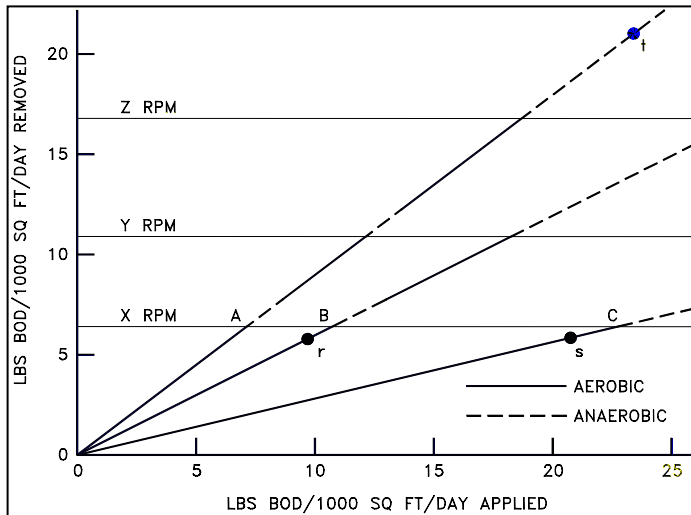


Take a New Look at the RBS Process

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Innovative approach should improve understanding of the rotating biological surface process; prevent over spending while optimizing treatment performance.

By **C. G. Steiner** Reprinted from the May 1979 issue of Water & Wastes Engineering



RBS Process Curves.

In a one for two improvement, a new understanding of the RBS process has been developed. One square foot of disc surface properly arranged can perform the work of removing BOD to the same degree as two square feet of disc improperly arranged.

Obviously, the RBS process itself cannot change. The information presented in this article, however, should significantly improve the state-of-the-art understanding of the RBS process and thereby prevent equipment overspending while optimizing treatment performance. This design approach fits all of the RBS process data published worldwide through calendar 1977.

Suppliers of RBS process equipment have done a poor job in researching the true basis upon which the RBS process technology is dependent. As a result, widespread and bitter disappointment exists with end users, engineer designers, and governmental funding sources over actual RBS process treatment results that generally fall short of theoretical expectations.

As this new understanding increases and as the associated mechanical systems mature into mechanically reliable control equipment, the RBS process should become more attractive to the design engineer during the evaluation and selection of the proper treatment method.

The RBS process is a fixed-film biological process for the treatment of wastewater. Sanitary engineers accept the RBS process as a variation of the trickling filter process. Rather than the liquid being distributed over a fixed

surface, a fixed surface is rotated through the liquid. Trickling filters are almost always used in a single stage arrangement whereas the RBS process is almost always used in a multiple stage configuration.

Design and regulatory agency engineers generally agree on the process design and expected performance of trickling filters. Subsequent treatment results have usually agreed well with projected treatment efficiencies. The RBS process, on the other hand, has often failed to measure up to the theoretical projections, especially on industrial applications and combined BOD/nitrification installations.

A gross misunderstanding of two RBS process treatment concepts exists today that has caused end users to purchase about twice the disc surface area needed for required treatment performance. The misunderstood concepts deal with hydraulic loading and oxygen mass transfer. The correct concepts are:

- ◆ Hydraulic flow must be completely replaced by organic loading as the design approach basis, and
- ◆ In addition to being a fixed-film support for biological organisms, the RBS process equipment is and must be understood as an oxygen mass transfer device.

RBS process pilot plant testing in the field is extremely time consuming, relatively expensive, often void of positive, substantive data, and invariably subject to several quasi-valid interpretations. However, from massive technical data obtained from numerous good and more numerous not-so-good RBS process pilot plant studies certain conclusions can be drawn about the RBS process.

The RBS process is a biological process and therefore somewhat beyond the precise characterization of physical and chemical reactions. RBS process data points do not fall precisely on the line and therefore published curves which depict this straight line over the data points ought to be viewed as suspect.

Even under highly controlled laboratory conditions, the end data vary considerably more than those obtained on physical and chemical type reactions. Notwithstanding this expected variation in results, one can observe definite and predictable trends which, when considered scientifically, warrant these findings.

