CHAPTER II

LITERATURE REVIEW

Based on the original studies of FULLER (1898), IVES (1960) confirmed that the average gravity flow rapid sand filter was designed to function at the rate of 2 gpm per sq ft. and operate at 3 gpm per sq ft. or 50 percent overload was frequently used. In gravity filtration, the deposit of the floc particles fill upon the sand grains and the voids between them. Only few inches at the top of sand bed serves as the principal filtering medium. ARMSTRONG (1936) reported that the upper portion of the sand performed most of the removal of suspended materials at the beginning of the run, but as the upper voids became clogged, the loading was taken successively by the lower portions of the filter. This increasing penetration was confirmed by ELIASSEN(1941) who concluded that the entire bed functioned in the removal of the suspended materials.

The Work of Dual and Mixed Media filters

The study of dual media was first carried out by BAYLIS (1930) at Chicago. Because of difficulties in operation and maintenance, it was concluded that the use of antharcite-sand filter was not proven practicable. No significant development of dual media was reported from

1937 to 1960, until CONLEY and PITMAN (1960) concluded, from a filter evaluation program, that the performance of filters containing the proper size and depths of antharcite and sand together were superior to the performance of filters using either material alone. SHULL(1967) successfully used a dual bed filter consisting of 20 inches layer of antharcite coal with an effective size of about 0.90 mm. placing upon 6 inches layer of sand having an effective size of 0.44 mm. HAZELSWART (1966) obtained improved performance over sand alone by using filter bed composed of 2 inches of antharcite coal with 0.90 mm. effective size on top of 24 inches layer of sand having an effective size of 0.55 mm.

To the dual media filter, CONLEY (1965) added one more layer of garnet sand having an effective size of 0.15 mm. to prevent the breakthrough of turbidity when the flow disturbance occured. CULBREATH (1967) demonstrated the feasibility of enlarging capacity of treating raw water of the Williams Creek Plants by changing from conventional rapid sand filter to multi-media filter with better quality effluent. RIMER (1968) found that the trimedia filter resulted in headloss reduction approximatoly 50 percent with no reduction in filtrate quality as compared with the conventional sand filter under the same operating conditions, but the trimedia filter required more wash water and higher rate to clean the bed effectively. LAUGHLIN and DUVALL (1968) concluded, after the investigations at the municipal plant at Greenville, that a clearer effluent was obtained and less wash water was required in mixed-media beds. He also said that the mixed-media beds could operate at a nominal filter rate of 5 gpm per sq ft., and a peak rate of 8 gpm per sq ft and 10 gpm per sq ft in emergencies. MOHANKA (1969), indicated that the filter coefficient was an inverse function of the filtration rate and the filter grain size, and the headloss constant varied with filtering velocity and specific surface. He, agreed with RIMER that more backwash water was required and indicated that there was no surface headloss with flocculant suspension. HARRIS (1970), after trial of new development in California, indicated that 10 gpm per sq ft was not a limiting value for efficient value and the filter demonstrated an ability to filter 55 percent more water than another filter operated at 4 times the rate, through the same amount of headloss. EUNPA (1970) obtained a result after six month observations at Virginia, that an increasing capacity of approximately 20 per cent filtrate as compared to an unmodified unit was obtained and the addition of polyelectrolyte applied to the filters during cold water conditions would improve filter run. Based an the twelve month study for the Sturgeon Point Filter Plant, WESTERSOFF

(1971) made concludsions that the mixed media filters operating at filtration rate of 2 to 10 gpm per sq ft consistently produced a lower filtered water turbidity than the sand media filters operating at filtration rate of 2 gpm per sq ft and the mixed media filters operating 5 to 6 gpm per sq ft used a considerably lower proportion of washwater than the sand filters operating at 2 gpm per sq ft. He also found that the length of filter run was more dependent on total microscopic count than turbidity and the total microscopic count was independent of turbidity.

