Handbook of Design

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UNDERDRAINS OF ENDURING

VITRIFIED CLAY

Foreword

TRICKLING FILTERS were in use in 3,506 municipal wastewater treatment plants in the United States in 1962, as reported in a statistical summary issued by the U. S. Public Health Service in 1964, the latest compilation available. Of these plants, 2,135 employed standard and 1,371, high rate filters. The total population served by these facilities at that time was 23,006,271. While a single stage filter was used in many cities as the sole secondary treatment process, in over 2,600 plants they were employed in multiple stages or in conjunction with other biological processes as intermediate or final steps. With the increasing need for advanced waste treatment, research is being directed toward taking advantage of the potential versatility of filters in developing processes that will exceed ordinary secondary treatment in performance.

The growth in popularity of trickling filters is illustrated by periodic census studies. In 1940, there were 1,486 plants in use, only a few of which were high rate. In 1945, 1,581 plants were reported, of which 122 were high rate; most of the construction in this war period was for military purposes, municipal construction of wastewater treatment plants being severely curtailed. The 1957 report showed the existence of 1,870 standard rate and 812 high rate filters. From 1957 to 1962, there was an increase of 265 standard rate and 559 high rate filters. None of these figures includes institutional or industrial data. For example, most secondary treatment devices for service areas on major turnpikes employ this method.

The first use of trickling filters of record was in 1889, when the Lawrence Experiment Station of the Massachusetts State Board of Health put two filters into service using gravel media. Their use led to an understanding of one of the essential features of this method of treatment—the slow movement of the liquid in films over the surface of the stones while in contact with air.

Even though these first filters were developed in the United States, English engineers developed the method and the means of applying the wastewater as a spray to the surface of the filter; and, highly important, the use of "false bottoms" to support the media and, at the same time, to eliminate clogging at the filter floor level.

The first trickling filter installation for a city in this country was recommended for Atlanta, Ga., in 1903, but it was not constructed until 1910. However, a small experimental unit had been installed in 1901 in Madison, Wisc., and from this and from test and pilot plants valuable design information was obtained. The plant for Columbus, Ohio, put into operation in 1908, provided 10 acres of filters. Also, in 1908, a one-acre plant was built for Reading, Pa., and another small plant for Washington, Pa. Trickling filters at Mt. Vernon, N. Y., were put into operation in 1910, and the large plant at Baltimore, Md., with 14 acres of filters, was completed in 1911. Other installations were made for the municipalities of York, Allentown and Meadville, Pa., Rome, N. Y., and North Plainfield, N. J.

This growth of use of trickling filters produced operating data on which many improvements have been based. One of the early observations related to the necessity of having a "false floor" to prevent the suspended matter in the wastewater from accumulating on the floor of the filter and interfering with drainage and ventilation. The use of an inverted half-round pipe was probably most common. However, at Baltimore, a series of channels were designed with perforated tile covers.

During the past twenty-five years, the use of clay filter bottom blocks or underdrains has grown and it is a very rare installation where such blocks are not used. The manufacturers making filter underdrains, united in the Trickling Filter Floor Institute, engage in research, improvement of manufacture, development of specifications, and advertising to contribute to the more effective use of trickling filters.

This booklet, the fifth edition of the "Handbook of Trickling Filter Design," is a product of the Trickling Filter Floor Institute in cooperation with PUBLIC WORKS Magazine. Its purpose is to furnish technical data and provide information whereby trickling filters will do a still better and more economical job in waste treatment.

Wastewater Treatment with Trickling Filters

CONVENTIONAL wastewater treatment procedures involve solids removal and stabilization of the organic compounds dissolved in the liquid fraction. The latter step is usually accomplished by biological oxidation, in which a culture of microorganisms "feeds" upon the organics. The devices used for biological oxidation establish *aerobic* conditions to develop the culture and keep it active for maximum effectiveness. This means providing an environment of oxygen or air. Consequently, as a biological treatment medium, a trickling filter is essentially an aeration device and provides very little mechanical removal of suspended solids as the term "filter" might imply.

The adaptability of trickling filters to varying organic and hydraulic loadings has resulted in their wide usage. Many variations in design have been developed capable of producing almost any desired end results. All of these variations, however, appear to retain the ability to operate in cold weather or in hot, or with overloads, with only reasonably skilled supervision.

Certain conditions are necessary for most effective operation. These include: 1) Proper pretreatment of the waste to remove solids, usually attained by passage through a sedimentation tank; 2) reasonably uniform application of the settled waste to the surface of the filter, as by a rotary distributor or spray nozzles; 3) use of properly sized filter media, free from fines and substantially uniform in grading; 4) provision of underdrainage facilities for the prompt and complete removal of the material passed through the filter bed; and 5) assurance of adequate ventilation so that each unit of the filter receives the air needed for the oxidation process.

Filters are classified according to the organic loading for which they are designed, as high rate or standard (or low rate); and by depth, as deep or shallow.

The amount of organic loading, in pounds of BOD applied per cubic yard, 1000 cu. ft. or acre-foot of media determines whether the filter is to be termed high rate or standard. Though there is no definite

Table 1—Abbreviations

5-day Biochemical Oxygen Demand	BOD
Suspended Solids	SS
Gallons per minute	gpm
Gallons per day	gpd
Million gallons per day	mgd
Gallons per person per day	gpcd
Acre-foot = 43,560 cu. ft.	af
Million gallons per acre per day	mgad
Milligrams per liter	mg/L

standard, a generally used loading for a standard filter approximates, as a maximum, 600 lbs. of BOD per acre-foot, 13.7 lbs. per 1000 cu. ft. or 0.375 lb. per cu. yd. Though many standard filters are carrying heavier loadings, they were not generally designed to do so initially. The Manual of Practice, Water Pollution Control Federation lists the standard rate filter range as 5 to 25 lbs. per 1,000 cu. ft. High rate filters are usually designed for an applied loading, based on settled sewage strength, of 2,000 to 3,000 lbs. per acre-foot or 1¼ to 1¾ pounds of BOD per cu. yd. However, the WPCF Manual of Practice gives the range as 25 to 300 lbs. per 1,000 cu. ft., which is 1,090 to 13,100 lbs. per acre-foot.

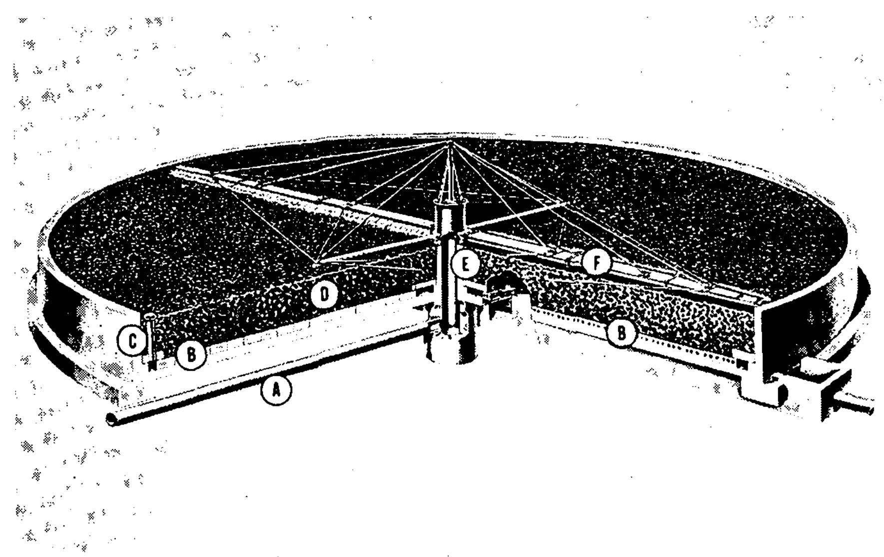
Just as in the case of organic loading, there is no clear line to distinguish deep from shallow filters. A generally used standard in respect to depth considers a filter in which the media is less than 4.5 ft. in depth as a shallow filter; and one with media more than 4.5 feet in depth as a deep filter. The depth is the average distance from the top of the underdrain floor to the top surface of the filter media.

Definitions and Abbreviations

For the purpose of this text, the abbreviations shown in Table 1 will be used. Definitions of other terms used are as follows:

The *organic load* on a filter is the BOD content in pounds that is *applied* to the filter. It is usually the BOD content of the raw sewage less the BOD that is removed by the pretreatment devices such as screens and clarifiers. For instance, if the sewage flow is 1 million gallons per day and the BOD of the raw sewage is 240 mg/L, the total BOD will be 2,000 pounds. If 30 percent is removed by primary treatment devices, the organic load applied to the filter will be 2,000 x 0.70 = 1,400 pounds BOD.

The *volume* or *hydraulic* loading on a filter is the amount of sewage or waste applied to it, computed on



Courtesy W. S. Dickey Clay Mfg. Co.

■ **ALL elements of a trickling filter are shown in this cutaway view. A is the influent line; B, the drainage floor; C, a vent; D, the media; E, distributor feed column; and F, the rotary distributor. The various functions are described in detail in the text.**

the basis of millions of gallons per acre of filter surface per day. If the sewage flow is 1 mgd and this is applied to a filter which has a surface area of 0.10 acre, the volume loading will be 10 million gallons per acre per day.

A *single-stage* filter is one in which treatment is accomplished by one or more passes of the sewage through the filter. This term is usually restricted to high rate filters using recirculation. If there are two or more filters in a single-stage plant, these filters are operated in parallel. In a *two-stage* filter system there are two filters in series, with the effluent from the first or primary filter being passed through the secondary filter. Recirculation is usually employed on both filters. Large two-stage treatment plants may have four, six or more filters, each pair of them working as a team.

Recirculation is the return of a portion of the sewage or waste which has already passed through the filter, and sometimes also has been settled, for another passage through the filter. This return may be directly to the filter or it may be to the inlet of the primary settling tank.

The *primary clarifier, primary tank* or *primary settling tank* is the sedimentation device ahead of the filter which pretreats and prepares the waste for application to the filters. An *intermediate clarifier* or *tank* is the sedimentation device between any two filters. A *secondary clarifier* or *secondary* or *final settling tank* is the sedimentation device following the final filter. This usually provides the final treatment for the waste except for chlorination.

In considering trickling filters, the filter or filters and the following clarifier should always be considered as a unit in both design and operation. There is no place in sewage treatment for a trickling filter without a final clarifier in which to settle the filter effluent. (This does not apply to the first stage filter of a two-stage filter system.)

Other Units of Expression

Hydraulic load, including recirculated flow if used, is in gallons of flow per square foot of surface area of the filter. The standard rate filter range will be 25 to 100; the high rate range will be 200 to 1,000. The rate in million gallons per acre per day multiplied by 23 will give gallons per square foot per day. Thus a rate of 20 mgad equals 460 gsfd.

The rate in pounds of BOD per acre foot per day multiplied by 0.023 equals the pounds of BOD per 1,000 cu. ft. per day. Conversion from pounds of BOD per cubic yard per day to pounds of BOD per 1,000 cu. ft. per day is accomplished by multiplying by 37. Thus 2,420 pounds of BOD per acre foot, multiplied by 0.023 represents 55.6 pounds per 1,000 cu. ft., as does the equivalent 1½ lbs. per cu. yd. multiplied by 37. For high rate filters, the recirculated flow is not considered in contributing an additional BOD load.

Percentage of recirculation equals recirculated flow divided by waste flow multiplied by 100. The standard rate filter range is 0 to 50 and the high rate range is 25 to 300.

Courtesy Koppers Co.

■ **TYPICAL distributor in operation at Salisbury, Md. wastewater treatment plant.**

Comparison of Filter Types

There is no essential difference in construction between the high rate and the standard or low rate filter. The same media, the same underdrains and the same ventilation facilities are provided in either case. The distributors are essentially the same, except that those used for high rate filters must be designed for larger volume rates of application. The potential BOD removal appears to exist in every filter; the rate and method of application of the sewage to the filter determines how and to what extent this potential is utilized. The high rate filter, because it is loaded much more heavily—the BOD loading may be three to six times as great as that on the standard rate filter—is correspondingly smaller and usually costs less to build.

There are differences in the quality of the effluents from high rate and standard filters. The latter produce a higher degree of nitrification, so that strengths of effluents from the two types of filters, stated in milligrams per liter of BOD, cannot be directly compared. This is especially true of single-stage high rate filters; two-stage high rate filters may produce some degree of nitrification. However, local conditions usually govern in determining the degree of treatment needed and the actual reduction in the organic load discharged to the stream is a most important factor.

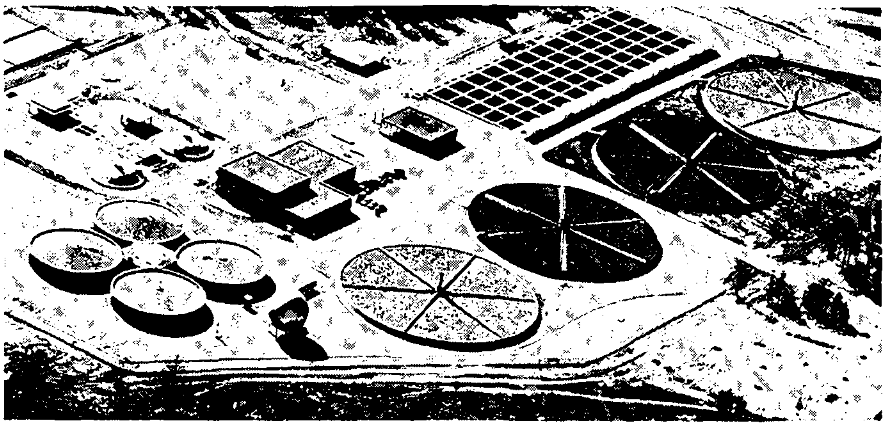
If local conditions dictate the selection of a plant to produce an effluent low in BOD, well nitrified and highly stable, full consideration should be given to a deep filter and a low rate of loading. If a less completely stabilized effluent is permissible, with a slightly higher BOD content, a single-stage high rate filter may be selected because it is usually lower in initial cost. If the waste is very strong and a good effluent is necessary, a two-stage filter may be preferable, since this combines many of the cost-saving features of the single-stage high rate filter with an effluent that may approach that of the standard filter in BOD content.

Pre-Treatment

Standard practice is to provide pre-treatment ahead of filters by means of settling tanks, either round or rectangular, equipped with mechanical apparatus for removing the sludge and preceded by a comminutor and properly cleaned screens.

Standard practice usually provides for a detention period of about two hours in the primary settling tank for design flow plus recirculation, in the case of a high rate filter. However, there is considerable variation in requirements among the several states and the applicable regulations should be determined and followed.

Surface overflow rates, tank depths and other factors are also subject to state regulations and



Courtesy P.F.T. Div. Rex Chainbelt, Inc.

■ **AERIAL view of Winston-Salem's treatment plant and four 200 ft. diam. filters.**

these may vary materially among the states.

In the treatment of cannery wastes and creamery products, some engineers use a fine screen and a small equalizing tank for pre-treatment instead of the usual primary tank. This is based on studies and observations which indicate the "microbial forest" on the filter media can treat any material not large enough to interfere with the application of the sewage to the filter.

Intermediate and Post-Treatment

Intermediate clarifiers have been used in a relatively small number of plants. They are of most value where the sewage or industrial waste is very strong. Detention periods are usually somewhat less than for primary clarifiers.

The secondary clarifier is the key factor in the design of filters for best operation. It is not the function of the filter to remove suspended matter, but to change this to a relatively stable form. This material, and the spent gelatinous film which sloughs off the filter media, continuously in the high rate filter and from time to time in the standard filter, must be removed by the clarifier.

As with primary tanks, the detention period, overflow rate, weir overflow rate and tank depth of the secondary clarifier are subject to state health department regulations. In general, detention periods of 2 to 3 hours should be provided for design flow plus recirculation, if the secondary clarifier is involved in the recirculation process. Where recirculation is used, the necessary volume may be taken from a launder installed in the secondary tank.

Effects of Temperature

Trickling filters operate better and produce better effluents in warm weather periods. However, though they are affected in some respects by low temperatures, extreme cold is necessary to create any serious adverse effect. In the North Central States, it is fairly standard practice to provide covers, either of prestressed concrete or of wood, for filter units, for experience has shown that operating results are improved and troubles from icing are eliminated.

Cold weather effects may be of two kinds: 1) the surface of the filter may become iced; and 2) the efficiency of the filter in respect to BOD removal may be impaired.

In ice formation, to which snowfall may contribute, wind appears to be an important factor as it drives spray to the downwind side where deposits may build up. However, difficulties are restricted to the really cold areas. No such troubles were reported in the operation of uncovered filters at more than 300 Army posts during World War II, though some of these were located in low temperature areas.

