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GAS — LIQUID CONTACTING WITH IMPELLER MIXERS

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A Unit of General Signal

MARCH 1977 PAGES 85-89

Gas-Liquid Contacting With Impeller Mixers

Experimental studies of physical and mass transfer characteristics helped develop a number of useful suggestions for evaluating gas-liquid contacting applications.

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One of the fascinations and complexities of fluid mixing is that there seldom is a single unique process requirement. Even the fluid mechanics of the mixing process involves unseen fluid shear rates and fluid shear stresses that are responsible for many process results, even though observable phenomena such as fluid motion, blending and dispersion, are an integral part of the process result.

Gas-liquid contacting involves two separate areas of consideration. One is the mass transfer of a solute from one phase to another. Examples are the transfer of oxygen from gas to liquid in various aeration processes, and the reverse case—the stripping of CO_2 from a solution by passing an inert gas through the liquid. In addition, the physical appearance of the gas bubbles passing through the tank and the surface action of the bubbles as they break free from the surface is of interest for many kinds of process equipment design considerations. When dealing with surface phenomena (such as is common with surface aeration impellers), or in the drawing down of a gas via a vortex from the head space in a dead-end, gas-liquid process, there are additional features of these flow patterns that are of concern from both a process and mechanical standpoint. Mass transfer is related to the physical dispersion of the gas, but the two must be considered separately in terms of the required process result.

This article deals with each of these two separate bases. The first part presents the results of mass transfer measurements in which the oxidation of sodium sulfite with air at various gas rates and mixer power levels was analyzed to yield a volumetric mass transfer coefficient based on gas phase concentrations, K_GA. These mass transfer studies evaluated the effect of many geometric properties on the overall mass transfer rate.

Many explanations for the effect of various geometric ratios involves a knowledge of whether the flow pattern of the tank is controlled by the gas phase passing up through the tank, or if it is controlled by the mixing impeller as it pumps the mixture of gas and liquid in its normal flow pattern. These phenomena have been discussed in a previous article. (*1*)

The effect on optimum impeller diameter to tank diameter ratio (D/T) of the ratio of the power drawn by the mixing impeller to the gas expansion energy passing

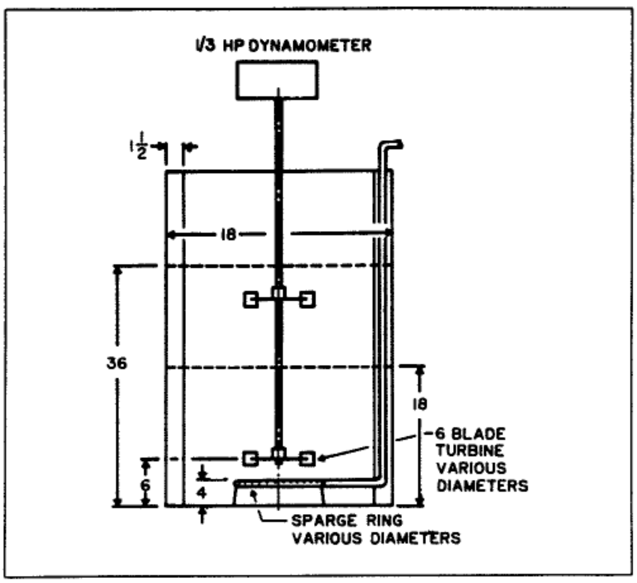

Figure 1. Equipment for mass transfer studies.