Filtering Media

The physical differences between the mixed media and other types of filters becomes apparent when the filter cross section in Figure 1, 2, and 3 are compared. Figure 1 illustrates a cross section of a sigle media filter bed. This filter came into general use around the turn of the century and has little changed. Typically, sand media having an effective size between 0.4 and 0.5 mm., is normally operated at about 2 gpm per sq ft. and is cleaned by backwashing. In backwashing process, the reversing of flow to flush out the trapped floc particles causes the hydraulic grading of the sand particles to occur. Because the media is of the same density, the finest sand will

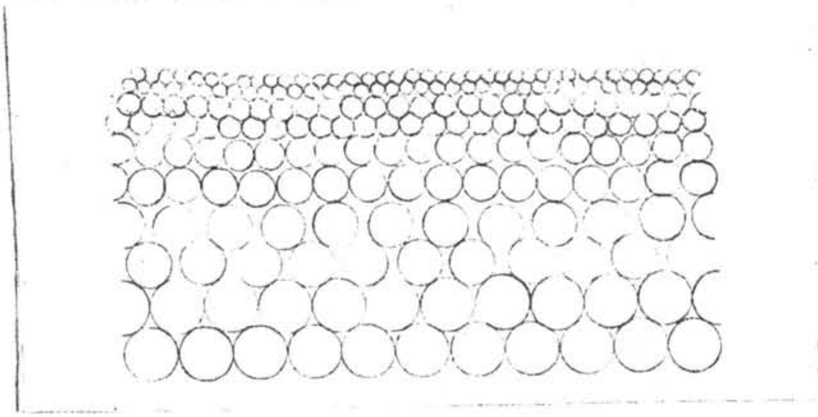

FIG. 1 CROSS SECTION THROUGH SINGLE-MEDIA BED

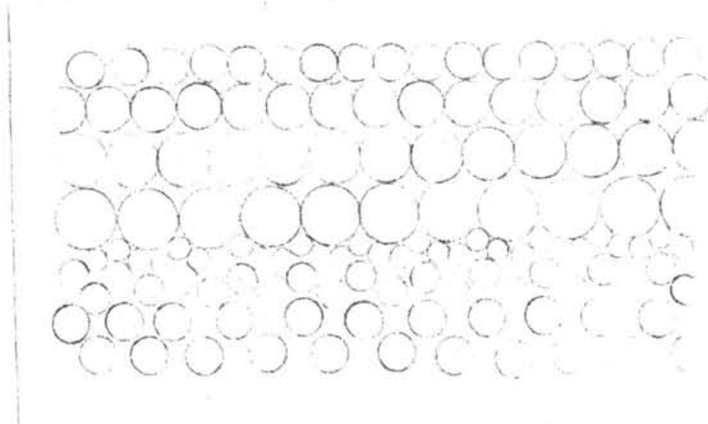

FIG 2 CROSS SECTION THROUGH DUAL-MEDIA BED

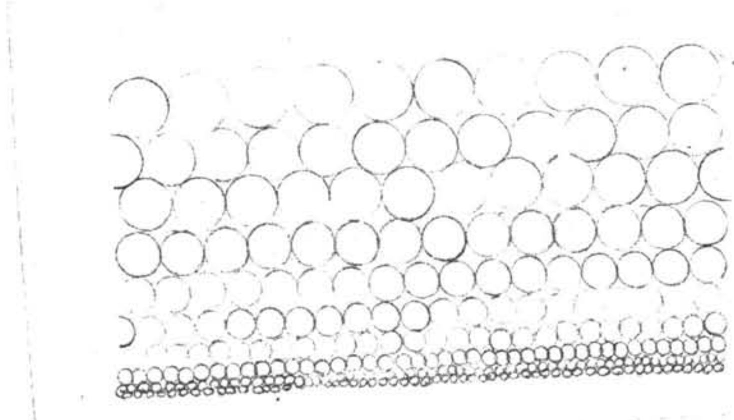

FIG 3 CROSS SECTION THROUGH AN IDEAL FILTER UNIFORMLY GRADED FROM COARSE TO FINE FROM TOP TO BOTTOM.

concentrate at the top of the bed, with the coarser sand particles lying below. The bulk of filtration will be accomplished at the finest part of the bed, that is, in top few inches. Once the floc particle has passed this top layer, its chance for penetrating the entire bed is greatly increased because the filter media becomes coarser, presenting less surface area in the direction of flow. If finer sand is used, the filter has greater resistance to breakthrough and produces a clearer water. On the other hand, headloss increases rapidly, filter runs shorten, and backwash water consumption becomes excessive. Coarser filter media decreases headloss and prolongs filter runs, but at the risk of lower resistance to breakthrough.