It is good practice to provide bleed valves in the distributor support posts of rotary distributors and in the distribution system of spray nozzle installations so as to prevent freezing and consequent damage if the flow of sewage stops or becomes so small that the dosing siphons work only at long intervals. In some plants, a small pipe is tapped into the feed pipe at the distributor base and is left open all winter.

To determine the effect of temperature on the efficiency of BOD removal by low rate trickling filters, the records of nine military sewage treatment plants were studied by a Sub-Committee on Waste Disposal of the National Research Council. These were all standard rate plants. Results obtained in July, August and September of 1943 were compared with results in December, 1943, and January and February, 1944. With adjustment for differences in loading during the two periods, there was a small but significant drop in efficiency during the colder months during which the air temperature averaged 38.1°F lower than the summer months. The subcommittee reports that: "With military sewage of the usual concentration, this difference in efficiency results in effluents with a BOD about 20 percent larger in winter than in summer."

On this basis, it was estimated that a filter should be about 43 per cent larger if it is to operate as well at an average temperature of around 40°F as the normal filter will operate during the warm summer months. The army designs of World War II specified that filters in the northern states should be 25 percent larger than those in southern areas.

Under the best of conditions, some time is required to build up the biologically active film necessary on the filter media. The time required depends on the temperature and probably on a variety of local conditions. Usually 3 to 4 weeks are required. If the plant is started late in the fall, when air and sewage temperatures are low, an even longer period will be required before adequate treatment results can be expected. A change from high rate to low rate operation, or vice versa, will probably require 4 to 6 weeks to develop the proper biological growth. Changes in rate of loading are also likely to require considerable periods before results truly reflect the change.

Applicability

Trickling filters are applicable to weak or strong domestic wastewaters and to many types of industrial wastes. By utilizing recirculation, whereby the incoming sewage is reduced in strength, even exceedingly strong wastes can be treated satisfactorily and economically. Recirculation may be applied to either high rate or standard filters. High rate and standard filters may be combined in a single treatment plant, a procedure especially adaptable to the production of an excellent effluent. In such cases, the high rate filter is used as the primary filter to remove as much as possible of the organic load; and the effluent from the high rate filter is applied to the standard filter. Final treatment, following the high rate filter, may also be provided by an activated sludge plant. In either case, the high rate filter markedly reduces the organic load on the secondary unit and delivers to it a waste of uniform strength.

Media, Drainage and Ventilation

THE five essential elements in a trickling filter are the base support; the underdrain blocks which carry off effluent and provide ventilation; the containing wall; the media to support the growth of microorganisms; and the distributor for applying settled wastewater to the filter.

Filter Floor and Center Channels

The floor should provide a firm and uniform base on which to build the remainder of the filter. It should be of concrete, poured on a well-compacted earth base. Since the load carried by the floor is not great, a concrete thickness of 4 to 6 inches is ample. Light reinforcement is desirable for not only must the floor be uniform initially to facilitate good drainages, but it must retain that uniformity for the life of the plant. The floor may be poured in one run, or there may be joints. If used, joints should run in the direction of the floor slope, and reinforcing dowels should be carried through the joints. Floor slope toward the drain channels should be not less than 2 in., for any semi-diameter, and is usually about 0.3 ft. per 100 ft. There are various designs, but the most common practice involves bisecting the filter floor with a center channel toward which the two halves of the filter slope.

Precise analysis of the flow in the center channel is difficult because of the interference with the flow due to the discharges from the many underdrains entering at right angles to the main flow. Generally, satisfactory capacity will be provided by a cross-section and a slope that will, as determined by the usual flow formulas or charts, carry the maximum possible flow that may occur with the liquid surface in the channel slightly below the bottom of the underdrain channels.

Design of center channels differs somewhat for shallow high rate filters and for standard rate deep filters. In a shallow filter, the feed pipe for the distributor must generally pass under the filter floor and up through the distributor support. In the standard rate deep filter, the feed pipe is usually passed through the body of the media. This is largely because of the relative sizes required for the feed. In a standard rate filter 100 ft. in diameter with a rate of surface application of 2 mgad, the flow to the filter will average 0.36 mgd, which can be carried by an 8-inch pipe (or even a 6-in.). In a high rate filter, of the same size, using a surface rate of application of 20 mgad, the feed pipe will have to carry an average of 3.6 mgd and a 16-in. or 18-in. pipe is required. If it is necessary to conserve head, an even larger pipe may be used. The larger pipe would block off an undesirably large portion of the filter if the pipe were carried through the media instead of beneath the floor.

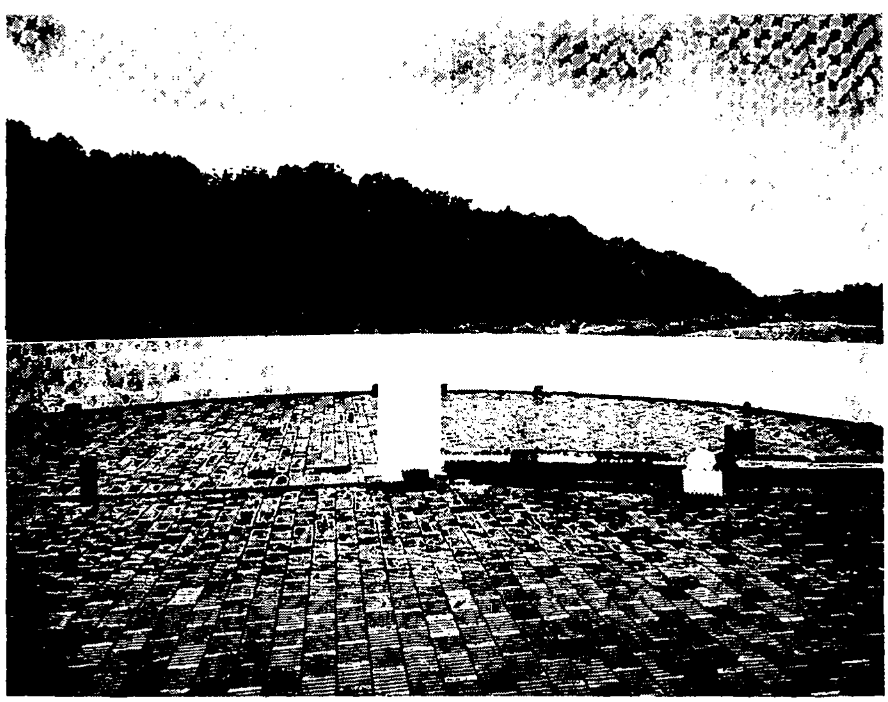
The center channel in the standard rate filter can be smaller because it carries a lesser volume of wastewater. As a result, it is often passed through the distributor support, though sometimes split or carried around it. In the high rate filter, the center channel must be larger and consequently cannot be carried through the distributor support. It is common practice to offset the channel from the center enough to clear the support column. A few large filters have been built with two channels and fewer have used peripheral channels, the floor sloping to the circumference.

Center channels may be rectangular in cross section or the bottom may be semi-circular. In either case, channel covers are necessary to support the superimposed media. These covers will be described under a later heading.

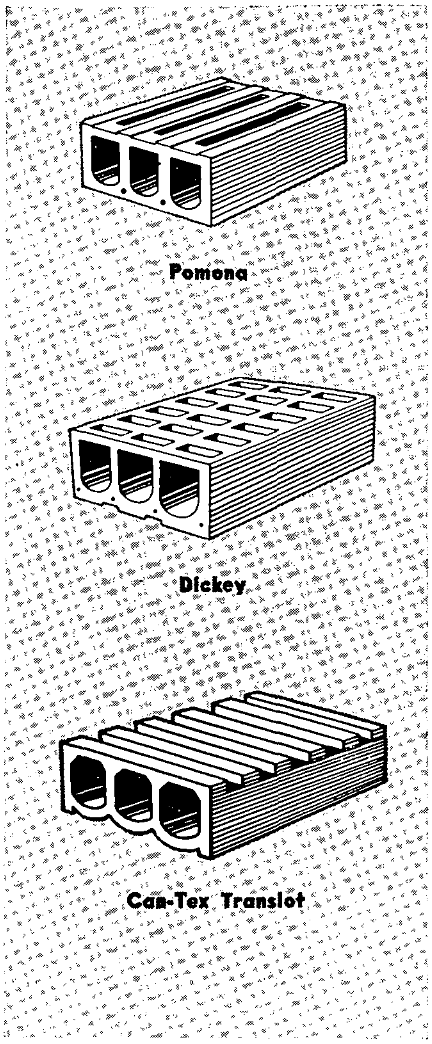
To facilitate cleaning and inspection, the center channel may be extended through the filter wall at both ends, terminating at the upper end in a small open box covered with a grating. The box should be of sufficient size to permit entrance.

The value of ample ventilation is proved by the excellent operating records of many filters where vitrified clay underdrain blocks have been used. Some engineers add vertical vent pipes around the inner circumference of the walls at the periphery of the filter and others also extend the drainage ducts through the filter walls. This is advantageous if provision for flushing of the channels is desired, as when industrial wastes are treated.

The absolute necessity for adequate drainage and ventilation in a



■ **DICKEY high-rate blocks were used in the trickling filter at Springdale, Ark.**



■ STANDARD rate filter underdrain blocks made by the member firms of the Trickling Filter Floor Institute. All are made to conform to ASTM specifications given in this Handbook and are of corrosion resistant vitrified clay.

trickling filter should be recognized. Complete systems of vitrified clay blocks are laid directly on the filter floor. These units are not affected by the action of wastewater and thus are as long lived as the filter itself. The units of these systems are quadrangular prisms having openings in the upper face which collect the wastewater passing through the filter. Ample conduit capacity is provided for rapidly discharging the effluent, and for admitting air into the filter for ventilation and aeration. The blocks are laid on a thin layer of grout or of dry mortar, rapidly and precisely, so that the drainage channels are automatically aligned. The strength of the blocks is greatly in excess of that required under any condition of service. ASTM specifications for these blocks are given on pages 9 and 10.

Underdrain Blocks

Underdrain blocks differ in design primarily according to use in standard or high rate filters. The latter are deeper and have channels of greater capacity for carrying off the filter effluent. Actually, the standard blocks have the ability to handle any application rate up to 50 mgad on a 200-ft. diameter filter, but the high rate blocks provide additional space for air penetration into the filter and are preferred by some engineers, especially for industrial waste applications.

The blocks described below comply with all requirements of ASTM Specification C159. All blocks are of vitrified clay which experience has shown to be resistant to all elements in either domestic or industrial wastewater; to have excellent flow characteristics because of the smooth surface; and to resist attachment of growths which might tend to clog the ventilating openings or flow channels.

Standard Blocks

DICKEY, made by the W. S. Dickey Clay Mfg. Co., are 18 in. long, 11¾ in. wide and 4¼ in. deep, with 18 top openings.

POMONA, made by Pomona Pipe Products, are 13½ in. long, 12 in. wide and 5⅛ in. deep.

TRANSLOT, made by Can-Tex Industries, Inc., a division of Harsco Corp., are 11¾ in. wide, 18 in. long and 4¼ in. deep.

High Rate Blocks

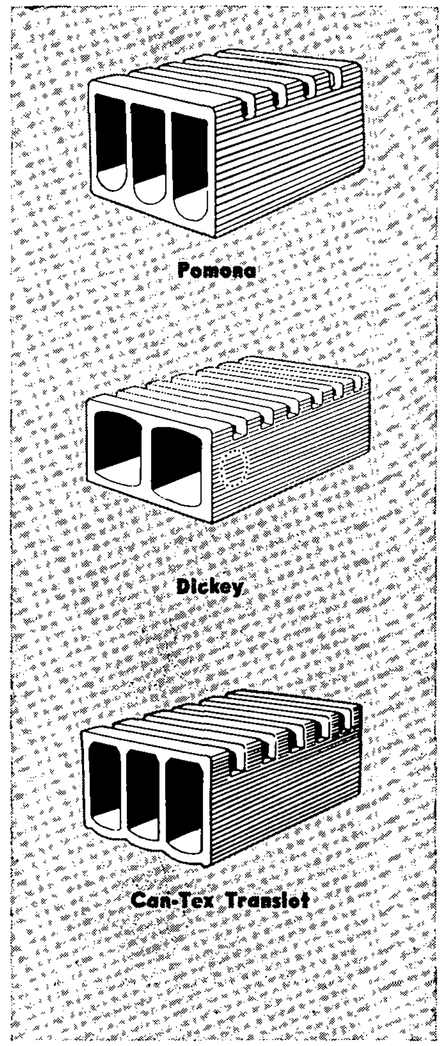
TRANSLOT "Hi-Rate" blocks are 18 in. long, 11¾ in. wide and 7¼ in. deep. They have three flow channels and five transverse top slots. These are made by Can-Tex Industries, Inc., a division of Harsco Corp.

POMONA "Rapid-Flo" high rate blocks are 13½ in. long, 11⅝ in. wide and 7¼ in. deep, with three slot openings 1⅜ in. wide—made by Pomona Pipe Products.

DICKEY, made by W. S. Dickey Clay Mfg. Co. are 18 in. long, 11¾ in. wide and 7½ in. deep with two flow channels and six transverse top slots.

It is important to insure in the specifications the use of good materials and installation methods. A specification which will assure good underdrainage construction follows (the latest ASTM standard revision number should be used).

Underdrains—The contractor will furnish and install vitrified clay underdrains as shown on the plans. These shall be laid in a dry mortar bed, on the floor of the filter before



■ HIGH-RATE filter blocks made by members of the TFFI. These high-rate blocks feature deeper channels by two inches or more than those used in the standard-rate filters. In all other respects, the blocks are quite similar.

the stone is placed. Underdrains must comply with standard specifications ASTM C159, and shall be equal and similar to those manufactured by members of the TFFI. The mortar shall consist of sand and cement, 1 cement to 6 sand. After the underdrains are laid and before the stone is placed, the dry mortar bed shall be wetted by sprinkling. Blocks must be laid in true alignment, with cross joints staggered in longitudinal rows at right angles to the center drains.

Angles, Cover Blocks, Ventilation and Laying

For use in circular filters, blocks cut to 22½°, 30°, 45° and 67½° are available to match approximately the curvature of the filter walls, and cross-sections at the pier, effluent channel and perimeter wall.

Also short sections of standard blocks are provided to fill out runs and eliminate the necessity for cutting blocks on the job. Vent blocks to support pipe riser vents to the surface of the filters are furnished; and also wall reducers for carrying ventilation ducts through the filter walls for use where flushing or added ventilation is deemed desirable.

In ordering blocks for a filter, it is necessary only to provide the manufacturer with a plan of the filter, showing essential dimensions. Shipments of blocks are then made with the correct number of straight blocks, angle blocks, short sections, specials and cover blocks.

Guidance in laying is also provided by the manufacturers to insure good practice with the minimum labor requirement.

Standard cover blocks for the center drainage channel are normally limited to 30 in. in length. At least 3 in. of bearing should be allowed at either end. If it is necessary to provide a center channel wider than 24 in., either a central support should be used or a special channel cover designed.

Filter Design Details

Filter depths range all of the way from 3 ft. to 10 ft. Recently experimental work has been carried on with filters up to 24 ft. deep; and some deeper test units have been built. Low rate filters, however, are usually designed with minimum depths of 5 to 6 ft., and with a maximum of 9 to 10 ft.; most are about 6 ft. deep, which depth is more or less standard. High rate filters vary quite widely. The Biofilter is designed with depths all the way from 3 to 6 ft., but 4 to 5 ft. is probably most used. The Aerofilter is normally not less than 6 ft. deep and may be deeper. The Accelo filter is normally 6 ft. The depth function depends much on local topography and on cost factors. No matter what the depth or what the volume loading, the underdrains previously described have ample load, drainage and ventilation capacity. That is, they are strong enough to carry the weight of the deepest filter, with a very wide margin of safety. The drainage channels are sufficiently large to handle properly the flows from a filter 200 ft. in diameter operating at a volumetric rate of 50 million gallons per acre per day. The top openings are ample in size to provide the necessary air to insure good operating results.

Much experimental work has been done in attempts to improve filter operation by blowing air through the media; even oxygen has been used. No results have been obtained which indicate that added ventilation, over and above that provided by the standard vitrified clay underdrains, is helpful in better operation.

Wall Construction

Most walls for filters have been of reinforced concrete. When used, such walls are reinforced circumferentially, using the hoop formula for design, with some vertical reinforcing extending into the footing. Walls of this type are usually 8 to 12 in. thick.