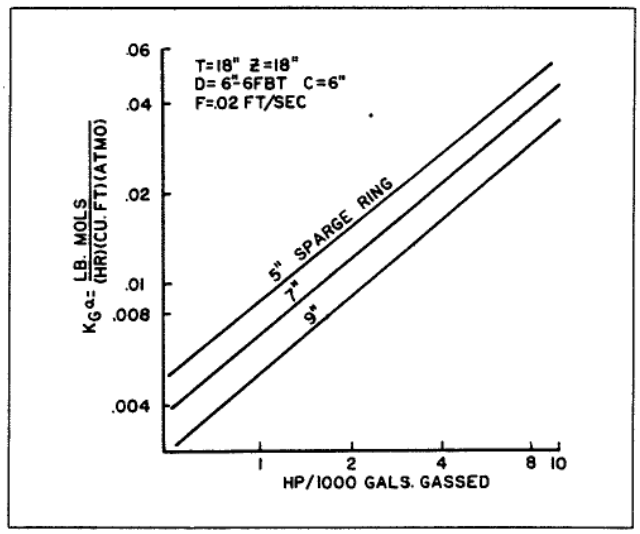

Figure 2. Effect of sparge ring diameter on mass transfer performance of a flat blade turbine impeller, based on gassed horsepower, at gas velocity, F, of 0.02 ft./sec.

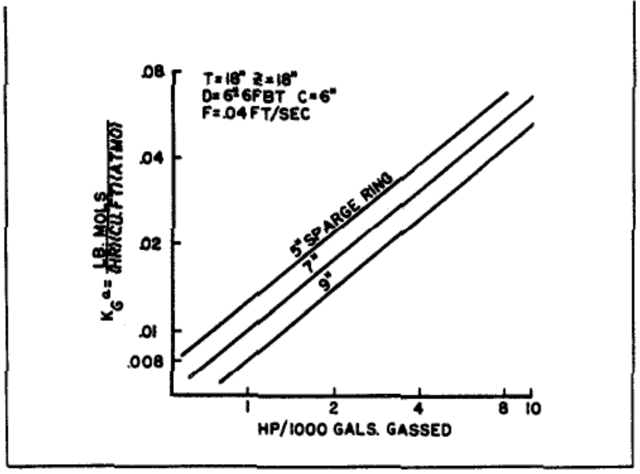

Figure 3. Effect of sparge ring diameter on mass transfer performance of a flat blade turbine impeller, based on gassed horsepower, at gas velocity, F, of 0.04 ft./sec.

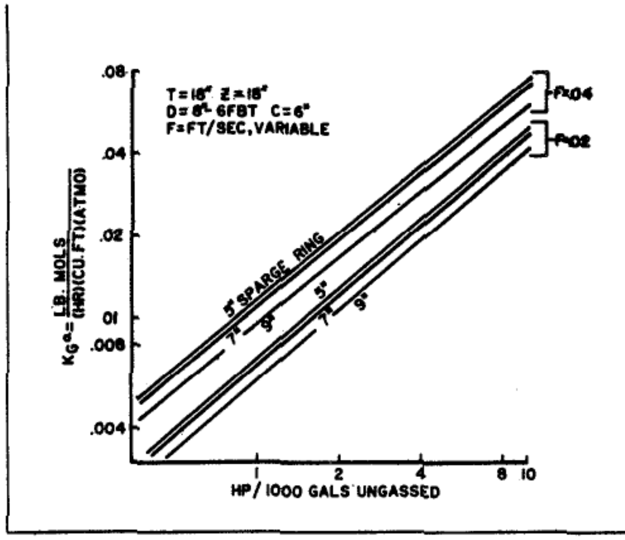

Figure 4. Effect of sparge ring diameter on mass transfer coefficient for various gas rates and ungassed horsepower input from the impeller.

Table 1. Agreement between replicate runs.

Tank: 18 in. dia., 18 in. liquid level, flat bottom, four 1 1/2 in. baffles
Turbine: 6 in. dia., 6 flat blade, 6 in. off bottom.
Turbine Speed: 196 rev./min.
Air Flow: 0.0375 ft./sec.
Center Inlet: 1/4 in. i.d., 1: below turbine, on center

Run	Horsepower Ungassed	Horsepower Gassed	$K_G a \times 10^2$ (lb.-mols)(Atm.)/(hr.)(cu.ft.)	Deviation From Average, %
1	0.0204	0.0112	0.568	−4.0
2	0.0204	0.0112	0.568	−4.0
3	0.0204	0.0112	0.619	+4.0
4	0.0204	0.0112	0.619	+4.0
			0.594 (average)	