Finding Requires Emphasis

The most significant finding requiring particular emphasis is that the RBS process follows first order biological

reaction kinetics for each stage of treatment. The extent of BOD reduction per stage is directly dependent upon the organic loading applied per stage. More specifically, under aerobic conditions the weight in pounds of BOD removed in each stage of RBS process treatment is directly proportional to the weight in pounds of BOD applied.

This first order relationship is completely unaffected by hydraulic or organic loadings (within limits of aerobic operation), temperature, rpm of RBS process equipment, disc spacing, waste treatability or K-factor, hydraulic retention time within tank basin, disc area per tank volume ratio, or RBS process equipment design.

It is no mystery, when one observes less biological growth in stage 2 than in stage 1, lesser yet in stage 3, and so on. Design curves published by RBS process equipment suppliers compel this result since equal disc surface areas are incorrectly specified for each successive stage of treatment.

If stage 1 of the RBS process removes in excess of 50% of the influent BOD, which is often the case, stage 2 has less than half the organic loading of stage 1. In turn, stage 3 would receive less than 1/4 the BOD loading of stage 1 and stage 4 would receive less than 1/8th. Discerning engineers would never design two, three, or four trickling filters in series flow of the same filter media size. Yet, the microbiological similarities between the trickling filter process and the RBS process are far more evident than their differences.

The frequently used concepts of disc surface area/tank volume ratio, oxygen limitation point, hydraulic loading, % BOD reduction per stage, and equal disc surface are in successive flow stream stages all have little viable importance either in understanding the RBS process or, more importantly, in designing optimum RBS process treatment systems.

The disc surface area/tank volume ratio is an incidental relationship to the RBS process. Doubling or halving this ratio has little or no effect on process efficiency, the ability of each square foot of disc surface area to remove a specific number of pounds of BOD per day. Increasing the tank volume by removing the downstream side tank or basin gussets does increase the stage to stage flow equalization and thus helps dampen out variations in influent feed.

Therefore, it is recommended if and only if the RBS process equipment is properly designed and rotated fast enough to prevent sludge accumulation with the system. The use of this ratio as a design requirement or regulatory agency approval condition however, is discouraged because it is incidental rather than controlling.

An oxygen limitation point does not exist. Biological activity depends on the simultaneous presence of BOD, nitrogen, phosphorus, and DO in a definite ratio. In stronger wastes, present RBS process equipment can fail to aerate the liquid to the extent demanded by metabolic rates. The process becomes oxygen deficient and

goes anaerobic. It then becomes necessary to lower the organic loading (and thereby the hydraulic loading) to the degree necessary to maintain aerobic conditions. This is not the phenomenon that can or should be described as an oxygen limitation point, however.

The process is simply oxygen limiting with respect to that particular set of load conditions. If nitrogen or phosphorus were not present to the extent required by metabolic rates, the process would become either nitrogen or phosphorus deficient. In other words, all four components are required in a definite minimum proportion to realize the full efficiency provided by the RBS process.

Having the proper amount of dissolved oxygen is just important as having the proper nutrient balance. With stronger wastes, and the organic loading approach disclosed in this article, the correct design of an RBS process treatment plant becomes dependent upon the amount or rate of oxygen mass transfer that can reasonably be expected from the particular RBS process equipment and rpm under consideration and the stage to stage sizing of disc surface area.

Hydraulic Loading Incidental

Hydraulic loading is only an incidental relationship to the RBS process. The hydraulic loading considered by itself can vary from 1 to 100 gal/sq. ft/day without appreciable effect on disc efficiency, that is, the ability of each square foot of disc surface area to remove a specific number of pounds of BOD per day. The same anaerobic system results whether one applies 100 gal/sq. ft/day of 50 mg/L BOD waste or 1 gal/sq. ft/day of 5000 mg/L BOD waste, assuming insufficient oxygen mass transfer. The organic loading in both examples is the same, namely 0.042 lbs. BOD/sq. ft/day (205 g BOD/sq. m/day).

Moreover, if a loading of either 50 gal/sq. ft/day of 50 mg/L BOD waste or 1/2 gal/sq. ft/day of 5000 mg/L BOD waste (again the same organic loading in both instances) is applied, the system will probably remain aerobic, depending again on sufficient oxygen mass transfer. The disc efficiency will be the same in both examples.

In Europe, where the RBS process originated, the vast majority of the first commercial applications were on domestic wastes. Even though these wastes did show some degree of variation in organic strength, the variation was not sufficient to warrant a variation in the design approach. It then became easier from an application standpoint to figure the hydraulic flow and population equivalent rather than organic strength.

