosity.

ii) Influent Characteristics

Effluent quality is reported to fluctuates with the raw water characteristics. Best filtrate is often produced when the influent turbidity is at 10 mg/l or less. However, raw water low in dissolved oxygen content or high in biochemical oxygen demand can bring about anaerobic conditions and, as a result, the effluent quality may be unacceptable for drinking purposes (HUISMAN, 1970).

iii) Filter Media

HUDSON (1958) reported that the efficiency of filter media to remove turbidity is related to the square of the grain size. Media of 0.5 mm diameter is twice as good at removing turbidity as media of 0.7 mm size, and media of 0.35 mm size is twice as good as 0.5 mm media. Porosity is another important factor governing the filtrate quality. Low porosity medium functions better in removing suspended matters than the one of higher porosity.

iv) Depth of Filter Bed

The thicker the filter bed is, the better the removal of suspended matters will be. Great thickness of the filter bed gives rise to effective sedimentation and adsorption. With greater combined surface area of grains, a larger habitat is offered to the microorganisms responsible for the biological degradation of organic solid matters. However, there is obviously some optimum depth beyond which further improvement is insignificant.

v) Filter - Bed Conditions

Bed conditions as regards degree of cleanness of filter media after run, short - circuiting, cracking of bed, mud balls formation, air binding and etc. affect the filtrate quality significantly.

4. Factors Affecting the Filter Run

HUDSON found that media of same porosity and effective size give almost identical filter run which varies as the 3.8th power of the porosity of the filter medium, indicating that the angular medium gives longer filter run than rounded one does. He also found that high filtration rate has undesirable effects on the filter run, where as the thickness of the filter bed has practically no effects on the length of the filter run (HUDSON, 1938 and 1958).

BAYLIS (1937 and 1956) reported that filter run varies approximately as the 2.15th power of the diameter of the effective grain size. He also stated that clogging rate of the filter is inversely proportional to approximately the 1.5th power of the filtration rate.

HUISMAN (1969) stated that excessive turbidity clogs the filter rapidly; 10 mg/l or less turbidity gives best results.

5. Filtration Rate

To determine on optimum filtration rate, it is necessary to consider the quality of raw water, pretreatment facilities, sand size, bed depth, head conditions and hydraulic conditions in the filter piping. As filtration proceeds, the bed is clogged up and fewer voids are left as a result. To maintain the same total flow, the velocity of water passing through the bed must be increased. When this velocity gets too high, sediments are transported clear through the bed. This can be remedied by supplying varying inflow to the filter by direct pumping but can't expect to get good water.

CLEASBY and BAUMANN (1962) reported that total headloss in filter bed is the sum of headloss in surface cake and headloss in sand bed. Headloss within sand bed is linear, whereas in compressible surface cake it develops exponentially with the progress of run. The optimum filtration rate can be identified as the lowest rate at which the headloss development curve becomes more or less linear, indicating that surface cake influence has been minimized. The higher the filtration rate, the thinner the surface cake formation.

6. Parameters that Will Predict Filter Performance

BOUCHER (1947) stated that there are six factors involved in the performance of a filter, namely :

1) Rate of inflow
2) Length of run
3) Initial hydraulic resistance
4) Final hydraulic resistance
5) Effective area of filter
6) Influent characteristics with regard to suspended solids.

He also worked out and introduced "filtrability index" to provide a scientific definition of filtrability and hence to predict filter performance.

He introduced the following expression :

$$\log_e H = nV + \log_e H_o$$

in which $H = me^{nV}$, headloss

V = volume of raw water

m, n = constants

When $\log_e H$ is plotted against V to give a straight line, the value of n is obtained and taken as "filtrability index" for the water with respect to the filter. It is later on denoted by I and may be written as,

$$I = \frac{1}{V} \log_e(\frac{H}{H_o})$$

where H_o is the initial resistance of the filter.

Water with low filtrability index is readily filterable whereas high filtrability index implies difficult filtration.

7. Alternative Media for Slow Sand Filter

J.W. ARMSTRONG (1931) Suggested from filtration point of view that it is desirable to have a medium that will :

i) prevent any flocs from passing through the filter,

ii) hold flocs as loosely as possible in order to permit easy washing and prevent the formation of mud deposits, and

iii) hold as large volume of flocs as possible without clogging.

HEIPLE (1959) carried out a pilot plant study on filtration using $\frac{1}{4} - \frac{1}{2}$ in. (0.635 - 1.27 cm) pea gravels. He found the average turbidity removal efficiency was above 50% and occasionally went up to 90%. The filtrate turbidity was within 3 and 30 ppm and bacterial removal was at least 50%. The filtration rate was maintained at 0.1 gpm/ft^2 (0.26 $m^3/m^2/hr$).

Many researches have been done on the comparison between sand and other materials as filter media. In case of anthracite, it is reported that anthracite produces an effluent equal in quality to that of sand but the former gives softer effluent (BAILEY, 1937; and HUDSON, 1938). As far as shape is concerned, angular anthracite particles are more efficient than angular sand grains, but round sand performs better than round anthracite (HUDSON, 1938; and TURNER, 1943).

Filtration using combined media of sand and others have also been studied. In case of anthracite, some thickness of top layer of sand is replaced by anthracite of 0.40 - 0.45 mm size and 1.4 uniformity coefficient, to perform as a "roughing filter". The result is satisfactory. Anthracite can withstand violent cleaning action, and sand and anthracite stayed in distinct layers virtually unmixed. Except for very fine particles there is no large anthracite particle loss during first few washings (BAILEY, 1937). As for coal, a thin layer of crushed coal is substituted for the top layer of sand of 0.5 mm size. The filter performs very well, with the coal layer serving as a roughing filter, thus relieving the sand of much load. This gives low clogging rate of coarse coal together with high filtering ability of the finer sand below it.

Properties of Burnt Rice Husk

Burnt rice husk is composed mainly of silicon dioxide (88.66%) and magnesium oxide (3.53%). It has a cellular structure, probably composed of crystalline silica. On compacting, the particles tend to break down into very irregular shapes, but to great extent the cells are retained. Its moisture content is 8%

on dry weight basis, at 105°C. Its specific gravity is approximately 2.29 and its density varies within 752 and 768 kg/m^3 (47 and 48 lb/ft^3). The density increases when the material is recompacted (WILLIAMS and SOMPONG, 1971).

Most of the rice husk is disposed of as waste, although a small amount is used as fuel for the mills. The raw rice husk is easily burnt to produce an ash. According to FRANKEL (1974), its heat content is about 600 BTU/lb and the burnt rice husk ash consists of about 90% silicon dioxide, 6 - 7 % oxides of magnesium, aluminum, calcium and iron, and the remaining 3 - 4 % organic matters (mostly carbon). The medium has a very high surface area to volume ratio, adsorption properties similar to activated carbon, small pore size and high permeability and very low cohesion, making the ash very suitable as filter material.

From the preceeding literature review and theoretical considerations, it is evident that the use of burnt rice husk as filter medium to reclaim used wash - water for subsequent reuse is possible and its feasibility study is worth further attention.