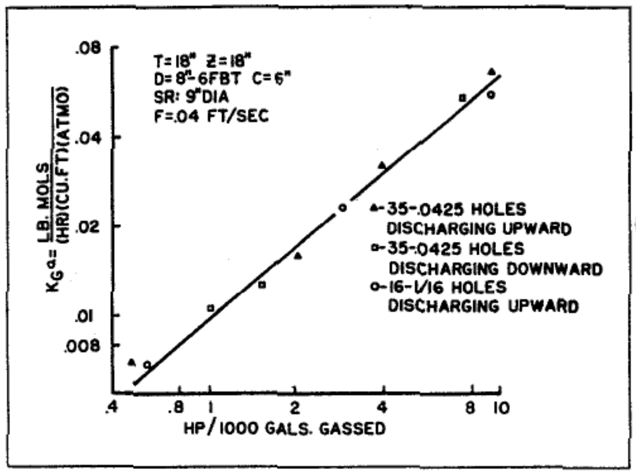

Figure 7. Effect of size of holes and direction of discharge for various sparge rings on absorption coefficient, based on gassed horsepower drawn by the impeller.

through the tank has also been discussed elsewhere. (2)

The second part of this article examines the physical characteristics of gas-liquid systems. Data were taken from a purely physical, visual measurement standpoint, which illustrates some of the observation criteria that can be made. Examples of where surface action is important include the area of flotation, when it is desired to scoop off the foam on a flotation unit. Also involved are considerations of foaming, which may be either good or bad, depending upon the circumstances.

The actual observations made during this part of the program included a very basic observation in measurement of the power required under various geometric conditions, to switch the flow pattern from a gas-controlled flow pattern to a mixer-controlled flow pattern. Observations were made of bubble size, bubble volume, various discharge areas of the gas bubbles, and similar characteristics.

For illustration in this discussion, we have chosen two of these measurements:

1. The diameter of the swell, brought on by the gas phase, increases as the power level increases to the point when it reaches the diameter of the tank, at which point the mixer is ready to take over the flow pattern and reverse it.

2. The height of geysers that leave the surface are measurable drops of water rising to the observed height, which erupt in a separate and distinct fashion. When the geysers approach zero height, this is another necessary condition for the mixer flow pattern to take over and control the overall dispersion in the system.

Should oxidation rates and flotation rates be satisfactory with a gas-controlled flow pattern, it is very difficult to economically justify putting in additional mixer horsepower merely to get a mixer-controlled flow pattern, even

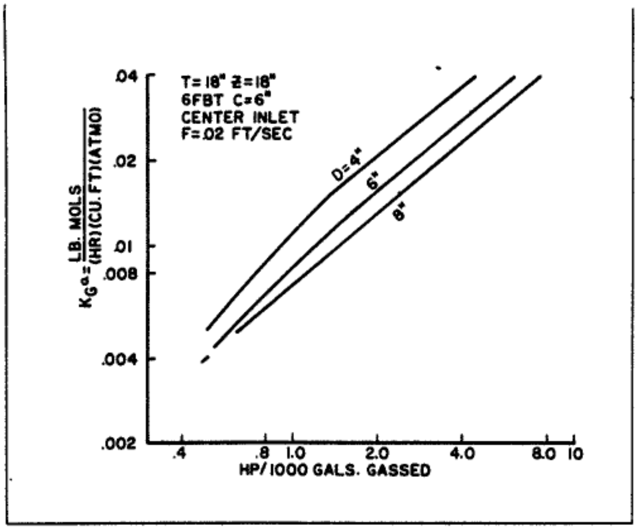

Figure 5. Effect of horsepower and impeller diameter on mass transfer coefficient at gas velocity of 0.02 ft./sec.