It has been proposed to construct filters without walls, allowing the filter media to seek its angle of repose. It will generally be found that such construction is not economical. The additional stone required for the peripheral unused filter media, plus the cost of extending the filter floor out to the toe of the slope of the stone, will usually exceed the cost of constructing walls to retain the stone. Moreover, experience has shown that this marginal area of stone, which is partly or occasionally wetted is liable to be a producer of filter flies.

Filter Media

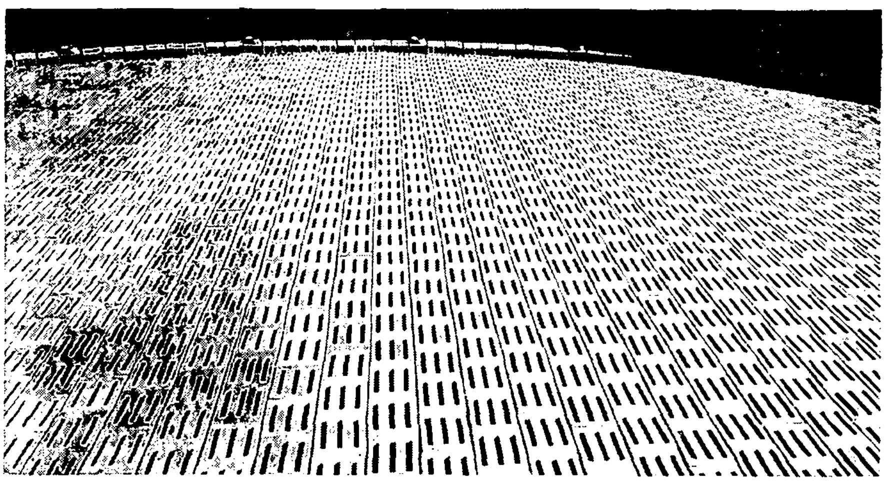
Crushed stone is the most widely used media for trickling filters. Crushed slag is also used, especially in areas where it has a price advantage over stone. Rounded gravel is sometimes used but some reports indicate it does not give as good results as do the angular aggregates resulting from crushing. However, in other plants well-graded gravel has produced excellent effluents, although an approximately cubical shape appears preferable. Federal specifications SS-S-448 require media "as nearly equidimensional as possible. Pieces that are elongated or flat, or both, shall not exceed 10 percent by weight. These shapes are defined as having length exceeding width, and width exceeding thickness in ratio of more than 1.5 to 1.0, dimensions being maximum for the size of pieces under consideration."

The media should be free of fine particles, grease and oil and should be properly screened and washed to remove dust and dirt before placement in the filters. Even with washing, enough sand and fine stone particles may remain to cause trouble when filter operation is begun. Unless precautions are taken to prevent it, fine inorganic material will be carried to the secondary clarifier and thence to the digester, where it may cause further operating difficulties. In extreme cases, the mixture of sludge and dust may clog the sludge lines. It is good practice for the designer to make provision, either temporary or permanent, to permit the filter effluent to be bypassed around the secondary clarifier until after a sufficiently long operating period to assure that all fine particles have been removed. Slag media should be free from all free iron.

Media Specifications

There are differences of opinion in regard to stone and slag media size. The modern trend is toward use of larger aggregates—2½-inch minimum. Uniformity is also important, and particles smaller than the lowest limit should not exceed 10 percent by weight of the total.

Federal Specifications SS-S-448 state that the filter media shall be as uniform in size as possible and, when tested with standard laboratory sieves having square openings,



■ **POMONA Rapid-Flo floor block in a 93-ft. dia. high rate filter at Lynchburg, Va.**

Table 1—Federal Specifications for Filter Media Grading Sizes

(Specification SS-S-448, Int. Amendment-1)

Nominal Size (square openings in inches)	Amount Passing Sieve (square openings) percent by weight						
	4 in.	3½ in.	3 in.	2½ in.	2 in.	1½ in.	1 in.
3½ to 2½	100	90-100	.....	0-10	0-5	...	..
3½ to 2	100	90-100	.....	.....	0-10	0-5	..
3 to 2	100	100	90-100	.....	0-10	0-5	..
3 to 1½	100	100	90-100	.....	...	0-10	0-5
2½ to 1½	100	100	100	90-100	...	0-10	0-5

shall conform to the gradings shown in Table 1 of this text. Any of the first three sizes given are preferable to the smaller sizes, for domestic wastewater.

Commercial aggregate specifications are now generally based on the use of screens having square openings. Federal SS-S-448 has been cited. ASTM specifications C88, C136 and D75 apply to aggregates and include grading, soundness, wear and other factors.

In recent years, other materials have been developed by certain manufacturers. Among these are plastic sheets (polystyrene or polyvinyl chloride) and redwood slats. The plastic sheets are assembled in "honeycomb" modules small and light enough to be placed by hand. Corrugated or alternate corrugated and flat sheets are used. The modules have an effective surface area of 27 sq. ft. per cu. ft. and have greater than 90 percent void space. The weight is 2 to 3 lbs per cu. ft. Advantages are light weight, ease of placement and superior ventilation qualities. These permit the construction of deep filters—up to 40 ft. PVC modules are made by Dow Chemical Co., B. F. Goodrich Industrial Products Co. and Ethyl Corp.

The redwood slats are also available in module form. These are rough sawed to provide purchase for biological growth. They are ⅜ in. thick, 1½ in. wide and either 35½ or 47½ in. long. Spacing is 0.69 in. between edges. They are furnished by Del-Pak Corp.

Placing the Media

No generally acceptable method of placing the media in the filter has been developed which will insure that pockets of fines do not occasionally occur in filters. If these are deep in the filter, they may reduce filter capacity and effluent quality. However, shallow surface ponding is not always due to such fines and often does not affect the operation of the filter. In view of the excellent operating results obtained from so many filters, it is probable that usual methods of controlling fines are adequate. However, it should not be forgotten.

The methods used in placing media in the Fort Worth filters represent very good practice. The specifications required that, in the placing of the filter media, breakage and segregation and the entrance of fine particles into the filter "shall be prevented. Media shall be placed in the filter using a belt conveyor, by boxes, or by other approved methods, which method does not require traffic of any type over the top of the stone placed in the bed, whether on the stone or on mats placed on the stone." It was also required that "immediately prior to final placing, the media shall be passed over a suitable screen with not less than 1-inch square openings."

■ CHANNEL block made by Can-Tex Industries being placed in one of the filters which serves the Central Sewage System of the Trinity Valley Authority near Dallas.

Distributors

Rotary distributors, which are made for all sizes of filters from the smallest to the largest, are generally used for distributing the sewage over the stone. Spray nozzles are also available for rectangular installations and special disc distributors for some types of small filters. The rotary distributor has the advantage —important in most plants—of requiring very little head for its operation.

Rotary distributors are made by the following firms: Ralph B. Carter Co.; Dorr-Oliver Inc.; Eimco Corp.; General Filter Co.; Infilco Div. of Fuller Co.; Water Pollution Control Div. of Keene Corp.; Lakeside Engineering Co.; Link-Belt Div. of FMC Corp.; Pacific Flush Tank Div. of Rex Chainbelt Inc.; Smith and Loveless; Walker Process Equipment; and Yeomans Bros. Nozzles for rectangular filters are furnished by Pacific Flush Tank Div. Special disc distributors are made by Lakeside and Yeomans.

Any of these manufacturers will supply the detailed drawings covering the installation of equipment.

…DARD

SPECIFICATIONS

for vitrified clay filter block for trickling filters

ASTM DESIGNATION: C 159–63

(Engineers using these specifications should check with A.S.T.M. to make sure they have the latest edition.)

SCOPE

1. These specifications cover vitrified clay filter block made from clay or shale or mixtures thereof.

TYPES

2. **(a)** Two types of filter block are covered:

Type I.—A one-piece filter block suitable for use in constructing a single-course trickling filter floor, that provides continuous drainage channels or ducts through the lower portion of the block for conveyance of liquids from the filter bed, and drainage and aeration grilles in the upper portion of the block for passage of liquids from, and air into, the filtering media.
One-piece filter block shall include: Type I-S, standard-rate block, and Type I-H, high-rate block.

Type II.—A two-piece filter block system suitable for use in constructing a two-course trickling filter floor, that provides drainage and aeration. When placed or assembled, a course of the lower pieces or units forms continuous drainage channels or ducts for conveyance of liquids from the filter bed and for passage of air into the filter bed. An assembly of the upper units forms drainage and aeration grilles for passage of liquids from, and air into, the filtering media.

(b) When in position of use both types of block shall completely cover the floor of the trickling filter bed.

(c) The purchaser should specify whether block shall be type I-S (standard-rate), type I-H (high-rate), or type II.

COMPRESSIVE STRENGTH

3. **(a)** The average compressive strength of five full-size filter blocks shall be not less than 600 psi, based on gross area of the block, with the load applied in the same direction as in service. No individual block shall have a compressive strength less than 500 psi.

(b) Both component units of type II systems, tested individually, shall conform to the compressive strength requirement of Paragraph (a).

ABSORPTION

4. The average water absorption of five filter block, by 1-hr submersion in boiling water, shall not exceed 6 per cent of the dry weight of the block.

ACID RESISTANCE

5. Filter block shall be acceptable only when the percentage of acid-soluble matter for specimens representing such block does not exceed 0.25 per cent by weight.

SHAPE

6. **(a)** Type I filter block shall be square or rectangular in plan, as laid. When placed in parallel rows on the subfloor of the filter bed, cells in a single course of type I filter block shall form continuous drainage ducts, and the apertures or slots shall provide for drainage and aeration of filter media.

(b) Units for the lower or drainage course and units for the upper or aeration course of type II filter block shall be square or rectangular in plan, as laid. When placed in parallel rows on the subfloor of the filter bed, the lower units shall form continuous drainage channels. Upper units, when laid in parallel rows on lower units, shall provide for drainage and aeration of filter media.

PERMISSIBLE VARIATIONS IN DIMENSIONS

7. **(a)** Length, width, or height of a type I filter block shall not vary by more than 1/4 in. per ft. over or under the nominal dimension stated by the manufacturer.

(b) Lower drainage channels and upper aeration grilles of type II block shall not vary by more than 1/4 in. per ft. over or under the nominal dimension stated by the manufacturer.

FOLD FLAP OUT ➧

APERTURES

8. **(a)** Apertures in the top of type I filter block shall be not more than 1½ in. in width, but may vary in length. Aperture area shall be not less than 20 per cent of the top area of the filter block when in position of use.

(b) Apertures in the top, or aeration course of type II filter block shall be not more than 1¼ in. in width, but may vary in length. Clear unobstructed aperture area shall be not less than 30 per cent of the top area of the block when in position of use.

Table I.—Cross-Sectional Drainage Areas

	Minimum Effective Area, Sq. in. per foot of Width
One-piece systems:	
Type I-S, standard-rate	20
Type I-H, high-rate	40
Two-piece systems:	
Type II	20

SHELL AND WEB THICKNESSES

9. **(a)** Exterior walls (shells) of type I filter block shall be not less than 9/16 in. in thickness, and interior webs shall be not less than 1/2 in. in thickness.

(b) Exterior walls (shells) and interior webs and struts of type II filter block comprising the lower or drainage course shall not be less than 9/16 in. in thickness. Exterior walls (shells) and longitudinal webs of type II filter block comprising the top or aeration course shall be not less than 1⅛ in. in thickness. Stiffening webs for stiffening the longitudinal webs, shall be not less than 9/16 in. in thickness.

DRAINAGE CHANNELS

10. **(a)** Effective cross-sectional drainage area shall be defined and measured as the sectional area lying below the lowest level of the aperture slots. Aggregate effective cross-sectional area of drainage channels in a filter block shall be not less than shown in Table I.

(b) The bottom of the drainage channels of any filter block shall be curved or narrowed in width to form a trough in the bottom of each channel to accelerate flow of effluent and to minimize stranding of solids in such channels.

(c) The height of drainage channels in any filter block shall be not less than 2½ in., measured from the lowest level of the aperture slots.

(d) There shall be not less than two parallel drainage channels per foot of width of a type I filter block.

WORKMANSHIP AND FINISH

11. **(a)** Filter block may be either glazed or unglazed. If glazed filter block are specified, at least 90 per cent of the inner and outer surfaces of the block shall be covered with glaze, excepting the wire-cut ends where it may be entirely absent.

(b) The lower bearing surface of filter block shall not vary from a plane by more than 3/16 in. per foot of the greatest length or width of the block.

(c) All filter block shall be well burned and substantially free of laminations and fractures. All block shall be free of open cracks exceeding $1\frac{1}{2}$ in. in length (such cracks shall not extend completely through a connecting portion of the web or shell), and shall be free of other cracks exceeding 3 in. in length that do not extend through the webs or shells. All block shall be free of chips larger than 2 by 1 by 3/16 in. and of blisters whose diameters exceed 2 in. and which project more than $\frac{1}{8}$ in. above the normal surface.

MARKING

12. All filter block shall bear the name, initials, or trade-mark of the manufacturer and shall be marked to show compliance with ASTM Specifications C 159. These marks shall be indented on the exterior of the block and shall be legible.

REJECTION

13. If test specimens fail to conform to requirements for compressive strength, absorption, or acid resistance, the manufacturer may sort the shipment, and new samples shall be selected by the purchaser from the retained lot and tested at the expense of the manufacturer. In case the second set of test specimens fails to meet requirements, the entire lot shall be rejected.

EXPENSE OF TESTS

14. Except as specified in Section 13, expense of inspection and testing shall be borne by the purchaser.

SAMPLING AND TESTING

15. (a) The purchaser or his authorized representative shall be accorded proper facilities for sampling and inspection of filter block, both at the place of manufacture and at the site of the work. At least ten days from the time of sampling shall be allowed for completion of tests.

(b) Filter block shall be sampled and tested in accordance with the Methods of Sampling and Testing Structural Clay Tile (ASTM Designation: C 112), except that resistance of block to the action of acids shall be determined in accordance with the applicable portions of Sections 14 to 18 of the Methods of Testing Clay Pipe (ASTM Designation: C 301).

TRICKLING FILTER FLOOR INSTITUTE

GUARANTEE

OF VITRIFIED CLAY UNDERDRAIN FLOOR BLOCKS

The ______________________________

of ______________________________

Warrant and Guarantee to

____

that all vitrified clay underdrain blocks manufactured by the above said company and furnished for installation in ______________________________

______________ under contract dated ______________

between ______________ and ______________

are proof against impairment of service or failure due to rust, corrosion, decay, chemical decomposition and/or disintegration caused by any action of acids, alkalis, sewage, sewer gases, ground waters or industrial wastes, excepting Hydrofluoric Acid only. Also guaranteed against destruction by rats, rodents or termites.

The undersigned bind themselves for a period of

FIFTY YEARS

after date hereof to furnish to the above named ______________

free of cost, vitrified clay underdrain blocks in the same quantity and sizes equal to any of the vitrified clay underdrain blocks manufactured and furnished by above named manufacturer under said contract which may have been damaged, destroyed or impaired in service by reason of any of the above named causes.

It is expressly understood that the conditions of This Guarantee do not provide for Furnishing of Blocks which have been broken or impaired by reason of Improper Handling, Placement or Construction.

The ______________ ______________ Company

By ______________ Title ______________

Signed this ________ day of ______________ 19____

Standard Rate Filters

THE first trickling filters were of the standard rate type, designed to use the concept of low rates of application, up to 600 lbs. of BOD per acre-foot, on relatively deep beds of rock or crushed stone. The popular method of distribution of wastewater over the media was by means of fixed nozzles, with distributing manifolds buried in the media.

In the 1930's, the trend switched to circular beds with rotating distributors which consisted of arms extending over the diameter of the filter suspended from a central influent column. In this same decade, the concept of continuous application was developed, which resulted in recycling the effluent in a predetermined ratio to influent on an average flow basis. The recirculation principle also helped maintain application to the beds, regardless of influent flow conditions. This device became known as a *high rate* filter because the overall dosage is much higher than that of standard filters.

Both high rate and standard rate filters are in use today, though the trend is toward higher loadings and high rate filter construction.

Many studies have been made on trickling filter performance, the most notable of which was that of the Committee on Sewage Treatment at Military Installations of the National Research Council. This was done in 1944-45 and was reported in the *Sewage Works Journal*, September, 1946.

Trickling filters are constructed in varying depths to carry varying organic loadings with equally varying hydraulic loadings. Thus, there are problems in determining what may be expected of a proposed filter under varying loading conditions. The National Research Council Study (hereafter referred to as NRC) established empirical formulas which can be used to determine quite closely what may be expected under given conditions of loading. Other formulas have also been derived, but these relate generally to high rate filters.