This technique is quite acceptable to size systems (not unmindful of the concepts of organic loading and oxygen mass transfer explained in this article so long as one is dealing exclusively with either sanitary wastes or such other wastes that are comparable in strength and treatability or K-factor. However, the hydraulic loading principle drifted over into the area of industrial wastes in this country because a full understanding of the RBS process was wanting. Consequently, some of the systems

installed on industrial wastes in the United States on a hydraulic loading design basis have performed poorly.

For example, the Twin Cities, Minnesota Metropolitan Waste Control Commission purchased 5 million square feet of RBS equipment to remove 52,700 lbs. BOD/day average and 65,200 lbs. BOD/day maximum from a 1.35 mgd filter cake pressate return liquor flow stream. The design was based on hydraulic loadings following pilot plant testing with full size RBS process equipment. The system is scheduled for start-up in April, 1979. Unfortunately, it will not and cannot work.

Even with the presumption of 100% efficiency in the motor and drive system, the 375 available horsepower (7.5 hp on 50 shafts) must transfer 5.86 lbs. oxygen/hp-hr average and 7.24 lbs. oxygen/hp-hr maximum to satisfy biological metabolic demand assuming zero DO in influent feed. On dirty water, mechanical aerators such as the RBS process equipment are just not this effective.

Indeed, the first stages of this ten flow streams of five stages each installation are organically loaded at 0.062 lbs. BOD/sq. ft/day (303 g BOD/sq. ft/day) average and 0.087 lbs. BOD/sq. ft/day (425 g BOD/sq. m/day) maximum. Worldwide, there isn't a single RBS process equipment installation in satisfactory operation that is treating a first stage loading beyond 0.020 lbs. BOD/sq. ft/day (approximately 100 g BOD/sq. m/day). The hydraulic loading design approach is responsible for this inevitable RBS process failure.

Regardless, then of the biological treatment system employed, whether the RBS process, or trickling filter, or activated sludge and its multiple variations, one cannot escape the biological reality that one pound of BOD (by inherent definition) requires approximately one pound of dissolved oxygen to satisfy its metabolic demand. Hydraulics had absolutely nothing to do with this fundamental microbiological fact. Organic loading principles coupled with oxygen mass transfer efficiencies must be looked to as the controlling design approach. Existing state-of-the-art design curves based on hydraulic loadings must be abandoned if successful RBS process installations are contemplated.

Percent BOD reduction per stage treatment is another somewhat incidental relationship to the RBS process. In the design of any waste treatment system, it's a matter of removing a minimum number of pounds of BOD, suspended solids, and so forth, to meet regulatory agency requirements. The percent reduction (overall or per stage) is another method, and a secondary technique, of merely describing the primary requirement of removing X pounds of BOD. By changing the disc loading (organic loading) one can obtain removal efficiencies from 1 to 99% at a constant rpm on identical wastes treated with identical RBS process equipment.

Attention should be focused on the number of pounds of BOD each square foot of disc surface can remove. Somewhere between 1 to 99% is an organic loading rate that results in the maximum disc efficiency; the ability of

each square foot of disc surface area to remove a maximum number of pounds of BOD per day.

Maximum disc efficiency in turn means minimum plant size and minimum costs. If the RBS process permits the removal of 5,000 lbs. BOD/day by 1 million square feet of disc surface, what practical difference does it make if the removal takes place in one stage or ten stages?

Designing equal disc surface area into successive stages of treatment is always a most wasteful application of the RBS process. If, for example, the discs remove 0.004 lbs. BOD/sq. ft/day (20 g BOD/sq. m/day) in the first stage of treatment, the same square feet of disc area might only be removing 0.0004 lbs. BOD/sq. ft/day (2 g BOD/sq. ft/day) in the fourth stage. The fourth stage discs are performing at an order of magnitude less efficient than the first stage discs.

To achieve equal RBS process efficiency regardless of treatment stage requires equal organic loading per square feet disc area in each treatment stage. There must be more square feet of disc area in the first stage than the second, more in the second stage than the third, and so on. To maximize the RBS process efficiency is to maximize the organic loading in each stage of treatment to the extent that aerobic conditions can be maintained.