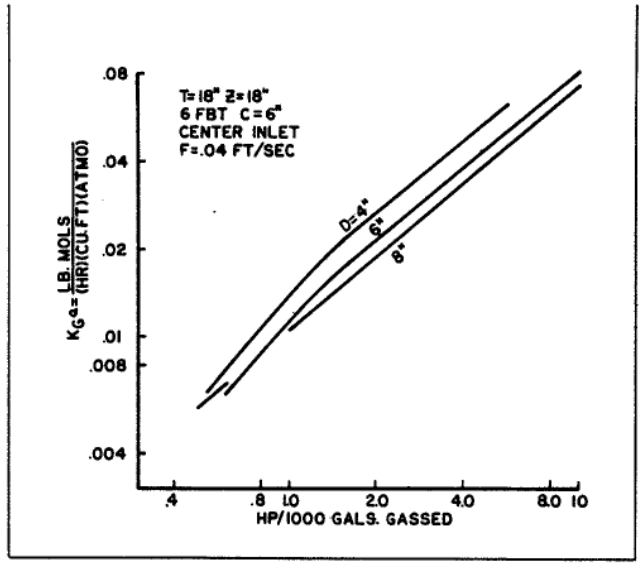

Figure 6. Effect of horsepower and impeller diameter on mass transfer coefficient at 0.04 ft./sec. gas velocity.

though this may drive the gas bubbles down to the bottom of the tank, or do other things to dispersion that logic says should be a part of a properly designed gas-liquid system.

A required mass transfer rate can be achieved at various combinations of mixer horsepower and gas flow, and will encompass a wide variety of fluid regimes. It is often requirements other than the mass transfer rate that dictate the flow pattern, including overall cost considerations and the practical facts of foaming, flotation, and the effect on mechanical characteristics.

It should be kept in mind with regard to mass transfer that the physical appearance of the gas stream can be very important in terms of foaming, splashing, surface conditions, and on impeller fluid forces. In addition, when considering physical characteristics of dispersion, if there is a mass transfer step going on, *controlling parameters for mass transfer may be quite different from parameters that visual criteria indicate should be controlled.*

Experimental apparatus

Mass transfer experiments were conducted in an 18-in. diameter tank with liquid levels between 18 and 36 in., using the oxidation of sodium sulfite by air as a measure of the mass transfer result.

The flat blade disc impellers used in most of the studies were carefully proportioned 4-, 6-, and 8-in. diameter models of commercial prototypes.

Five types of gas introduction devices were used; four sparge rings and one open-ended pipe with a discharge area of 0.049 sq. in. Three sparge rings with diameters of 5, 7, and 9 in. had 16 holes each 0.0625 in. in diameter, for a total area of 0.049 sq. in. The other sparge rings had 35 holes, 0.0425 in. in diameter.

Figure 1 is a schematic diagram of the equipment, and Table 1 shows the reproducibility of replicate results.

Figures 2 and 3 present data for 5-, 7-, and 9-in. diameter sparge rings used with a 6-in. diameter impeller at two different gas rates and several power levels. The plots are

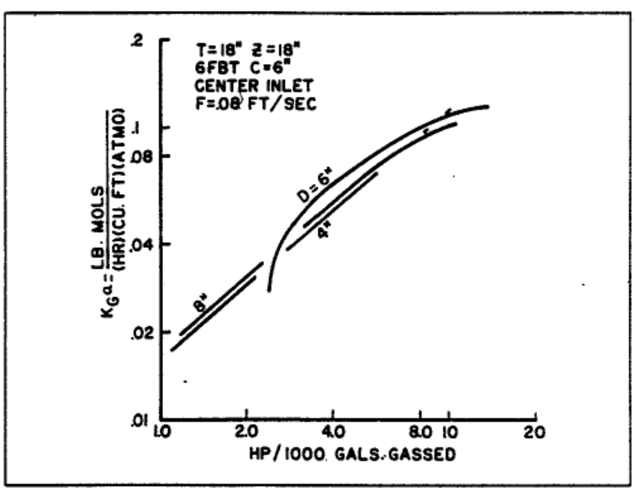

Figure 8. Effect of horsepower level and impeller diameter on the mass transfer coefficient at 0.08 ft./sec. gas velocity.