Figure 2 represents a dual-media or coal-sand filter, where the effective depth is increased by placing a layer of coarse coal over a layer of fine sand. The work area is extended, although it still does not include the full depth of the bed as there is fine to coarse stratification within each of the layers. The bulk of the filtration is done in the topmost inches of both the coal bed and the sand bed. A particle that escapes the top of the coal tends to pass all the way through the coal, but, if it is the proper size and condition, it will be removed by the top of the sand. Whatever penetrates the top of the sand may well appear in effluent water. Care must be taken in preventing breakthrough by not exceeding optimum filtration rate which ranges from 3 to 5 gpm per sq ft., by not applying turbidities higher than 10 JTU.

In the ideal filter, the size of the particles making up the media should decrease uniformly in size from coarse at the top to fine at the bottom in the direction of flow. Figure 3 represents such an ideal configuration. Because the first media that the water reaches is the coarsest, and the last is the finest, this bed is sometimes called an "upside down" filter. Also, because void spaces between media grains decrease uniformly in direction of flow, the bed is capable of filtering in depth. In such bed, any particles that escape the top inch may be captured in the next inch or further down in the bed and so on. Because filtering with the entire depth of the bed allow storage of large amounts of particulate matter in the bed, this ability results in longer filter runs, faster operating flow rates, the acceptance of higher incoming turbidity loads, or a combination of all three.

The mixed media bed approaches the ideal as closely as can be practically produced. Typically, such a filter will contain 60 per cent coal (1.0 mm. in size, sq.gr. 1.5); 30 per cent silica sand (0.45 mm, sp.gr.2.6); and 10 per cent either garnet or ilmenite (0.15 mm, sp.gr 4.2 or 4.5).

Thus the coarsest material is the lightest, and the finest is the heaviest. Proper size and density ratio between materials are essential, and a carefully controlled fine fraction is included in the two heavier materials. During normal backwash, the materials mix to a degree, and, once so mixed, remain in that condition, The result is a bed which has some of each material at every level with no sharp interface. The upper portion of the bed is pre - dominantly coal with traces of sand and garnet. The center is essentially sand with some coal and garnet. The bottom is primarily garnet with small amounts of the other two. It is this media mixture which forms the coarse to fine gradation in the downward flow direction.

Because the bottom media is quite fine, very high clarity water can be produced. This fine media can operate sucessfully without rapid clogging only because the coarser material above it has removed most of the turbidity before the water reaches the fine material. Investigators in the water treatment field have found that the primery mechanism in particle removal by filtration is the adhesion of the particles to the surface area of the media. Fine sand with a relatively large surface area will be more effective than a coarse sand. Unfortunately, the use of a very fine sand alone will give a rather high headloss buildup and therefore very short filter runs. However, it has been found that only a samll amount of finely sized material is needed to not only promote more efficient filtration, but also to provide greater resistance to flow surges and greatly improved bed stability. Typical flow rate, for such a bed are 5 to 7 gpm per sq ft., although in actual practice rates as high as 10 to 12 gpm per sq ft are used, depending on water source, hydraulic characteristics, and end use. The initial headloss is also reasonable, approximately $1\frac{1}{2}$ ft of water at a 5 gpm per sq ft rate. Filters beds are cleaned by simple water backwash at a rate of about 15 gpm per sq ft.