What might be termed an average depth for standard filters is 6 ft. but actual depths of installations in use vary from 5 to 10 ft. It has been contended that the greater depths results in increased nitrification of the effluent. The NRC study referred to above stated that "no significant degree of nitrification occurred in plants with a daily BOD load in excess of 500 pounds per equivalent acre-foot." Some plants "did not produce a significant amount of nitrate despite low loading."

The BOD loading standards for standard filters are by no means fixed. The upper limit is generally about 600 lbs. of BOD per acre-foot per day, but a loading of the order of 400 lbs. is more common. On 15 New Jersey plants studied by Forman and Shaw, applied BOD loadings averaged 367 pounds of BOD per acre-foot. The average loading on 10 Army plants as reported by the NRC Committee was 377 lbs. In general, primary consideration in designing and in determining the load on standard filters should be based on local conditions and on State Health Department or other regulatory agency standards. Heavier loadings are possible in warm climates than in cold climates.

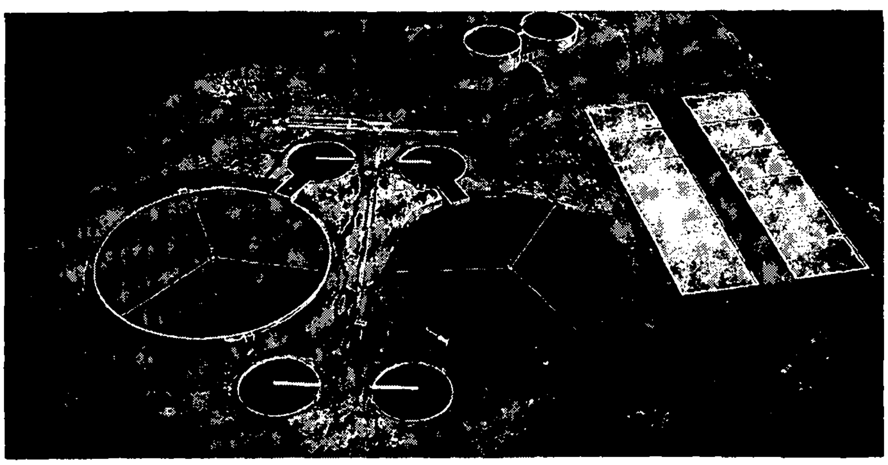
Volumetric Loading

The volumetric loading on standard filters averages about 300,000 gallons per day per acre-foot; or, for a 6-ft. deep filter, a surface loading rate of about 1.8 mgad. There is, however, no fixed standard. Based on a BOD strength of raw sewage of 240 mg/L, a flow of 1 mgd, a removal of 30 percent in the primary settling tank, and an organic loading of 400 pounds of BOD per acre-foot, there would be required 3.5 acre-feet of filter. In this case the volumetric loading rate would be about 285,000 gallons per acre-foot per day, or about 1.71 mgd per acre of surface. As in this example, the organic loading will often govern the volumetric loading. The median volumetric loading on the 10 Army plants referred to was 1.13 mgad, a rather low value.

The media used in standard trickling filters should comply with the requirements given elsewhere in this text. Specifications should include resistance to freezing (not needed in far southern states); size range; percentage of fines; screening before placement; method of placement in the filter; and other items contained in the sample specifications given.

For underdrainage and ventilation, specially designed blocks, also described in another chapter, should be used. Specifications for such blocks are included elsewhere. Center channels in standard filters are small in comparison with those required for high rate filters, and standard channel cover blocks should be used. Vent blocks for openings through the wall, and cover blocks for vent risers, are available from the same sources as are underdrain blocks and channel covers.

Rotary distributors are normally



■ **LARGE areas occupied by standard rate filters compared with those used by high rate units have favored construction of the latter type in modern design practice.**

used for applying the sewage to the filter. Most of these are revolved by the reaction to the discharge through the orifices which are placed on opposite sides of the opposing arms. Most distributors will operate satisfactorily with a minimum discharge that is 40 percent of the maximum, that is, they will handle flows up to 2½ times the minimum, but 4 ft. of head should normally be provided with this ratio.

The flow of wastewater does not always fall within the operating limits of the distributor, and a dosing tank is usually provided. The high water level of the dosing tank may be 2 to 4½ ft. above the level of the orifices in the distributor arms. However, where local conditions require that every possible inch of fall be conserved, special designs are available and the manufacturer's engineers should be consulted. Distributors having 4 arms, arranged so that 2 arms serve for low flows and 4 arms for high flows permit operation with flows up to about 5 times the minimum. The same result can be obtained by having two channels in each arm, an upper and a lower one. In all cases where high flows may occur, the hydraulics of the siphon, the feed pipe and the distributor should be calculated carefully to insure that the friction head is not so great as to cause the siphon chamber to overflow.

Head Losses

The head losses between high water level in the dosing tank and the top of the filter media include: a) The entrance loss in feet due to discharge into the siphon piping which may be assumed at $4v^2/2g$, where v is the velocity in the filter feed pipe; b) the dosing tank loss or the drop in level in the dosing tank required to fill the distributor arms which equals the volume of the arms in cubic feet divided by the area of the dosing tank in sq. ft.; c) the friction loss in the feed pipe which is computed from pipe flow tables with allowances for bends and for increase in velocity head if the feed pipe is smaller than the siphon; d) the distributor loss which should be obtained from the manufacturer; 12 in. is the usual permissible minimum; and e) the distance from the center line of the distributor arm to the top of the media which is usually 6 in.

The dosing tank should provide about 2 minutes detention at twice the average rate of flow. This allows frequent dosing and keeps the size of the dosing tank within practical limits. Since every foot of drawdown in the dosing tank represents so much head loss, and since the top layer in the dosing tank is distributed most effectively over the filter surface, it is customary to maintain a drawdown of 10 in. but not over 12 in. The total loss of head from the high water level of the dosing siphon can be determined from these data.

Where dosing tanks are not employed and the wastewater is pumped, the distributor must be designed to take the flow as it is received.

Pretreatment

Pretreatment is normally by settling; a period of 2 to 2.5 hours should be provided, with proper allowance for future-growth. Since recirculation is rarely used with standard rate filters, though it can be, settling tank capacity is based on the expected flow of wastewater at the date selected for design. Retention period, overflow rate, depth of tank, weir design and some other factors are subject to State Board of Health or other regulatory agency requirements and may differ materially from state to state.

In design, a BOD removal of 30 percent to 35 percent in the primary settling tank is used, depending on overflow rate and retention period. The specific figure to be used will generally depend on State Board of Health or other regulatory agency requirements.

In general, the above applies also to secondary settling tanks following the filter.

Filter Performance

Though standard filters are quite uniformly stable in day-to-day performance, there are variations in effluent quality from filter to filter and even occasionally from month to month, for which adequate explanations are not available. The formula which follows is based on the curve of best fit for 10 Army plants studied by the NRC Committee previously mentioned. It shows what a standard filter may be expected to do on the average. There will be variations from such average, especially seasonal variations. The 10 Army plants produced effluents ranging from 14 to 89 mg/L, BOD with an average of 38.0 mg/L.

Design Computations

The formula shown below was derived by the NRC subcommittee previously referred to. It measures the probable efficiency of the filter and the following clarifier. It will not always indicate what a particular filter is doing, but it will closely approach what may reasonably be expected from a well designed, well constructed and properly operated filter. The efficiency of such a filter should be:

$$E = \frac{100}{1 + 0.0085\sqrt{L}}$$

where E is the efficiency of the filter and following clarifier in terms of the percent removal of applied BOD; and L is the organic loading in pounds of BOD per acre-foot that is applied to the filter. Since, in a filter of the type discussed in this chapter, there is no recirculation, L is the applied BOD in pounds divided by the filter volume in acre feet.

The procedure in using the formula is shown in the following illustrative examples.

With a flow of 1 mgd, a raw sewage BOD of 240 mg/L and 30 percent removal in the primary clarifier, the BOD applied to the filter is 240 x 8.33 x 0.70, or 1400 lbs. Assume an organic loading of 400 lbs. of BOD per acre-foot, which will be the value of L in the formula. There will be required 1400 ÷ 400, or 3.5 acre-feet of media. With a filter depth of 6 ft., the area of the filter will be 0.583 acre. The efficiency of removal by the filter and following clarifier by the formula will be 85.5 percent. The effluent from the secondary clarifier will contain 1400 (1.00-0.855) or 203 pounds of BOD which is the equivalent of slightly more than 24 mg/L. The overall reduction through the plant will be 90 percent.

The filter in the above example has been loaded at what is probably the best standard loading. The effect of using a somewhat higher loading will now be shown. Assume a loading of 600 pounds of BOD per acre-foot which will be L in the formula. With a depth of 6 ft., the filter area will be 0.39 acre and the filter volume will be 2.33 acre-ft. E then is 82.8 percent and the effluent will contain 29 mg/L of BOD. The overall reduction through the plant will be about 88 percent.

The standard filter, properly loaded, gives very fine results in BOD removal, with the production of a stable effluent. The volume of media and the area of filter required is large. If these factors are of importance from the viewpoints of space required or of cost, it is better to use a high rate filter than to overload a standard filter.

A Nomographic Solution for Design

THE PURPOSE of the nomograph presented here is primarily to reduce the computation time for a preliminary investigation of the size of units for a trickling filter complete treatment sewage plant. While nomographic solutions cannot offer the accuracy of mathematical computation, they can be used to give quickly an estimate of general unit sizes for a proposed plant. The nomograph for the design of trickling filters is essentially correct in terms of its representation of the NRC formula, but great precision is lost in scale distributions. Consequently, it is suggested that this nomograph be used primarily for initial estimates or gross estimates of trickling filter sizes.

Another use is for the computation of the theoretical percentage of BOD removal in any filter, given the filter diameter, the depth, recirculation factor, and the pounds of BOD applied per day. Computation of filter dimensions can be made by selecting the desired percent of BOD removal and the pounds of BOD to be applied to the filter per day. The filter bed diameter, the depth, and the recirculation ratio can then be determined.

The design limits are not indicated on the nomographs. It is suggested that those utilizing this graph familiarize themselves with the appropriate state limitations.

For using the nomograph for filter design only three values must be known: 1) The percent BOD removal desired through the filter; 2) the pounds of BOD which will be applied to the filter per day; and 3) the total gallons of waste (in mgd) applied to the filter. (A valid assumption is that 65 percent of the daily raw sewage BOD will be applied to the filter.) Knowing these values, it is then possible to examine and select comparative sizes, depths, rates of application and recirculation, if required.

Step 1. Through the scale "% BOD Removal" locate the % of BOD to be removed from the filter (within the latitude ranges as indicated on these scales).

Step 2. Extend a line through value on "% BOD Removal" scale through intersection of R-R and T-T until it strikes a point on "Pounds of BOD Applied per Acre-Foot" scale.

Step 3. Join known values of "Pounds of BOD Applied to Filter Per Day with the point located in *Step 2* and note intersection of Scale R-R.

Step 4. Project this point on Scale R-R along the parallel guide lines to a point of intersection on scale T-T.

Step 5. The point located in *Step 4* (above) becomes the pivot point for relating depth and area figures to meet design requirements as found in *Step 2.* With a straight edge pass a line through pivot point on scale T-T and read values from scales "Effective Depth (Ft)" and "Filter Bed Diameter (Ft)". Any combination of Effective Depth and Bed Diameter will meet design criteria in terms of organic loading. Note: The concept of effective depth is related to recirculation in high rate filtration. In a standard rate filter, the effective depth is equal to the actual depth and recirculation is zero. The effect of recirculation, or the recirculation factor F where:

$$F = \frac{1 + R/I}{(1 + 0.1\,R/I)^2}$$

allows, in the NRC formula for trickling filters, for a mathematical combination of depth and F, which is labeled "effective depth." Consequently the recirculation factor F has the effect of increasing the depth. The actual depth can then be found through a nomographic solution shown on the chart which relates the effective depth through a recirculation ratio R/I.

Step 6. Practical selection of depth and area-diameter values will be dependent upon design criteria and economic considerations to be evaluated by the designer.

Step 7. The "Hydraulic Loading Rate" may be checked by passing a line through "Filter Bed Diameter" as selected in *Step 6* and the "Daily Flow to the Plant (mgd)" to the "Hydraulic Loading Rate (mgad)" scale. Area and flow combinations should fall into the category of high or standard rate depending upon criteria chosen. If this does not occur, adjustment of filter diameter and depth should be made to accommodate the hydraulic loading rate.

When an existing filter is in operation the theoretical efficiency can be easily computed with this nomograph. All the following factors should be known from the installation: 1) Filter diameter; 2) actual depth; 3) recirculation ratio; and 4) pounds of BOD applied to the filter.

Step 1. If recirculation is used, join values of "Actual Depth" and "Recirculation Ratio" to determine the "Effective Depth."

Step 2. Join value of "Effective Depth", as found in *Step 1,* with values of "Filter Bed Diameter" and note point of intersection with scale T-T.

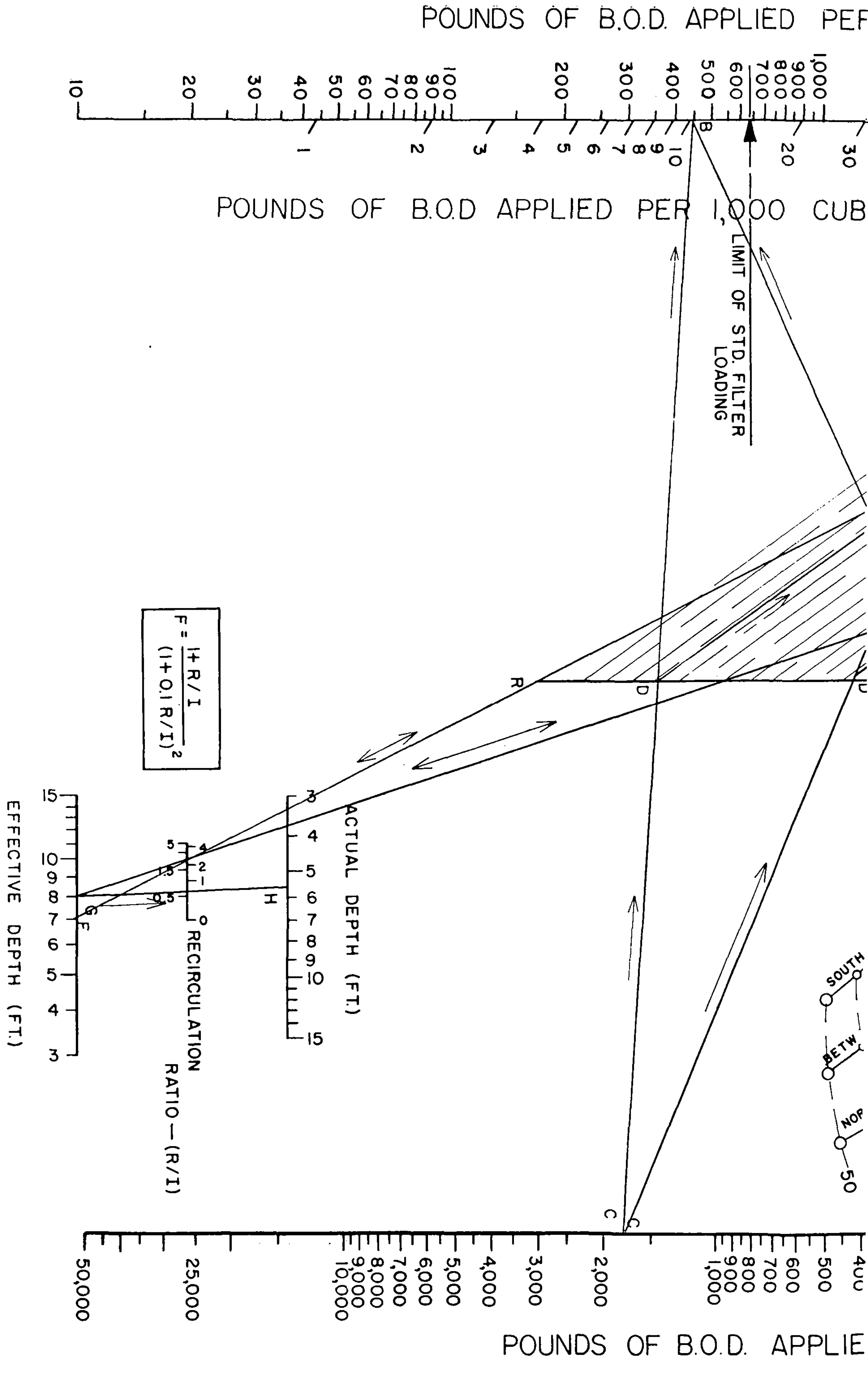
Step 3. Project point at T-T along parallel lines to intersection with scale R-R.