RPM Proves Important

RBS process pilot plant scale-up and disc rpm are closely interrelated. In researching the RBS process literature and case studies, not a single exception appears to the finding that the higher the rpm, the better the process performance, however measured. Almost all RBS process studies have attempted to maintain a disc tip speed or peripheral velocity of somewhere between 30 and 90 ft/min with about 60 ft/min being promoted as optimum.

No argument exists that higher rpm's provide better treatment. However; as the rpm is increased, the energy required to rotate the discs increases at an exponential rate.

For example, if it takes 1-1/2 hp to rotate a shaft of discs at 1 rpm, it would require approximately 5 hp to rotate at 2 rpm, and approximately 17 hp at 3 rpm. These hp requirements are only approximations dependent upon disc/shaft geometric design, shaft weight, amount of biological growth on the disc surface, and efficiencies in the drive system. The dramatic increase in hp required for each additional rpm indicates to the designer that some trade off in performance is better than the slightly higher installed cost and substantially higher operational costs dictated by the use of higher rpm's.

The point regarding rpm goes far beyond these fundamental power relationships. At a constant tip speed of 60 ft/min, a 1 foot diameter disc pilot plant rotating at 19 rpm operates better than a 2 foot diameter plant turning at 9.6 rpm. The 2 footer in turn provides better treatment than a 4 footer running at 4.78 rpm, and the 4 is better than the 6 foot disc at 3.18 rpm.

All the pilot studies on faster turning RBS process pilot units invariably provide a higher degree of treatment than the eventual full size commercial installation operating at around 1.6 rpm. The idea that tip speed is the proper scale-up basis is simply and obviously incorrect and should not be used.

The rpm phenomenon should be analyzed further. It is readily apparent that a 1 foot diameter shaft of discs rotating at 19 rpm transfers atmospheric air into dissolved oxygen at a higher rate than a 12 foot diameter shaft of discs rotating at 1.6 rpm on a square foot to square foot disc area basis, keeping percent submergence, water temperature, and initial DO the same in each case.

The peripheral speeds are indeed the same but the oxygen transfer rate per square foot of disc surface area surely must favor the higher rpm unit. Oxygen transfer rate per square foot of disc surface area is the controlling scale-up factor rather than tip speed. This conclusion is virtually inescapable when one investigates the RBS process literature.

For all practical purposes, rpm of the pilot plant study is the proper scale-up criterion rather than peripheral or tip speed of the discs. The higher the rpm, the greater the oxygen mass transfer, hydraulic biomass scour, and BOD reduction. A study to determine optimum disc rpm versus amortized RBS process equipment capital and operational costs is suggested. An optimum disc speed in the 2-3 rpm range on full size RBS process equipment is anticipated.

The technological fulcrum of all biological wastewater treatment is oxygen mass transfer. The RBS process should not escape the classical requirements for oxygen mass transfer. Adequate dissolved oxygen in sufficient contact with soluble organics and suspended solids is the common objective of all biological treatment systems. Even introducing oxygen into the wastewater en route to the municipal treatment plant produces measurable benefit.

Recognizing the need for dissolved oxygen, a company has developed an air pressurized packed tower mass transfer device to increase the DO of septic sewer wastes to 20 mg/L while it is en route to treatment. Whether one subscribes to the traditional two-film theory of mass transfer, the penetration theory, the boundary layer theory, or the recent zero-film theory oxygen transfer must ultimately occur somehow and somewhere.

So the disc aerator epithet is correct in categorizing the RBS process equipment. Using an air mixing tank just prior to the RBS process, intermediate interstage clarifiers, diffused air drive systems, aerotubes, and recommending 50% more disc surface area when treating septic wastes, are specific and individual admissions of the inability of the RBS process to transfer sufficient oxygen under the attendant hydraulic loading design conditions.

Comprehensive studies at a meat packing plant using flat discs on anaerobic lagoon effluent proved the ability of the RBS process to treat septic wastes without adding

additional disc surface area or more stages. Having a thin liquid film alternately exposed to the atmosphere and wastewater flow is insufficient by itself of producing optimum oxygen mass transfer.

Experienced sanitary engineers are well aware that open top trickling flatters decrease markedly in process efficiency in the spring and fall seasons. This phenomenon is explained by the lack of natural draft, or gas ventilation, through the bed. The diminished ventilation decreases oxygen mass transfer.