The Selection of Size and Depth of Filter Media

The best method of selecting the fiter media for a particular plant is by pilot plant tests on the water to be treated. ARMSTRONG (1931) concluded that, for selecting filter media, it was essential to consider two factors: i) From the standpoint of filtration, it was desirable to have media that would a) prevent any floc passing through the filters, b) hold the floc as loosely as possible in order to permit easy washing and prevent the formation of mud deposit, c) hold as large a volume of floc as possible without clogging. ii) From the standpoint of washing, it was desirable to get the media that would a) cleanse itself a nd be free from adhering at the end of a wash, b) permit the passage of water at sufficient velocity to remove all the sediment without losing media.

MILLER (1967) suggested that in multi-layer bed, the media sizes should be chosen with two criteria as follows, 1) the combination of media should give an optimum filtration efficiency, 2) the layers should retain their relative positions during backwashing. Both of these criteria are difficult to define theoretically. The optimum combination of media for floc removal will depend to some extent on the raw water to be treated and the chemical conditions used, due to varied pattern of floc removal. The only certain approach is to carry out pilot or full scale trials on the water in question.

It was found that the most common multi-layer unit includes 18 to 24 inches of antharcite coal over 6 to 8 inches of sand. PITMAN (1961) recommended that the total depth of sand-coal filter should be approximately 30 inches.

CONLEY and SHIUNG (1969) suggested formular for proportioning the different media as follows:

$$\frac{d_1}{x_1} = \frac{d_2}{x_2} = \frac{d_3}{x_3}$$

$$\text{and } x_1 + x_2 + x_3 = 100\ \%$$

where: d = effective diameter of media

x = percentage of media used.

EUNPU (1970), in the testing of high rate filtration in Fairfax Country, Virginia, used antharcite coal 18 inches placing over sand of 7 inches and the lowest media was 3 inches of ilmenite.

The Arrangement of Grains

In order to prevent the abrupt changes of headloss between each layer of media, CONLEY (1965) suggested that specifications for the materials should be set to insure that each material would not lie in a distinct layer, but would mix with adjoining layers. The idea is to have a more uniform taper in the number of media grains from the top of the filter to the bottom, then would be possible with a stratified bed. That is a filter, in stead of being made of three materials lying in distinct lalers, which consists, from top to bottom, of a layer of coal, a layer of mixed sand and coal, a layer of relative pure sand, a layer of mixed sand and garnet, and a layer of relatively pure garnet.

Characteristics of Influent Water

The characteristics of raw water affects the design of multi-media filter plants. It seems possible to avoid coagulation and sedimentation prior to the filtration. ROBECK, DOSTAL, and WOODWARD (1964) suggested that when the water was relatively clear (less than 25 JTU), the flocculation and sedimentation steps of conventional treatment design could be omitted if coarse media were placed on top of the sand. According to the report of MOULTON, BEDE and GUTHRIE (1968), one of the largest direct filtration plants served the Crown Zellerbach Corporation at Wauna, Oregon. This 50 MGD plant obtains its raw water from the Columbia River. Raw water turbidities are normally 2 to 15 JTU although rare peaks of 100 JTU or more occur. The presence of industrial wastes make coagulation difficult. There are no pretreatment facilities for flocculation and settling. The raw water treated with chemicals, passes through a flash-mixer, and applied directly to the filter operating at 5 gpm per sq ft. The media consists of 3 inches of garnet 9 inches of sand and 24 inches of antharcite coal. The result filter effluent turbidities are 0.2 to 0.4 JTU.

SHEA, GATES and ARGAMAN (1971), investigating the possibility of producting a filter water by combining the steps of flocculation, coagulation, and filtration directly in the filter bed, concluded the results that it was satisfied when the suspended solids concentration of raw water was low.

Surface Loading

In the past, great reliance has been placed on the use of low rates filtration in the range of 2 to 3 gpm per sq ft. to insure a safe water. According to BAYLIS (1950) and others, it is believed that the filtration rate is not the most significant factors. It was found that a given filter may operate entirely satisfactory at 8 gpm per sq ft on a water properly prepared, yet fail to produce a satisfactory effluent at 1 gpm per sq ft with water of poor filtrability. With proper attention to these other factors in filter design, MILLER (1967) claimed that increasing in filter rates of a mixed media could be expected to provide greater economic gain than expanding in filter run would.