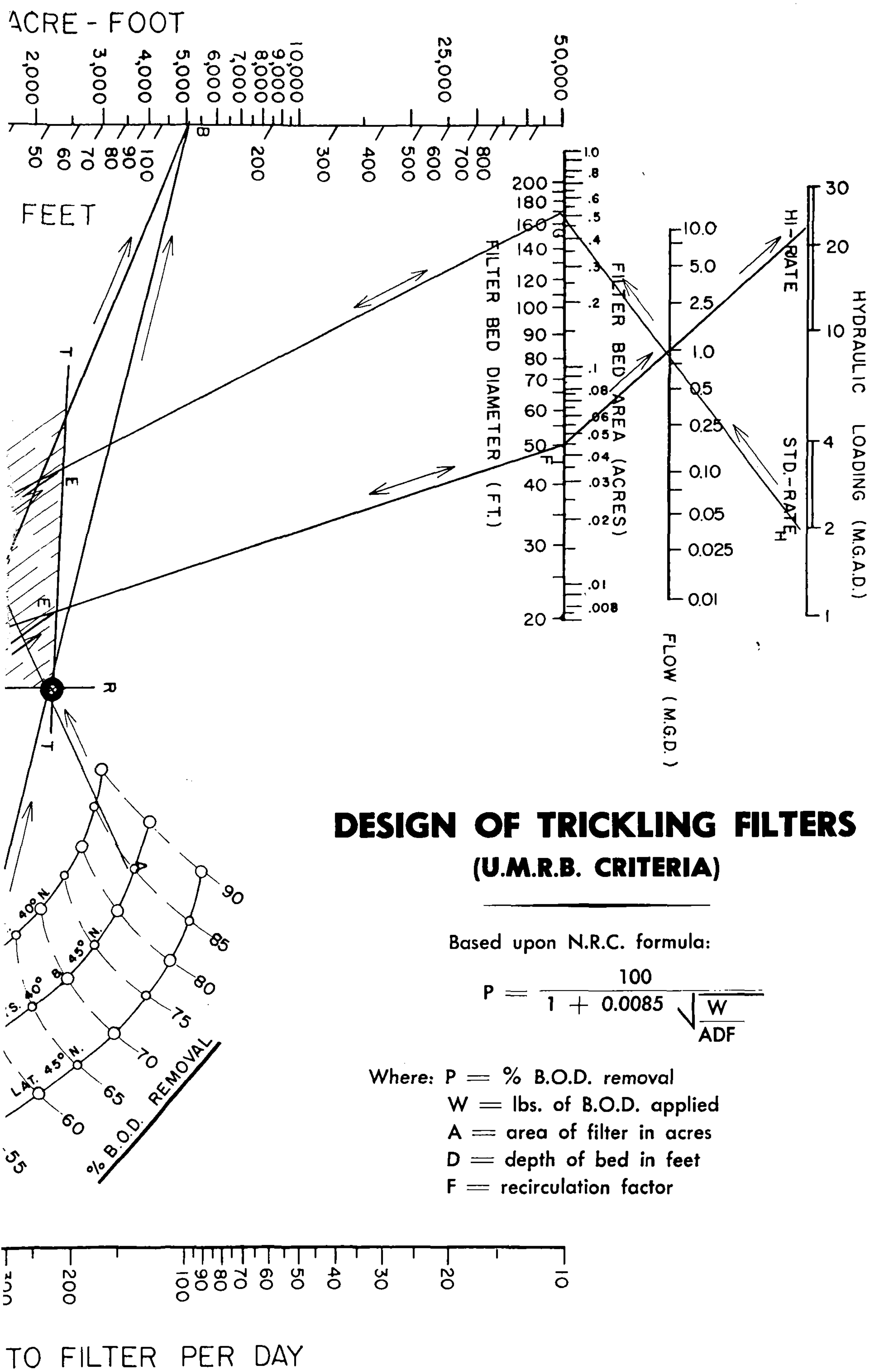
Step 4. Through R-R and value of "Pounds of BOD Applied to Filter" locate value of "Pounds of BOD Applied per Acre-Foot."

Step 5. Through value found in *Step 4* and point of intersection of scales R-R and T-T join a line to intersection with "% BOD Removal" scales. This value yields the theoretical "% BOD Removal" for the filter of given size.

The red lines indicate an example worked out for high rate filters; the green, for a standard filter.

From an article by Walter R. Lynn, PUBLIC WORKS, August 1957


POUNDS OF B.O.D. APPLIED PER
POUNDS OF B.O.D APPLIED PER 1,000 CUB
LIMIT OF STD. FILTER LOADING
$F = \frac{1 + R/I}{(1 + 0.1\,R/I)^2}$
ACTUAL DEPTH (FT.)
EFFECTIVE DEPTH (FT.)
RECIRCULATION RATIO—(R/I)
SOUTH
BETW
NOR
POUNDS OF B.O.D. APPLIE



DESIGN OF TRICKLING FILTERS

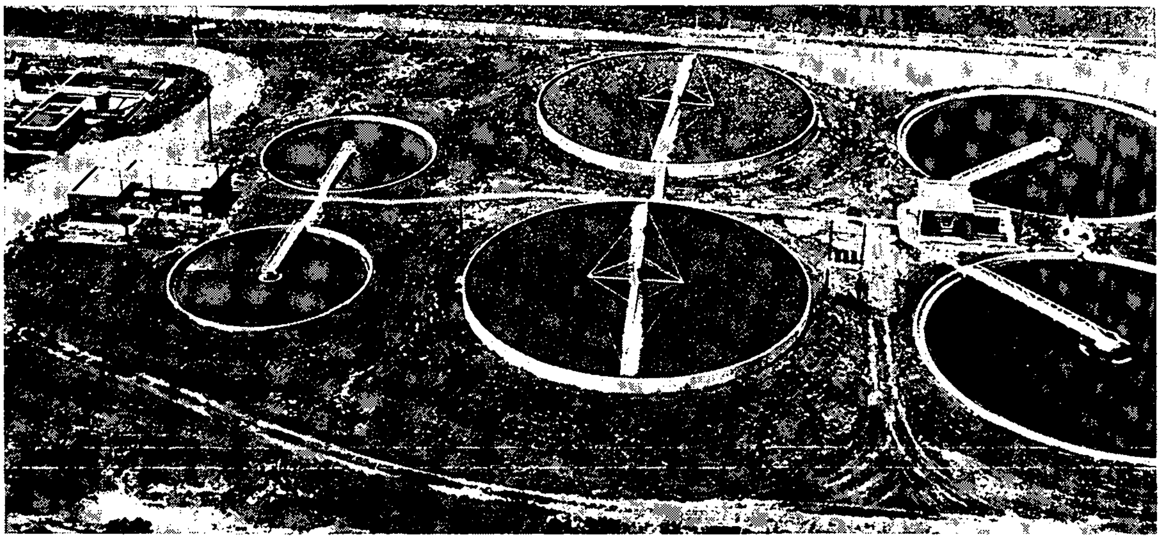
(U.M.R.B. CRITERIA)

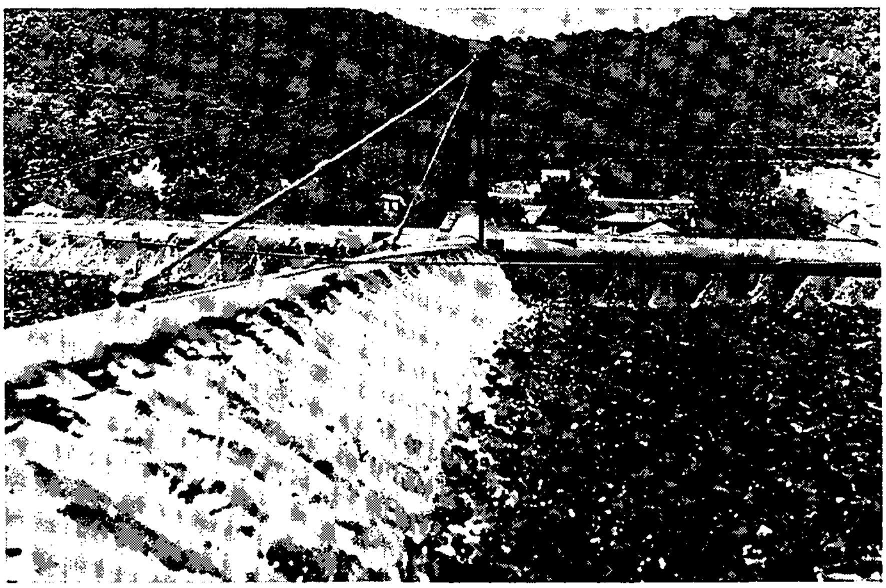
Based upon N.R.C. formula:

$$P = \frac{100}{1 + 0.0085\sqrt{\frac{W}{ADF}}}$$

Where: P = % B.O.D. removal
W = lbs. of B.O.D. applied
A = area of filter in acres
D = depth of bed in feet
F = recirculation factor

The Design of High Rate Filters





■ **HIGH RATE filter plant serving Salina, Kansas, with 115-ft. distributors is shown above. At right is a 70-ft. diameter distributor dosing at the rate of 25 mgad at Suffern, N. Y.**

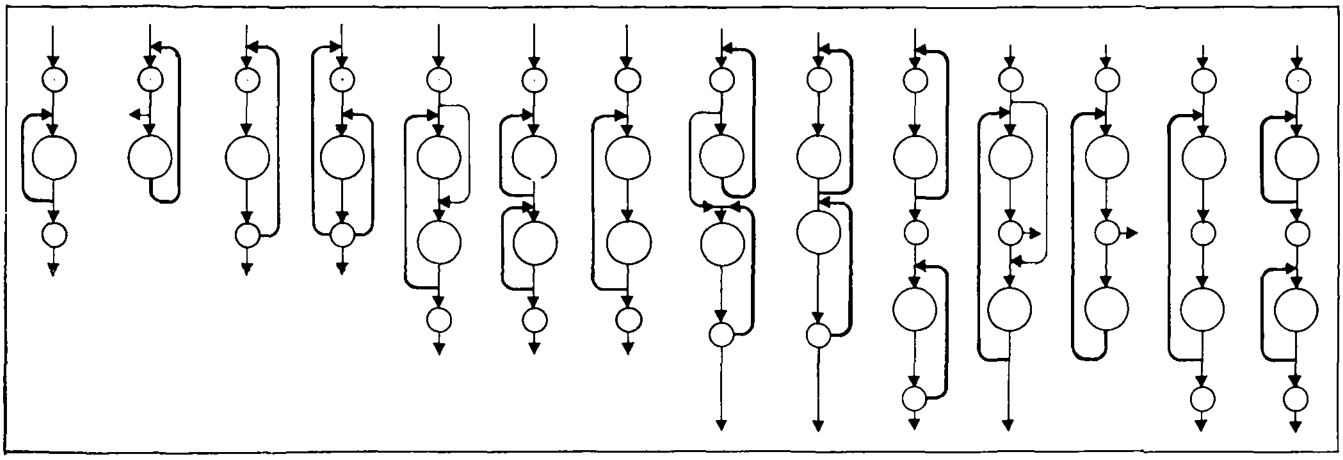
WALLACE J. BENZIE, P. E.
Director,
Sanitary Sewers and Engineering,
Genesee County Drain Commission,
Flint, Michigan

HIGH RATE trickling filters are those in which some portion of the filter discharge or final effluent is returned to the influent of the primary sedimentation tank where it joins the raw sewage; or to the filter influent where it joins the primary effluent. Plants can be designed to give any degree of treatment between sedimentation and complete treatment. Filters are usually dosed at 5 to 10 times the rates employed on standard filters, and with careful design, they can produce an effluent as low in suspended solids and BOD as a standard filter but with little, if any, evidence of nitrification.

The much heavier organic loadings used with high rate filters have resulted in the use of a variety of terms to designate such loading. The rather commonly used basis, with standard filters, of pounds of BOD per acre-foot, have been applied to high rate filters, and loadings of BOD of 2,540 to more than 3,000 pounds per acre-foot have been common. Some engineers have reduced this loading to a cubic yard basis, dividing the acre-foot loadings by 1,613. There has also been some use of 1,000 cu. ft. as a loading basis, and it has been recommended by a committee of the Water Pollution Control Federation that such usage be standardized in sewage treatment practice. Since 1,000 cu. ft. equals 37 cu. yds., the cubic yard loading is multiplied by 37 to obtain the 1,000-cu. ft. loading. Thus, 3,000 lbs. per acre-foot is the same as 1.86 lbs. per cu. yd. or 68.8 lbs. per 1,000 cu. ft. There may be a slight saving in time in making design computations by either the cu. yd. or the 1,000-cu. ft. basis, but most formulas now in general use, for determining filter efficiency are based on the acre-foot.

There are three principal types of high rate filter in common use today, based on rate of feeding, recirculation or loading.

In one type of filter operation, a portion of the trickling filter effluent



■ **RECIRCULATION design arrangements available are varied. In the diagram above, larger circles represent filters; small circles are clarifiers; and heavy lines, recirculation paths. BOD reductions are somewhat dependent on layout employed.**

is recirculated to the primary settling tank influent. It is sometimes desirable to add a second stage filter to this system where it is necessary to provide for additional treatment. Loading rates and recirculation ratios can be modified to provide the desirable effluent quality. Organic loadings are in the order of 2,500 to 3,000 lbs. of BOD per acre foot, or 1.5 to 1.9 lbs. per cu. yd. based on the strength of the primary tank effluent. The volume loadings range from 10 to 30 million gallons per acre per day (mgad).

The unsettled filter effluent may also be recirculated directly back to the filter influent with no intermediate settling provided. This recirculation principle can be used on either standard or high rate filters.

In addition, primary effluent may be distributed over a maximum area of the filter at one time with recirculation only at times necessary to maintain the flow requirements to provide for satisfactory distribution of the waste onto the filter media. Recommended organic loadings range from 3,000 to 3,200 lbs. of BOD per acre foot or 1.9 to 2.0 lbs. per cu. yd. based upon the applied sewage.

Additional treatment may be provided by utilizing a second stage filter. Because of the heavier organic load applied to a high rate filter per unit of filter volume, the effluent from a single stage high rate filter will be higher in BOD than that from a lightly loaded filter. To overcome this factor, the effluent from the filter may be mixed with the incoming raw sewage and passed again through the filter; or two filters, in series. These procedures may result in treatment comparable to that from a filter that is loaded less heavily, while the smaller units required in the high rate process compared with standard filters may reduce construction costs materially.

Flowsheets

Flowsheets most frequently used are shown in the accompanying diagram. The choice of flowsheet is dependent upon several factors, including the strength of the raw sewage, the quality of effluent desired and, to some extent, on the size of the plant. In a plant where multiple filter units are required because of size, local requirements or other reasons, it is frequently desirable to arrange for two-stage operation with small additional cost. A single-stage plant is differentiated from a two-stage plant by the fact that in the latter the sewage is passed successively through a primary filter and through a secondary filter. Recirculation may be applied to both filters.

Thus, a single-stage filter is one in which the filters, if there are more than one, are operated in parallel. Sewage may be, and usually is, recirculated through single-stage filters, the effluent from each filter being passed to a secondary settling tank after or before withdrawing the portion that is to be recirculated.

In a two-stage filter, the effluent from the primary filter or filters, after withdrawing that portion to be recirculated and returning it to and through the primary filter, passes to a second filter; and the effluent from the second filter, less recirculation, is discharged to the final settling tank.

Recirculation

In all high rate trickling filter plants, some form or pattern of recirculation is always used. The ratio of the volume of flow recirculated to the volume of average raw sewage flow is defined as the recirculation ratio R. Where more than one recirculation means is used in a plant, the ratios are distinguished as R_1, R_2, etc. The beneficial effects of recirculation have been demonstrated.

Return of recirculated filter effluent to the raw sewage has proved beneficial in reducing odors particularly in initial stages of plant operation when the sewage flow is frequently much below design conditions and often septic. Recirculated flow is also effective in reducing scum, particularly when treating stronger sewage.

There are many variations in the arrangements for recirculation. In a single-stage filter, the most common arrangement is to return a portion of the filter effluent to the inlet of the primary settling tank. In the two-stage plants, the most used plan is to return a portion of the primary filter effluent for another passage through the primary filter; and a portion of the secondary filter effluent for another passage through the secondary filter.