Applying this information to the RBS process, it seems logical that an open disc system that encourages gas ventilation between the discs is better as a mass transfer device than the closed-in varieties that have dominated the market. The same open design obviously compels greater hydraulic scouring action which flushes sloughed organic growths which have reached their stationary and death phases, thus permitting the exponential growth of new colonies in their place. Therefore, at the same rpm, an open geometric design should provide better RBS process performance than the closed-in configuration.

Forming A Design Approach

The single family of curves that characterize the entire RBS process are shown in the figure. Each of the curves A, B, and C can represent the same RBS process installation. The slope of these curves depends upon the treatability of the particular waste (K-factor) and the liquid temperature. If curve A depicts summertime operation performance, curve C might represent wintertime operation because of lower waste liquid temperature. Curve C could also represent summertime performance with a toxic condition present which retards biological activity and thus reduces the treatability (K-factor) of the waste liquid.

One need not be satisfied with lesser disc area efficiency because of a lesser K-factor or temperature. As the curves indicate, increasing the organic loading will permit higher removal efficiencies to occur. Points r and s exhibit equal removal rates.

Horizontal lines X, Y, and Z represent increasing disc rpm and/or aeration efficiency. The better the aeration, the greater the oxygen mass transfer. Thus, each RBS process equipment design at a specific rpm is capable of a specific aeration rate. If the oxygen demand exceeds this rate, the system goes anaerobic and very little treatment takes place. The solution, then, is to reduce the oxygen demand, to increase the aeration rate, or both. The correct design of an RBS process system starts with optimum conditions rather than worst case conditions.

Curves A, B, and C are virtually unaffected by hydraulic loading rate, hydraulic retention time, number of stages, tank basin design, or RBS process equipment design.

As a design approach example, assume an industrial customer generates 10,000 pounds BOD/day for 365/year with 24 hr/day continuous operation (thus removing the necessity for flow equalization design con-

siderations. The average daily flow is 1 mgd and the waste strength averages 1200 mg/L BOD. Further assume removal of 9,000 pounds BOD/day is required to satisfy waste treatment requirements.

Pilot plant testing produces curves A and B as representative of best and worst performance, respectively, that can be expected. Point r on curve B is chosen as the design loading level. The RBS equipment under consideration at a specific rpm is capable of aeration efficiency designated by line Y. Point r on the A curve (same organic loading as curve B but 68% greater removal rate) would still be within the aerobic region of that performance curve. RBS process plants have been designed with only worst case in mind which in turn have performed adequately under worst case conditions but have gone anaerobic under better treatment parameters.

At the design point, 5 pounds BOD are removed for each 10 pounds applied. The first stage of RBS process treatment would receive 10,000 pounds BOD. At an organic loading of 10 pounds BOD/1000 sq. ft/day (49g BOD sq. m/day), disc area translates into 1 million square feet. If an RBS process equipment shaft contains 100,000 square feet of effective surface area, the first stage of treatment requires 10 shafts and would remove 5,000 pounds BOD/day.

By repeating the same procedure, the second stage would require 5 shafts and would remove 2,500 pounds BOD/day for an accumulated total of 7,500 pounds BOD/day. The third stage of treatment would remove and additional 1,250 pounds BOD/day with 2-1/2 shafts (install 3) for a running total of 8,750 pounds BOD/day. A fourth stage of 1-1/4 shafts (install 2) would remove another 625 pounds BOD/day for a design total of 9,375 pounds BOD/day.

The ancillary hydraulic distribution is generally quite easy to design. The degree of conservatism used in the design is dependent upon engineer, customer, and regulatory agency judgment. The above design method is to be followed to determine both the square feet of effective disc area as well as the size and number of treatment stages. The preceding curves are not, of course, to be used for actual design purposes. They are illustrative only.

Using the same example, assume that for some reason, the performance of the RBS process plant is reduced to the degree represented by curve C. This performance curve is exactly 1/2 or 50% as effective as curve B. One might therefore predict that under curve C operation, 50% of 9,375 pounds BOD would be removed. Such is not the case.

By repeating the preceding steps, stage one receives 10,000 pounds BOD/day (specific hydraulics and stage size and numbers are now fixed according to curve B and point r) and removes 2,500 pounds/day. Since 7,500 pounds BOD/day remain, stage two sees an organic loading of 15 pounds BOD/1000 sq. ft/day (73 g BOD/sq. m/day) and removes 1,875 pounds BOD/day.