At a present time, the selection of the optimum filtration rate becomes a matter of economics rather than a question of safety. CLEASBY and BAUMANN (1962) after 3 years of pilot scale research, suggested that the rate that results in a water of acceptable clarity with the maximum overall economy in initial investment and operating costs, should be selected. The operating costs are partially dependent on the water production per run and on the percentage of product used in backwashing. The optimum rate is a rate that results in maximum production per filter run and therefore in minimum backwash percentage. Capital and labor costs have not been included in this optimization. THEERA (1968) found that, by using sand-coal filter, the filtration rate could be extended to 4 to 6 gpm per sq ft (10 to 15 m^3/m^2-hr) while that of rapid sand filter was only about 2 gpm per sq ft. At the South Lake Tahal PUD Plant, surface loading of a mixed media bed of 5 gpm per sq ft is used as the standard rate.

Characteristics of Effluent Water

The turbidity of the effluent from a properly operating filter should be less than 0.2 JTU, according to WHO standards. With the proper pretreatment filtered water should be essentially free of color, iron and manganese. Large micro-organisms, including the algae and amaebic cysts are readily removed, and the percentage removed of bacteria should be above 99 per cent but never 100 per cent. The water must also be chlorinated for satisfactory disinfection. More than 98 per cent of the polio virus is removed by flocculation and filtration at rate of 2 to 6gpm per sq ft.

Headloss

The loss of head through a filter offers several clues to the condition of bed and to proper operation of the unit. An increase in the initial loss of head for successive run over a period of time may indicate clogging of the underdrain or gravel, the need for auxilliary scour, or in sufficient washing of beds. The rate of headloss increasing during a run yields considerable information concerning the efficiency both of pretreatment and filtration.

The simplest form of headloss device for gravity filters is one made up of two transparent tubes installed side by side in the pipe gallery with gage board between graduation in feet. One tube is connected to the filter influent line, the others to the effluent line. The headloss is the observed different in water levels in both tubes.

In U.S.A., a survey of 50 plants shows a median range of 68 hours as the length of filter runs. Of these plants 62 per cent washes at about 8 ft. loss of head. Experiments by HULBERT and FEBEN (1933) at Detroit resulted in the following formula:

$$l = \frac{27}{10^5}\left[\frac{dr\ (73-p)}{S^{1.89}\ (t+20.6)}\right]$$

where l = loss of head in feet.

d = depth of sand in inches

r = rate of flow, mgd per acre

p = porosity (% voids by Jackson Turbidimeter method)

s = sand size in mm. (50% of median sieve size)

t = water temperature, $^{\circ}$F

HOPKINS and BEAN (1966), said that headloss varied directly with rate of flow and depth of bed and inversely with the porosity, temperature, size, uniformity and roundness of the grains. MILLER (1967) found that headloss was more affected by media sizes than by water quality, especially when a filter aid was used, however, coarse media were more susceptible to poor performance during several changes in influent quality.

Backwashing

Since the entire depth of bed is used to remove and store particles removed from the water, the backwash process of the multi-layer filter will be more difficult, especially in case of the tri-media filters, than that of the conventional rapid gravity sand filter. To achieve good results, backwashing is done in steps recommended by MOHANKA (1969). The first step is fluidization of each layer successively, to allow effective cleaning of that layer. The second is an over expansion of the bed to permit flushing out of deposits. If mud balls or heavy, tough alum floc present at the surface of beds, surface washing by air scour or other methods may be required.

CONLEY (1965) stated that the consumption of backwash water was usually 1 to 3 % for plants with settling basins and 1 to 6 % for those without settling basins. THEERA (1968) found that the wash water rise was required for effective backwashing of antharcite-sand filter ranged from 32.1 to 57.3 metres per hour at a water temperature of 30 ^{o}C .