However, excessive recirculation is not necessary. Very good effluents can be obtained with recirculation ratios of 0.5 to 1.

Loadings on high rate filters must be considered from two bases: The organic loading in pounds of BOD per acre-foot, cubic yard, 1,000 cubic feet, or square foot of surface area; and the rate at which sewage is applied to the surface, usually in mgad.

The organic loading is based on the strength of the sewage applied to the filter. In design, it is common practice to allow 30 to 35 percent removal of BOD in the primary settling tank and to assume that 65 to 70 percent of the raw sewage BOD will be applied to the filter.

Much heavier loadings than those stated above are applied to the primary filters of the two-stage plants. In a two-stage plant, the same volume of filter media is used as for a single-stage plant, with the media divided, usually equally, between two filters. The entire organic load, after primary settling, is applied to the primary filter. This may result in loadings of 3 to 4 lbs. per cu. yd. or 4,800 to 6,400 lbs. per acre foot. In effect, the primary filter becomes what has been called in the past, a roughing filter, with the principal function of removing BOD and preparing the sewage for the final passage through the second filter.

Volume loadings range from 10 to around 30 mgad, based on the surface application rate. Assuming a sewage flow of one mgad, a recirculation ratio of 0.5 to 1, in a two-stage filter, the BOD of the raw sewage is 240 mg/L and the removal in the primary settling tank is 30 percent, the organic load on the filter will be 8.33 x 240 x 0.70 = 1,400 lbs. If the unit organic loading in the filter is 1.75 lbs. per cu. yd., 800 cu. yds. of media will be required, divided into two filters, each containing 400 cu. yds. If the filters are 5 ft. deep, the surface area of each will be 2,160 sq. ft. or about 0.05 acre. Since the daily flow of sewage plus recirculation effluent will amount to 1.5 mgad, the surface load on the filter will be about 30 mgad.

If a single-stage filter were used, all of the 800 cu. yds. of filter media would be in a single filter, and a volume loading rate would be half as great, or 15 mgad. Few plants are designed for rates much above 30 mgad and 50 mgad is about the maximum that has been used.

Predicting Performance

When laying out new high rate filter plants, designers need to estimate or predict their performance. This can be done with reasonable confidence through the application of certain formulas developed from analysis of operating data from existing high rate plants. It should not be concluded that sewage treatment has become an exact science with precise performance predictable by formulas. Such formulas do, however, serve as a tool or guide to the experienced designer. One such basis is the accompanying Ten States Standard Curve. This shows that with BOD applied to the filter at the rate of 40 lbs. per 1,000 cu. ft. there will be 28 lbs. per 1,000 cu. ft. removed. Other expected removals are readily obtainable from this curve.

Another method of predicting performance preferred by some designers is on the basis of the NRC formulas developed specifically from trickling filter installations serving military bases in World War II. In these formulas, weight is given to the organic loading placed on the filter, and also to the ratio of recirculation, since it was found that these factors affect the quality of the effluent. The volume of filter media is stated in acre-feet. The organic loading is a function of the BOD loading, the acre-foot volume of the filter, and the recirculation factor.

Since, in recirculation, part of the organic material is removed in each passage through the filter, a recirculation factor F is derived from the recirculation ratio by means of the following formula, where R is the recirculation ratio:

$$F = \frac{1 + R}{(1 + 0.1R)^2} \quad \ldots (1)$$

For a 1 to 1 recirculation ratio, F is 1.65 and for a ratio of 0.5 to 1, F is 1.36.

The percent efficiency of removal of BOD in a trickling filter and its following clarifier is expressed by formula (3) below, where E is the efficiency in percent of removal of organic matter and L is the organic loading. L is derived by formula (2) below and, for filters with recirculation, is based on pound of BOD applied, filter volume and recirculation. With V representing filter volume in acre-feet, F the recirculation factor and W the pounds of applied BOD:

$$L = \frac{W}{V \times F} \quad \ldots (2)$$

Thus, if applied BOD is 1,400 pounds, V is 0.5 and F is 1.65, L = 1700.

The filter efficiency formula is:

$$E = \frac{100}{1 + 0.0085\sqrt{L}} \quad \ldots (3)$$

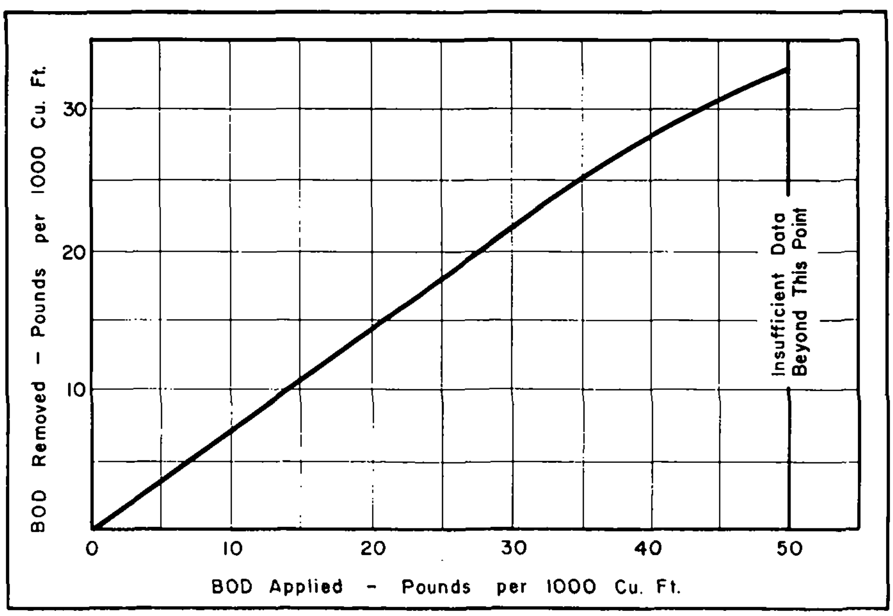
and where L = 1,700, the efficiency of the filter and accompanying clarifier will be 73.7; that is 73.7 percent of the applied BOD will be removed in the filter and final clarifier (not considering the removal in the primary clarifier.)

Thus, for the example cited, removal in the filter and following clarifier will be 1,400 × 0.737 or 1,032 pounds. BOD remaining in the effluent will be 1,400 − 1032 = 368 pounds. Overall removal in the plant, including that in the primary clarifier will be 81.6 percent.

The above formula applies to any single stage high rate filter no matter what the rate of loading. It also applies to the primary filter of a two stage plant; but it does not apply to the second stage filter of such an installation.

In predicting the performance of the second stage of a two-stage plant, the reduced treatability of the organic waste must be taken into account. A formulation is given in an article, "Design Considerations for Biological Filters," PUBLIC WORKS, February, 1967. Compilations of data on the operation of two-

■ **BOD REMOVAL curve used in Ten States Standards for filters and final settling.**



stage filters are available. Two notable references are "Sewage Treatment at Military Installations," *Sewage Works Journal,* Vol. 18, No. 5 (1946) and R. S. Rankin, *Transactions ASCE,* Vol. 120, p. 823 (1955).

Clarifiers

Primary and secondary clarifiers will normally be designed in accordance with the State Board of Health requirements; commonly recommended detention is about 2 hours in primary settling tanks, with overflow rates of 650 to 800 gallons per sq. ft. per day; and the same for secondary clarifiers. Depending on recirculation practices, clarifier capacity may be based on raw sewage flow; as when recirculation is merely to maintain distributor operation during low flow periods; or on raw sewage flow plus recirculation, when strong sewage or other factors dictate recirculation to provide dilution. The size of the primary clarifier is usually selected on the basis of average 24-hour raw sewage flow plus recirculated flow returned to the clarifier influent.

Treatment Results

Single-stage high rate filters will normally produce effluents of the order of 40 to 45 mg/L BOD when loaded in the range of 2,400 to 2,800 pounds of BOD per acre-foot. Two-stage filters, with the same loading will normally produce effluents in the range of 24 to 28 mg/L BOD. The Sandusky, Michigan, treatment plant has a filter volume of 9,850 cu. ft. and was designed with a recirculation ratio of 1:1. This plant has shown reductions in BOD through the filter of more than 80 percent when loaded at 54 pounds of BOD per 1,000 cu. ft. This plant is quite typical in its operating results, of a number of plants of this type existing in Michigan today.

The performance of trickling filters is affected by several factors including media size, depth of media, ventilation, hydraulic rate of application, organic loading and temperature variation. In a paper published in the *WPCF Journal,* Vol. 35, No. 4, pp. 445 to 455, the effects of temperature variation on trickling filter performance at several selected plants in Michigan were reported. The conclusions of this study are:

1) There is a significant difference in trickling filter efficiencies between the summer and winter months.

2) Recirculation of wastes through a filter has a marked cooling effect on the waste during the winter months; and by lowering the temperature of the wastes applied to the filter, the efficiency of the trickling filters is lowered.

3) Lower air temperature has a more significant effect on reducing filter efficiencies in plants that recirculate than those that do not practice recirculation.

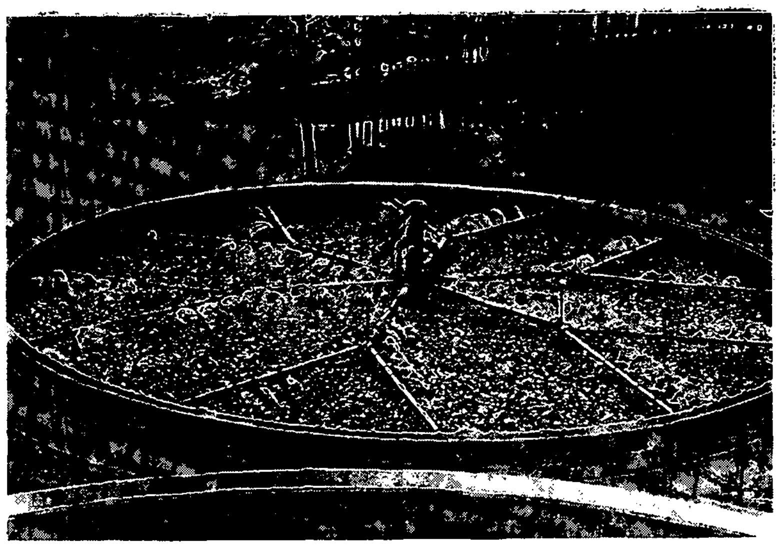
4) In plants that recirculate, the winter filter efficiency was 21 percent less than the summer efficiency.

5) Filters having a BOD loading of more than 10 lbs. per 1,000 cu. ft. of filter media showed no greater seasonal variation in efficiency than when loaded at less than 10 lbs.

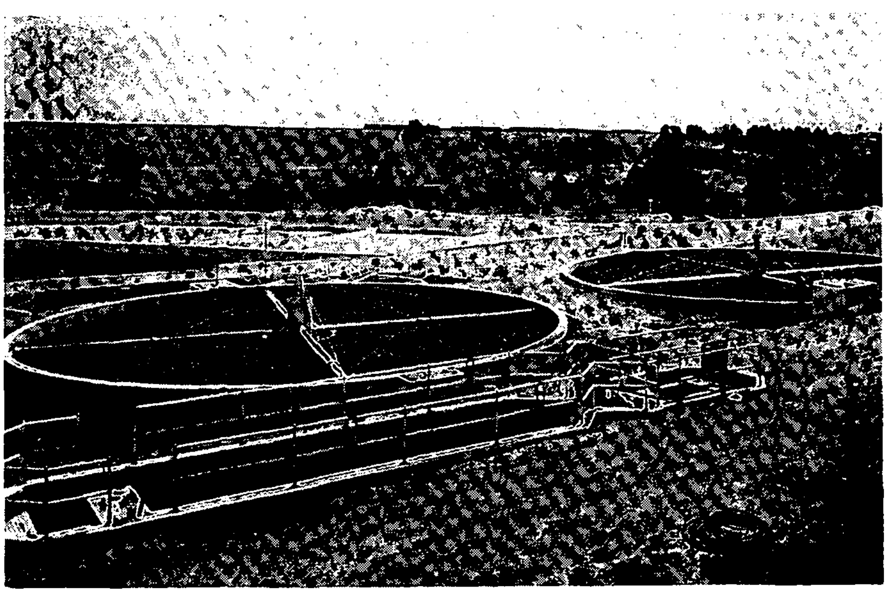
6) Filter efficiency was affected in those plants not practicing recirculation when the air and sewage temperatures were equal.

7) In the design of trickling filter plants in the northern part of the United States, consideration should be given to the marked change in efficiencies which occur between the summer and winter seasons.

To obtain the predicted performance in an operating plant, intelligence must be used in the selection of materials and equipment going into the plant and in obtaining a qualified operator to run it. Such items as filter media, filter underdrains and rotary distributors are very important and specifications should leave nothing to chance. Correctly sized pumps, particularly for recirculated flows, are also very important. Experience has demonstrated that properly designed, constructed and operated high rate trickling filter plants have little difficulty in obtaining results equal to the predicted performance. □ □ □



■ **DISTRIBUTOR with multiple arms is a feature of the Aero-filter in a Gaffney, S. C. installation. Below are shown the secondary units of a two-stage filter plant that provides treatment for the Air Force Academy.**



Trickling Filters for Industrial Waste Treatment

THE wastewaters from industry are, of course, extremely varied in character, even within the same industry or manufacturer's operations since much depends on the type of processing employed. Many, however, are organic, such as food wastes and those from distilling and pharmaceutical operations. These are subject to biological oxidation and consequently may be organically stabilized through treatment on trickling filters. Some may be deficient in elements required to sustain microbial growth or naturally lacking in organisms necessary to start growth on the filter. However, these conditions can be corrected by adding the required nutrients and biological seed. Some wastes, such as phenols, are toxic to microorganisms, but techniques are available to handle even these wastes on trickling filters. The selection of the type of filter, whether high or standard rate and its design, depends generally on the same factors as are encountered in municipal domestic wastewater treatment plant design: The amount of BOD to be removed; preliminary treatment; the load factor; the recirculation ratio; and site conditions. One usually different factor is the volume of flow.

Whereas municipal sewage flows are calculated in millions of gallons per day, the flow of industrial wastes will frequently be counted in the thousands of gallons per day. This would perhaps lead to the belief that trickling filters for industrial wastes can be small. This is not necessarily the case. A normal municipal sewage will have a BOD of 250 to 400 mg/L or 2085 to 3336 pounds per MG., but it is not uncommon for an industrial waste to have a BOD of 4000 mg/L, and in some instances as high as 30,000 mg/L. This means 33,600 to 250,000 lbs. of BOD per MG. The trickling filters for such high organic loadings, even though the daily volumes are small, must be very large.

Preliminary treatment may follow any one of a number of accepted patterns including anaerobic digestion of very strong wastes; plant management to modify operations producing strong and difficult to treat wastes; recovery; and blending. The method selected will depend on local conditions. The aim should be to reduce very high BOD contents and to adjust the wastes so they are amenable to aerobic treatment. Without prejudice for one type or another, it may be conceded that the high rate trickling filter will often have advantages in the treatment of industrial wastes, due to lesser space requirements and often lower cost.

There is a tendency, where feasible, to combine industrial and domestic wastes for treatment by a nearby urban complex, with the industries providing their share of the treatment costs. In designing such facilities, careful consideration has to be given to the influence of the industrial waste load. Some industries, such as canning, are seasonal in operation, which discourages the use of biological oxidation measures for handling the industrial waste alone, because time is required to start a trickling filter or an activated sludge plant.

The High Rate Filter

The higher the initial BOD concentration, the greater the loading factor per unit of bed volume or area may be. Also, as the BOD concentration increases, better results from the standpoint of percentage of reduction are obtained by increasing the ratio of recirculation. The volume of recirculated filter effluent has usually little effect on the size of the filter itself but principally affects the design of the distributor unit.

The flows from industrial plants are usually relatively small so that increased recirculation rates used do not require the use of large capacity pumps or result in high power demands. For instance, if the waste flow is 100,000 gpd and it has been determined that two-stage high rate filtration will produce a satisfactory reduction in BOD when the rate of recirculation in each stage of filtration is 3 times the volume of raw waste, recirculation will be 300,000 gpd in each stage. For this, in each stage, a centrifugal pump will be required with a capacity of 208 gpm against a total head of 15 ft. This may be obtained with a 3-in. pump, requiring a 1½-hp motor. As these pumps run continuously, the total daily usage of electrical power with the two pumps in operation will be only 54.0 kwh.