In succeeding fashion, stage three is loaded at 22.5 pounds BOD/1000 sq. ft/day (110 g BOD sq. m/day) and removes an additional 1,406 pounds BOD/day. Lastly, stage four is loaded at 33.75 pounds BOD/1000 sq. ft/day (165 g BOD/ sq. m/day) and removes 1,054 pounds BOD for an accumulated total of 6,835 pounds BOD/day or 72.9% of the removal experienced under performance curve B. This phenomenon explains why the RBS process is so stable against variations in both temperature and K-factor.

Another example exposes the fallacy of the currently accepted hydraulic design approach. Several RBS process plants have been designed to combine removal of BOD with nitrification. Columbus, Ind., and Spencer, Iowa, are two such examples. These designs are multi-stage with multiple flow streams. However, the first stages in these plants are subjected to the entire BOD organic loading.

The installed RBS process equipment can not possibly satisfy the first stage dissolved oxygen demand. Unknown to the designer, point t on curve A, or even higher organic loadings have been designed into these plants by relying on the hydraulic design approach. As a result, the first stage will go anaerobic, then the second, and so forth until the entire installation is disrupted. Ironically, more than sufficient disc surface area is present at the plant site to achieve required aeration, but the stage to stage sizing and arrangement are genuinely incorrect.

By adopting the organic design loading approach, RBS process equipment required for treatment of sanitary wastes will be less than half that designated by the current hydraulic design loading approach.

Evaluating Equipment Designs

RBS process equipment should be protected from the weather wherever installed. Enclosures can be close fitting covers or buildings. If covers, they need not be insulated because of the insignificant liquid heat loss. The small loss is sufficient, however, to prevent icing-up of the system during cold weather operation. Insulating the covers does nothing for the RBS process but does add to the installation cost.

In addition, the covers need not be specifically ventilated with louvers since 100,000 square foot surface area shaft requires about 10 cfm air for maximum aeration and 10 cfm air can easily enter the cover through structural fitting tolerances and leaks. Opening and closing ventilation louvers in reality has no effect on either heat loss or aeration. Insulation and ventilation louvers are luxury additions to cover design. If a building is chosen as the enclosure, auxiliary space heat is required in northern climates to prevent icing of the interior walls and to raise the air temperature sufficiently above the dew point for visibility.

The central shaft designs available are circular or square in section view. In dynamic operation and with either design there exists a linear compression of the disc media (to the extent of central shaft load induced deflection)

at the top elevation of rotation, and a similar but opposite linear extension of the disc media at the bottom elevation of rotation. In the case of the square shaft, there is an added torsional stress imposed upon the disc media because the amount of deflection of the central shaft varies as it rotates.

The load carrying capacity of the square shaft changes from a minimum to a maximum in 1/8th of a revolution whereas the load carrying capacity of a circular shaft is constant throughout its entire revolution. As the shaft rotates, load stresses are developed which require the disc media to move in both linear and radial directions.

In the case of square shafts, an additional twisting moment of force induced 8 times per revolution causes media movement in a plane perpendicular to the central shaft. In addition to the move movements of media surface, changes in temperatures can always cause three dimensional thermal expansion and contraction of the plastic. RBS process equipment designs that allow for media movement should be preferred over designs in which the media is bonded together, denying any movement without delamination occurring.

An experimental slow-speed air drive system or the standard speed electric motor gear-reducer drive system is now available. As the RBS process design curves illustrate, BOD removal capacity of the RBS process equipment is directly proportional to its rpm. A shaft of discs rotating at 0.8 rpm will not remove as much BOD as one rotating at 1.6 rpm.

Hydraulic scouring (or lack thereof) which occurs within the disc media to flush out the sloughed biomass is also important. Insufficient flushing can occur at low rpm and in turn means lesser surface area for new bacteria colonies to grow, a heavier shaft to rotate which translates into an increased energy demand, and more shaft deflection with more stress on the RBS equipment.

Nothing is inherently wrong with the air drive system other than the sluggish rpm and its low aeration efficiency. Increasing the air drive system will achieve equal BOD removal capacity.

Should one choose an open design or closed-in configuration? Is a square foot of one design equivalent to a square foot of another design? Probably not. Several differences, when considered together, produce a significant difference in terms of process efficiency. The open disc design allows for better gas ventilation and concurrent oxygen mass transfer.