To cite an example: The wastes from the production of alcohol from sugar cane molasses have BOD concentrations ranging from 22,000 to 33,000 mg/L. It is common practice, when treating the effluent from the pre-digestion step used in handling these wastes, to employ recirculation rates of 5 to 7 times the volume of digester effluent. Even in a large distillery of this type, a waste flow of 225,000 gpd is about the upper limit, so that with a two-stage plant, using 3.5 times recirculation in each stage, the pump size for each phase will be 547 gpm and the pump will require only 3 hp to operate it.

Specific Examples

Cannery Wastes. Trickling filters are satisfactory for these wastes because the BOD is exerted rapidly due to the high sugar content and its quick decomposition. For wastes averaging around 1000 mg/L BOD loadings of 5 to 6 lbs. of BOD per cu. yd. may be used. Tests on corn cannery wastes have indicated that loadings as high as 22 lbs. per cu. yd. may be used on primary high rate filters, preceded by sedimentation. With such loadings, reductions of approximately 50 percent of the BOD have been achieved, with the raw wastes having an average BOD of 8400 mg/L.

Sauerkraut packing wastes have been treated on filters using blast furnace slag as the medium. In the test period, raw waste loadings on the filters ranged from 575 to 6800 lbs. BOD per acre-foot per 9-hour day. The dosing rates ranged from 9 to 30 mgad, and the rates of recirculation from 3.3 to 19. The characteristics of the raw wastes were pH 4.0; acidity 1100 mg/L as $CaCO_3$; chlorides 4500 to 6500 mg/L; total solids 12,000 to 13,000 mg/L; BOD 2000 to 2400 mg/L. The filter used in the pilot plant was 10 ft. in diameter and 6 ft. deep with slag media. With adjustment of the pH of the wastes to a minimum of 6.6, a BOD reduction of 85 percent was obtained. Concentrations of chlorides up to 5000 to 6000 mg/L seemed to have little effect on the biological efficiency of the filter. There was no evident relation between the ratio of recirculation and the reduction in BOD.

Dairy Wastes. These comprise the waste waters from creameries, where milk is separated; bottling plants; milk condensing plants; powdered milk plants; and cheese, butter, ice cream and other milk products plants.

The BOD ranges from approximately 100,000 mg/L for whole milk wastes to 30,000 mg/L for whey. The wastes respond to treatment on trickling filters after preliminary treatment to remove coarse solids. In treatment, it is common practice to include a step of aeration to inhibit anaerobic action during the retention period and this also aids in BOD reduction. The screened and aerated wastes are applied from a batch holding tank to either low rate filters or to high rate filters with recirculation. High rate filter loading is 1.0 lb. of BOD per cu. yd. Reductions of 90 to 95 percent of the BOD have been obtained.

Single-stage recirculating type high rate filters are satisfactory where a final effluent with 70 to 100 mg/L BOD is acceptable. With two-stage high rate filters operating in series, with recirculation in each stage, reductions of 90 to 95 percent have been obtained with primary BOD loadings of 1.5 to 2.0 lbs. per cu. yd. and secondary filter loadings of 0.75 lb. per cu. yd.

Fermentation Industry Wastes. These comprise the wastes from breweries; distilleries for the production of whiskey, brandy and alcohol; and the production of alcohol from sugar cane molasses. Such wastes are normally high in BOD and low in suspended solids, with high total solids content and low pH.

Distillery Wastes. At one plant the design loading is 0.75 lb. of BOD per cu. yd. Dosage rate is 8.0 mgad with recirculation ratio of 4 times raw waste volume.

At another the raw waste averaged 685 mg/L BOD; the high-rate filter loading is 1.1 lb. per cu. yd. and the dosage rate is 30.0 mgad. A recirculation ratio of 11 to 1 produced an over-all BOD reduction of 77 percent.

Yeast Factory Wastes. Experiments on yeast wastes by Dr. Willem Rudolfs and E. H. Trubnick at Rutgers University, included predigestion, sedimentation and the application of digester effluent to trickling filters operated in series with recirculation. It was found that loadings up to 11,000 to 12,000 pounds of BOD per acre-foot per day could be applied to the filters without material deterioration of the normal 50 percent removal.

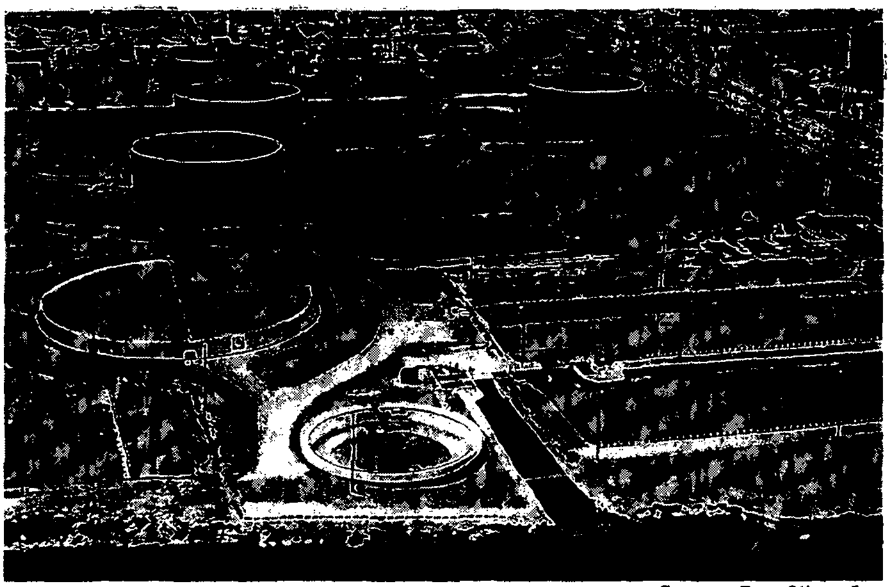
Slaughterhouse and Meat Packing Wastes. These wastes vary widely in BOD, ranging from 2200 to as high as 9100 mg/L. Treatment on trickling filters should be preceded by screens, sedimentation and means for removing grease. Sedimentation reduces the BOD 30 to 35 percent. Low rate filters may remove up to 80 percent of the remaining BOD. In several cases two-stage filtration, with the primary filter so constructed that it may be washed, followed by sedimentation and a second step of filtration has been used with an overall plant reduction of 94 percent of the BOD.

Phenolic Wastes. Wastewaters containing as much as 800 mg/L phenol can be treated on trickling filters to reduce the phenol content to less than 1 mg/L through careful control in acclimating the biological growth to the toxic nature of the wastes. Dilution from other waste effluents can be used to make the filter effluent acceptable for discharge.

Wastewaters containing other toxic organics such as formaldehyde, organic acids and wastes from petroleum refining have also been successfully treated.

Many hydrocarbons, particularly those of high molecular weight, are resistant to biodegradability, and experimentation with specific chemicals is advisable.

Pulp and Paper. Some degree of success has been achieved with these wastes, using plastic media. With loadings as high as 800 to 1,000 lbs. per cu. ft., 45 percent reduction of BOD has been obtained. Their use in this industry appears to be primarily for roughing filters. Experience with rock filters has been disappointing with rapid clogging of media a principal problem.



Courtesy Dorr-Oliver, Inc.

■ **DESIGNED** after extensive pilot plant tests, this high-rate trickling filter plant was built by Shell Oil Co. for treatment of refinery wastewater prior to discharge.

Textile Wastes. These are treatable with trickling filters, though plastic media is preferred. Efficiencies up to 50 percent have been attained, which indicates their use as preliminary treatment devices, followed by other biological devices.

Pharmaceutical Wastes. Wastes from plants producing penicillin, aureomycin, streptomycin and other antibiotics have been found to respond to treatment on trickling filters. The usual plant comprises storage and equalization tanks, grease flotation unit, aeration, sedimentation and high rate trickling filters followed by final sedimentation. Filters are designed to handle 4300 pounds of BOD per acre-foot, with 6-foot depth of stone, and an average recirculation ratio of 3 to 1.

Metal Finishing Wastes. Wastes containing cyanide have been applied to trickling filters but due to the extremely low final concentrations permitted in streams, filters have not been used in operating plants. In many cases regulatory agencies require a maximum of 1.0 mg/L in final effluents; others require 0.1 mg/L; and in one case the allowed maximum is "substantially none".

Design Considerations for Biological Filters

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and
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SEVERAL mathematical models exist for predicting performance of biological filters. All, at best, give an approximation of what can be expected from an actual installation. These empirical formulae give a good indication of the performance of the biological process, although they are by no means exact. Field data discussed later in this article will demonstrate the close correlation between calculated and actual results.

In the design of the biological process the engineer is confronted with two objectives. First, the process must stabilize the waste to a point that it can flow into the receiving stream without causing a nuisance, and second, the process must be as economical as possible. Until recently very little study had been given to the cost of the various filter units.

In a study undertaken at Mississippi State University, the National Research Council (NRC) formulae[1] were analyzed using the International Business Machine 1620 computer for the purpose of developing charts to aid the engineer in the design of the biological filter process. Numerous variables enter into the process and must be considered by the designer. Some of these, such as strength of waste, volume of flow, and condition of receiving stream are not normally controlled by the engineer. Therefore, to provide a good design the engineer must balance the remaining variables in an attempt to minimize cost while providing the treatment required. Two of the major items affecting cost are volume of media and recirculation. The design charts developed by computer analysis give the designer a comparison between these two variables. Knowing power and material costs for a specific locale, the engineer may then minimize cost for the process.

To provide design charts for a two-stage biological filter process, the effect of various volume ratios as well as various recirculation ratios for each stage had to be considered. With the aid of data from the computer and the original NRC study, the optimum condition was determined and used as a basis for the charts.

Field data were collected at the Mississippi State University treatment plant to demonstrate the effectiveness of the NRC formulae in predicting performance. Five different operating schemes for the plant were observed and compared with calculated results.

Development of NRC Formulae

The study entitled "Sewage Treatment at Military Installations"[2] was conducted by a subcommittee on sewage treatment formed by the Committee on Sanitary Engineering. The net result of the study was the formulation of equations to predict the performance of filters. The data collected were compiled, and a graph of efficiency versus filter loading was plotted. A curve of best fit was applied, and the resulting equation became known as the NRC formula. The second equation, used for two-stage operation, is simply a revision of the first with the reduced treatability of the organic waste taken into account. The equations are as follows:

First or Single Stage:

$$E_1 = \frac{1}{1 + 0.0085\sqrt{\frac{W}{VF}}} \qquad (1)$$

Second Stage:

$$E_2 = \frac{1}{1 + \frac{0.0085}{1 - E_1}\sqrt{\frac{W'}{VF}}} \qquad (2)$$

$$F = \frac{1 + R}{(1 + R/10)^2} \qquad (3)$$

E_1 = Fractional efficiency of BOD removal of the first-stage filter.

W = BOD loading of settled raw sewage in pounds per day. This does not include the BOD of the recirculated waste.

F = A factor reflecting increased removal due to recirculation.

R = Recirculation ratio on volume of recirculated flow divided by the volume of influent flow.

V = Volume of filter media in acre feet.

E_2 = Fractional efficiency of BOD removal of the second stage filter.

W′ = BOD loading applied to second stage process in pounds per day and does not include the BOD of the recirculated waste.

Development of Charts

As mentioned previously, the engineer must consider several variables when designing filters. Some of these variables have a direct effect on the design but normally cannot be controlled by the engineer. The required overall efficiency of the plant must be determined from the conditions of the receiving stream, the volume of flow, and the strength of the influent waste. Effluent BOD delivered to the receiving stream is of a major concern to federal, state, and local stream pollution control officials and acceptable permissible values should be determined in consultation with them. Some of the variables which the engineer may control are the size of the units, recirculation and flow diagram. The following is a list of variables that must be determined:

1) Amount of treatment required.

2) The strength of BOD of the influent sewage.

3) The quantity of flow and the hydraulic load of the filter.

4) The volume and size of the filter media.

5) Recirculation.

6) Temperature of the sewage.

These factors shall be briefly discussed with emphasis on their effect when using the NRC formulae.

The BOD load is the parameter used to determine the efficiency of the process when using the NRC equations. Since the NRC study included only plants with 8,000 pounds per acre-foot per day or less, this load is usually considered the upper limit of the equations. The suspended solids are not considered in the equations but are assumed to be reduced with, and approximately as, the BOD is reduced. This assumption is based on the results of the NRC study and is supported by field data collected in the Mississippi State study.

Although the actual volume of flow does not enter into the NRC equations, it is important in the design of the process because it determines the organic and hydraulic loads applied to the filter. Maximum hydraulic loads, established by state and local officials, are usually four million gallons per acre per day (mgad) for standard-rate filters and 30 mgad for high-rate filters.

The volume of the filter media, adjusted for recirculation, is the controlling parameter for the required efficiency. The conditions of design are usually such that the designer knows the influent BOD and the efficiency desired and must determine the recirculation and volume of media required. The design charts of this study are based on this condition. The size of the media is of importance for it determines the void spaces available for air flow, waste flow and slime growth. General media size is from 1½ to 4 inches with the upper ranges used for high-rate filters and the lower ranges for standard-rate filters.[3]

Recirculation is a very important consideration because it can improve treatment without increasing the filter volume. Recirculation is seldom used on standard-rate filters and almost always used on high-rate filters.[4] Recirculation has several advantages. These include:

1) Return of the organic waste for more than one pass through the filter.

2) Dilution of incoming waste for a reduced load to the filter. This helps to achieve a more uniform load onto the filter.

3) Continuous seeding of the raw sewage and filter with active micro-organisms for an increased rate of biochemical stabilization. Gallar and Gotaas[5] have conducted a statistical optimization analysis that demonstrated recirculation above 4:1 is generally uneconomical. If recirculation below 4:1 saves sufficient volume of media to offset the additional cost and operation of the units, then recirculation should be used. A factor "F" is incorporated into the NRC equations for increased efficiency due to recirculation. Equation (3) describes "F", and it simply indicates the average number of times the waste passes through the filter.

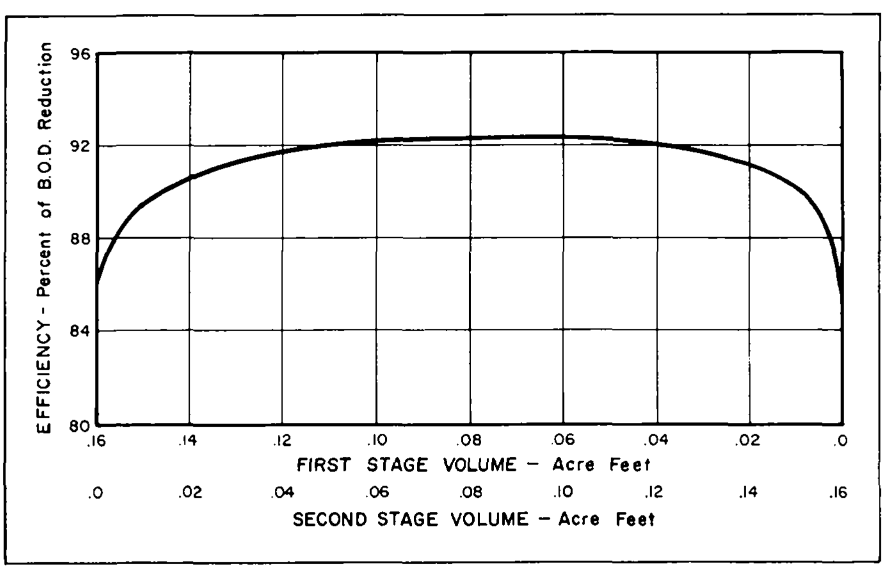
Temperature is important in any biological process. It was originally thought that air temperature had a profound effect on the biological filter, but experience has shown that the temperature of the sewage is the influential factor.[6] Should extreme temperature variations prevail in an area under consideration, the NRC equations should be used with caution.

In the study of the NRC equations, it became apparent that the volume of the media was varying directly with the BOD and flow of the influent sewage when the efficiency and recirculation ratio were constant. The linear relationship was utilized in the development of unit charts for design. Because of this linear relationship the volume of filter media required varies directly with the load applied to the filter when the efficiency and recirculation are constant. As an example, if the flow remains constant and the BOD doubles, then the load to the filter doubles and the filter volume doubles. The same would occur if the BOD remained constant and the flow doubles. Similarly, if the flow and BOD double then the load to the filter and the volume of the filter increase four times.