For example, at a West Coast paper mill, a customer pilot plant study on the two designs resulted in a 14° F water temperature drop through the open disc system compared with only 1° F water temperature drop across the closed-in corrugated design under identical and simultaneous loading conditions. The rotating open disc assembly operates as an elementary centrifugal pump with a 1 to 3 inch (depending upon the rpm) hydraulic head developing across the tank basin.

With the closed-in design of the corrugated media, the hydraulic head doesn't develop nearly as much. Producing the head differential is important because the greater the hydraulic gradient the more the liquid is forced between the discs resulting in thorough back mixing within the basin. The better the mix, the better the ability to keep suspended solids and sloughed biomass solids from settling out and becoming anaerobic. In addition, internal clogging of the discs with sloughed slimes cannot occur in the open disc design.

At a Minnesota paper mill, for example, the corrugated media design shaft became almost twice as heavy in actual operation as the supplier had predicted on account of accumulated biomass within the plastic corrugations. Because of these better mixing, scouring, and mass transfer characteristics, the open design discs can and do operate at a higher efficiency than the closed-in designs.

However, the same West Coast paper mill eventually specified over 40% more corrugated disc surface area than open disc area on a competitive bid. Data obtained on open design discs should not be used to determine square feet of the closed-in design required, or vice versa, until a study provides the comparative efficiency relationship.

Understanding precedes design

The RBS process is capable of treating virtually any waste that responds to biological degradation. It is, by no means, a panacea to the waste treatment engineer. A competent understanding of the RBS process should be developed before attempting to design a disc treatment system. With respect to biological treatment in general, the more uniform the waste flow, strength, proper pH, nutrient balance, and temperature, the easier and more consistent the resulting treatment.

Substantial variation in any of these parameters requires remedial design engineering. When designing an RBS process system, these parameters are even more important. By comparison, activated sludge and its variations provide a tremendous hydraulic equalization chamber for biological reduction, contact stabilization excepted.

Significant hydraulic surges, organic slugs, pH changes, nutrient imbalances, and influent temperature changes can be accommodated, in most instances, with only a minimal effect on treatment efficiency. The same variations in an RBS process application could have a significant effect on treatment efficiency. Therefore, unless an RBS process follows some type of hydraulic equalization system, appropriate flow equalization should be designed into the system to assure optimum RBS process performance.

The RBS process is a high rate system and detention times are generally an order of magnitude less than the activated sludge systems, contact stabilization again excepted. Flow equalization is relatively easy and inexpensive to accomplish and should not be overlooked as an important design requirement.

The above statements on influent variations are design generalities. The degree of variation is what's important. The RBS process has already shown an excellent ability to accept organic and hydraulic slugs and surges similar to trickling filters. The distinction is that the more uniform the feed, the higher the performance in any biological system, and especially in an RBS process system design.

Waste flow to the RBS process can be interrupted each week for up to 48 continuous hours without noticeable effect on average treatment efficiency or performance quality. Under these conditions, the discs are simply rotated in their tank mother liquor. The disc/shaft direction of rotation in relation to hydraulic flow has no effect on the RBS process. Rotating with the flow (co-current path) requires less drive energy and is therefore recommended for that reason only.

The required disc spacing is dependent upon treatability of the waste and organic loading. For most applications, 1/2 inch is sufficient to prevent bridging provided that the RBS process equipment induces sufficient scouring action by adequate rotational speed. In this regard, very thin zoogloea growths (1/32") can produce maximum BOD reduction ability.

The disc/shaft can vary in submergence from 25% to 45% without appreciable effect on RBS process performance. While there is an actual hydraulic head gain of from one to three inches across each stage of treatment, small hydraulic gradients across the complete system are usually necessary to facilitate stage to stage hydraulic distribution.

The usual suspended solids generated by the RBS process range from 50 to 200 mg/L. Solids are kept in suspension by hydraulic turbulence and are washed out to the next stage of treatment at the same rate they are generated or sloughed off the support surface. Each stage of treatment is a complete mix chamber. In fact, since the discs are good mixers, the addition of chemicals or carbon to one or more stages is possible for additional downstream reactions such as phosphate removal and/or adsorption treatment.