In order to determine the optimum volume distribution between filters in a two-stage system, the NRC equations were used to study effects that changing that ratio would have on overall efficiency. Using a fixed total volume of 0.16 acre-foot, a flow of 100 gpm, and a BOD load of 100 mg/L, the efficiencies were calculated for a series of volume distributions. The results, plotted in Figure 1, show that the maximum efficiency occurs at a volume of 0.07 acre-foot in the first filter and 0.09 acre-foot in the second filter. However, it is obvious that the efficiency at the point where the volumes are equally divided is only very slightly below the maximum efficiency. Therefore, the most economical design with optimum efficiency would be with the volumes divided equally between the two filters and the recirculation equal for both stages. Providing recirculation is constant, a volume of media divided between two stages will yield a higher efficiency than a single stage with an equal total volume. Therefore, when high efficiencies are required, the two-stage filter is normally utilized. In the medium range of efficiencies the engineer must compare the increase in cost of media volume for a single-stage filter with the increase in cost of multiple units to arrive at a minimum cost.

When recirculation is proposed for a filter system, direct recirculation versus recirculation through the clarifiers may be considered. Recirculation through a clarifier increases the total flow and consequently, will increase the size of the unit. Direct recirculation increases only the flow through the filters and does not alter the required size of the clarifiers. Many recirculation studies have been conducted which indicate that the quantity and not the system of recirculation is the important factor.[3] Culp[7] concluded from a study of a field installation that direct recirculation is as bene-

FIGURE 1. Optimization curve for two-stage filter with a fixed total volume.



ficial as recirculation from behind the clarifiers.

Design Charts

In most design problems the influent strength is calculated from available data, and the maximum effluent strength is promulgated by federal, state, and local authorities. With these two parameters known, the required efficiency of the plant may be determined. Since calculated results using the NRC formulae include the filter and subsequent settling, the primary clarifier is the only other unit entering into the overall plant efficiency. Depending upon its design, the primary clarifier can remove 20 to 40 percent of the BOD applied. A general assumption used by many engineers is that 35 percent of the applied BOD is removed. After assuming a value for removal in the primary stage of the process, the load to the filter can be determined, and the volume of media, corrected for recirculation, can be calculated.

The design procedure described above was used as a format for the development of the charts. Figures 2 and 3 are charts for the design of a single-stage plant and Figures 4 and 5 are for a two-stage plant. Figures 2 and 4 give the filter volume required for any desired efficiency of the filter stages and are based on the load actually applied to the filters. Figures 3 and 5 give the filter volume required for any desired efficiency of the entire plant and are based on the raw sewage load applied to the plant. Incorporated in Figures 3 and 5 is the assumption that 35 percent BOD removal is accomplished by the primary clarifier.

The charts are based on a BOD load of 100 mg/L and a flow of 100 gpm. Because of the linear relationship between load and volume, a simple conversion can be applied to arrive at a specific condition. If, for example, the BOD of the influent is 200 mg/L and the flow is 500 gpm, then one of the charts should be used to obtain a value which must be multiplied by (200 ÷ 100) x (500 ÷ 100) or 10. It should also be noted that the charts for the two-stage process are based on an equal volume existing in each filter and equal recirculation existing for each stage.

The charts were plotted using the output from computer programs. Basically the approach was very simple. Using the NRC equations, a set efficiency, a unit flow, a unit BOD and a very small volume increment, the computer made repetitious calculations until the total volume yielded the required efficiency. The computer typed out the volume required for the conditions set. A semi-log plot was then made of efficiency versus total volume. The resulting smooth curve plots are the design charts.

Discussion

In the design of the biological filter process using the NRC equations, the only three parameters the engineer may vary to achieve the required efficiency with minimum cost are the volume of media, the recirculation ratio and the number of stages. The charts produced by this study give the designer the required volumes for efficiencies varying from 75 to 95 percent for plant design and 40 to 90 percent for the design of the stages. The recirculation ratio was varied from 0 to 4:1, and charts are provided for both single and two-stage operation. With the required efficiency known, the decrease in volume with the increase in recirculation can be easily determined using the design charts. Knowing the construction

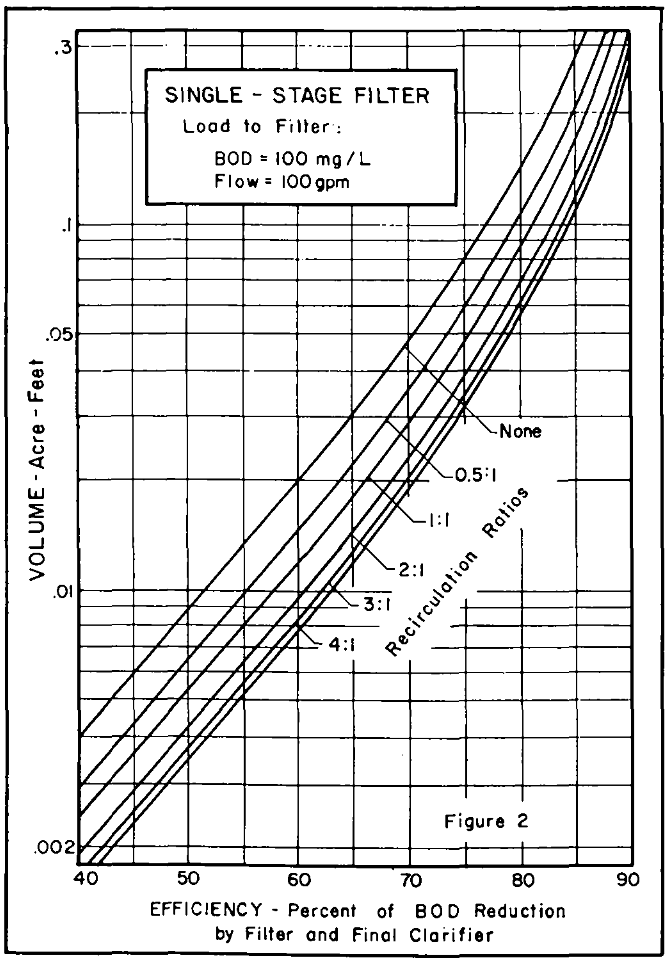


Figure 2

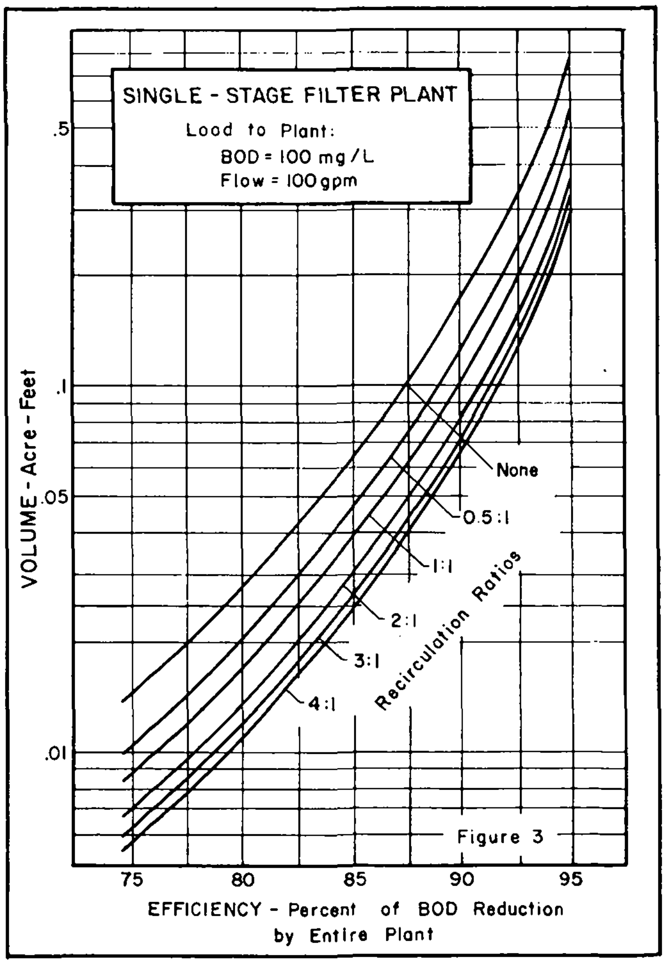


Figure 3

and electrical power cost for the particular locale the engineer can then compare the cost of recirculation versus decrease in volume. These two parameters constitute the major costs of the filter and aid the engineer in optimizing cost and efficiency. The charts do not give the designer a cut and dried solution for a particular condition. They simply compare two of the major factors affecting cost and leave the actual optimization up to the engineer.

In using the charts for the design of a two-stage plant, it must be understood that the curves are based on the total volume being equally divided between the two filters and the recirculation ratio being equal for both stages. However, in the study for the development of the charts it became evident that within practical limits the volume ratio between the units has a very limited effect on the overall efficiency.

If the volume of media in the first filter is approximately four times greater than the volume in the second filter, the decrease in efficiency from the optimum is slightly greater than one percent. Similarly, if the second filter is approximately four times larger than the first, the efficiency decreases slightly less than one percent from the optimum. This is an important factor when increasing the capacity of an existing plant because the additional filter may vary from one-fourth to four times the size of the original filter and still be very close to the optimum design.

Field Observations

The field observations were performed to demonstrate the effectiveness of the NRC formulae and the design charts to predict the efficiency of both a single-stage and a two-stage filter plant under various operating conditions. This is by no means a proof of the NRC formulae but rather a demonstration of the validity of the formulae and design charts for the operating conditions encountered.

The field data were collected at the Mississippi State University Treatment Plant. The plant is a two-stage filter plant with direct recirculation around each filter. The filters are 50 ft. in diameter and have an average media depth of 4 ft. with media size ranging from 2 to 3½ in. The primary, intermediate and final clarifiers are designed on the basis of the influent flow plus recirculation because provisions were made for recirculated flow to pass through any of the clarifiers.

Three sampling periods of 24 hours' duration were made on the operation of the plant. The first run was made with no recirculation. The second run was made with a 1.1 recirculation ratio. The last run was identical to the first except that the intermediate clarifier was bypassed. In Run III recirculation was not employed, and the effluent from the first filter passed directly onto the secondary filter. During the first two runs the intermediate clarifier was in operation; therefore, these field data could be used to study both single and two-stage filter operation.

Prior to each run the plant was allowed to operate under the specific conditions for a minimum of four weeks in an attempt to reach a steady state. Samples were collected every hour on the hour for the 24-hour period with a total of 25 samples being taken. The reading on the cumulative flowmeter of the plant was recorded at the beginning and end of the run to determine the total number of gallons passing through the plant.

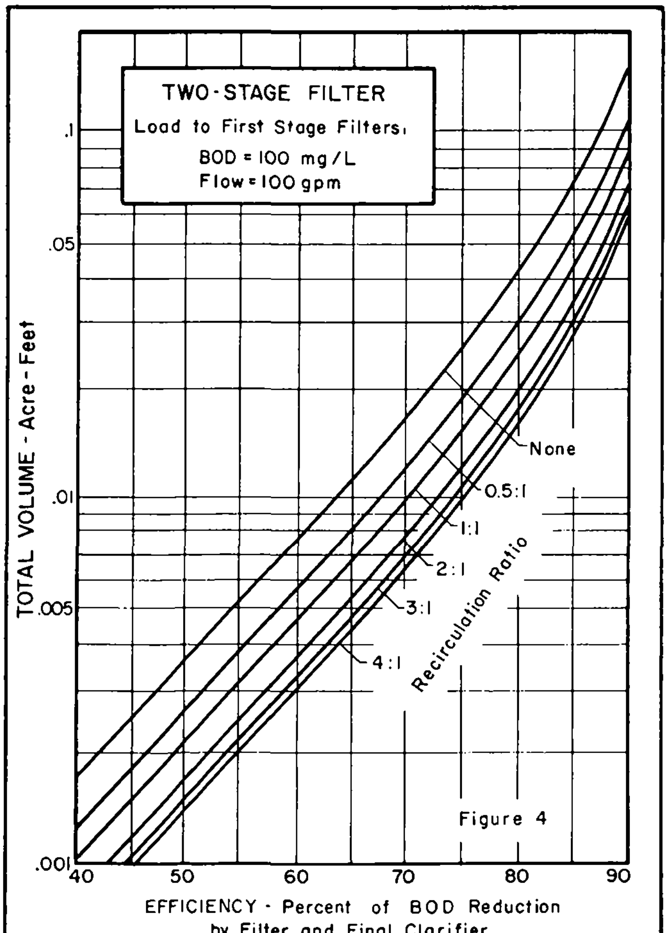


Figure 4

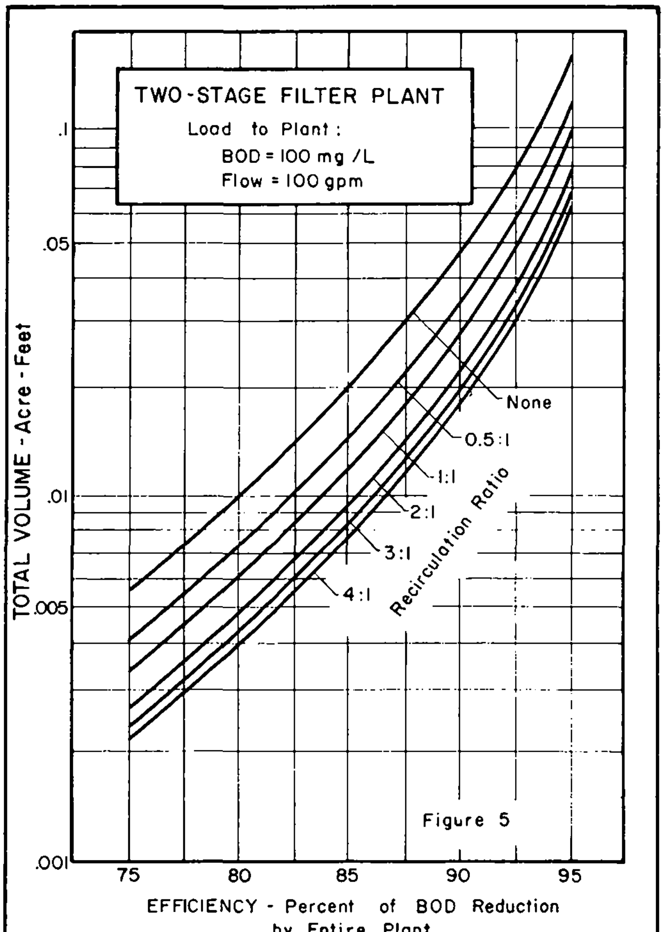


Figure 5

Table 1—Comparison of Field Observations with Calculated Results

Run	Removal By Primary Clarifier	Removal By First Filter and Inter. Clarifier		Overall-Efficiency Single-Stage Plant		Removal By Second Filter and Final Clarifier		Overall Efficiency Two-Stage Filter Plant	
	Field Data	Field Data	Calc.	Field Data	Calc.	Field Data	Calc.	Field Data	Calc.
Percent Removal of BOD									
I	30.0	49.7	63.3	64.9	74.4	44.4	51.1	80.4	87.4
II	36.8	68.5	68.7	80.1	80.2	69.3	55.1	93.9	91.1
III	27.9	35.8*	60.4	...	...	61.0	49.0	82.0	85.4
Percent Removal of Suspended Solids									
I	67.3	23.0		75.1		19.1		83.6	
II	50.0	24.8		63.3		34.2		75.9	
III	51.4	...		...		...		86.0	

*Filter only.

Results

The results of the field observations are compared, in Table 1, with the predicted value using the NRC formulae and the design charts. The good coorelation demonstrated provides an additional verification of the NRC formulae and the design charts, as well, for the prediction of filter efficiencies.

When using the NRC formulae, it is assumed that the suspended solids will be reduced coincidentally with the BOD. Except for Run II suspended solids removal agreed closely with BOD removal in the field observations. This tends to demonstrate that the assumption of the NRC report is reasonably sound.

Run I and Run III were compared to observe the effect of the intermediate clarifier on the efficiency of the plant. The results indicate that this unit is unnecessary and supports a similar conclusion of Sorrels and Zeller.[8]

Conclusions

In designing a biological filter using the NRC equations, the following can be concluded.

► The BOD of the influent, the volume of flow and the BOD of the effluent are the most important items to be determined.

► Up to a maximum ratio of 4:1, recirculation can greatly reduce the required filter volume for a given efficiency.

► Within reasonable limits, the volume ratio between the stages of a two-stage filter plant has very little effect upon the efficiency.

► When increasing the capacity of an existing plant, the additional filter may have as much as four times the volume in the existing filter and remain close to an optimum design.

► In addition to providing a rapid and accurate method of determining the required volume of filter media for any set of design conditions, the unit curves presented in this article make available an immediate visual comparison between media volumes and recirculation ratios for any given efficiencies.

The following were demonstrated in the field observations:

► Prediction of efficiency using the NRC equations agreed closely with field performance.

► Recirculation definitely improved the overall plant efficiency.

► Removal of the intermediate clarifier had no effect on the overall efficiency of the plant.

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