Except for trash and grit removal, primary clarification can and should be omitted since primary solids add a disproportionately small BOD load to the high rate RBS process system and do not impede RBS process performance. This primary solids pass-through capability of the RBS process permits excellent cost effective complete plant designs.

The use of intermediate clarifiers between RBS process treatment stages is discouraged for the same reasons. The use of several (5 to 12) stages of treatment does not have a deleterious effect on eventual sludge settling rates, and is therefore permissible.

Additionally, the use of more stages rather than fewer stages has a rather good stabilizing effect on the consistency of effluent quality. Under normal operating conditions of somewhat variable feed, the exact metabolic

rates in each stage of RBS process treatment are forever changing as are the predominating cultures. Increasing the number of stages has the effect of minimizing the deviation from average treatment quality.

The rotating discs can be made from practically any construction material. Biological growth has been established on disc surfaces made from expanded polystyrene, polyethylene, polypropylene, ABS, stainless steel, cement, aluminum, glass, PVC, rubber, Teflon, wood, and wire screens. Bacteria will grow on discs rotated at 500 rpm. Bacteria will also grow in vessels up to 200 atmospheres pressure. In short, microorganisms will grow on practically anything than can be rotated under the appropriate set of environmental conditions.

The RBS process can provide treatment as complete as any other biological process. Only manufacturing, transportation, installation, and construction capabilities limit ultimate disc size and shaft lengths. A 50 foot diameter disc on a 200 foot linear shaft would work well from a purely RBS process standpoint. Size of RBS plants is exclusively a cost consideration.

RBS process central station plants can be designed to be competitive when technology discussed in this article becomes accepted, the RBS process could well be judged the best available process for cost effective biological wastewater treatment. By adopting these design principles, the engineer is assured of an accurate consideration of the RBS process as it actually performs.

Future Improvements Possible

W. Torpey et al. have obtained significantly improved RBS process results by introducing bottled oxygen above the rotating discs in an enclosed container.

The enriched oxygen atmosphere permitted greater oxygen mass transfer rates with a resulting improvement in RBS process performance.

The same result can be achieved by pressurizing the containerized space above and between the discs with less expensive atmospheric air. Using enriched oxygen atmospheres at elevated pressure would increase oxygen mass transfer even more, as would increasing the gas ventilation between the adjacent disc surfaces.

Increasing disc rpm's has already been fully discussed as the single most important factor in oxygen mass transfer. In pilot studies, the RBS process has removed up to 14 lbs. BOD/1000 sq. ft /day (41 g BOD/sq. m/day). Some of the existing oxygen starved RBS process installations can most probably be modified to permit greater oxygen mass transfer and thereby better process performance, by utilizing these mass transfer improvement concepts.

Since the RBS process is immune from hydraulic loading principles as well as the consequences of excessive hydraulics, it is an ideal process (if not the exclusive process) to treat combined storm and sanitary flows and also sanitary wastes which have been increased by inflow and infiltration. The RBS process can remove about 200

pounds BOD/day/applied horsepower by using the organic loading design approach. This efficient use of energy is unmatched by all other biological processes.

Absent the requirement for sludge recirculation, maintaining F/M ratios, and controlling bulking and other operational problems, the management of an RBS process system is most simple by comparison. Suspended solids are an order of magnitude less than the A/S processes making liquid/solids secondary separation more consistent and less expensive.

The mechanical reliability of the system must improve. Suppliers should be held to task for publishing RBS process design manuals based on someone else's data rather than their own, or transferring data from one geometric disc configuration to another at will. RBS process papers that present the data as obtained and then draw reasonable conclusions should be in more demand.

Researchers are beginning to understand more about the RBS process. However, there persist other studies

that draw conclusions far beyond the scientific data generated. Another example is the equation:

$$\% \text{BOD Reduction/stage} = K \times C^a \times R^b \times T^c \times S^d$$

which reflects at best an unimaginative approach rather than true scientific achievement or a reasonable attempt at it.

In general, the principles outlined in this article are directly applicable to biological nitrification designs utilizing the RBS process. Nitrification is also controlled by realities of biology rather than the convention or invention of hydraulics.

RBS process equipment suppliers, designers, planners, reviewers, funding sources, and end users should recognize that the RBS process is nothing more than high-rate trickling filters arranged in series flow. It is relatively simple. It should not be represented as undeservedly complex.