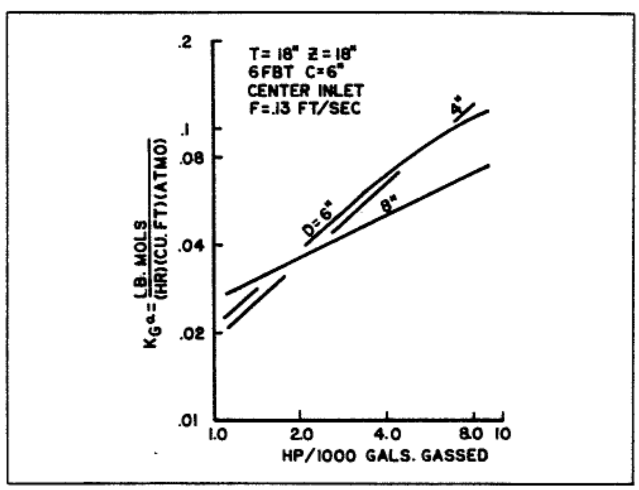

Figure 9. Effect of horsepower and impeller diameter on mass transfer coefficient for gas velocity of 0.13 ft./sec.

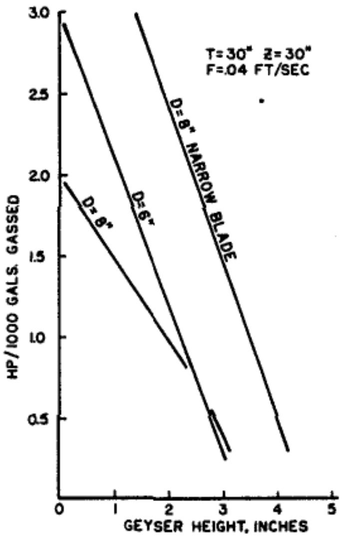

Figure 10. Effect of horsepower level on geyser height for a 30 in. diameter tank and various impellers.

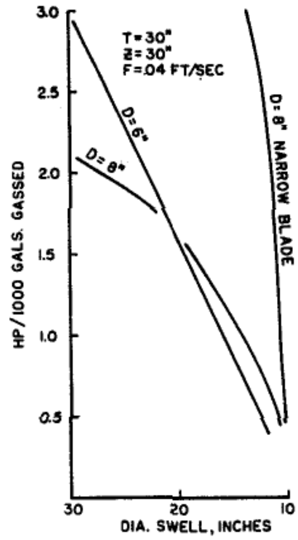

Figure 11. Effect of horsepower on the diameter of the swell of the rising gas velocity, with various impellers.

based on gassed horsepower drawn by the impeller. As shown, the 5-in. diameter sparge ring is more effective than 7- or 9-in. sparge ring. This is a general observation that, based on equal gassed horsepower, the most effective sparge ring diameter is between 0.8 and 0.9 of the impeller diameter, for overall mass transfer considerations.

Since impellers draw different horsepower at various gas rates and given speeds, comparisons can be made either on the basis of equal ungassed horsepower, Figure 4, accepting whatever horsepower results at a given gassed rate and speed, or may be compared as in Figures 2 and 3 at equal gassed horsepower.

Data using a center inlet pipe, shown in Figures 5 and 6, indicate that a center inlet has a lower performance than the 5-in. sparge ring, and about the same as a 7-in. sparge ring. A center inlet is about 10 to 15% less effective at a given gassed horsepower level than a properly designed sparge ring.

Figure 4 compares the 5, 7, and 9 in. diameter sparge ring with 8 in. diameter impeller at constant ungassed horsepower. Ungassed horsepower means that the equipment has been selected to operate properly at zero gas rate, and that one must then accept whatever horsepower is drawn by the equipment, under the conditions of gas flow and gas introduction design. In these cases, there is less advantage in a sparge ring of 0.8 to 0.9 impeller diameter, because it reduces the power somewhat more than a larger diameter sparge ring, which counteracts some of the increased mass transfer ability at a given ungassed horsepower.

The center inlet pipe turns out to be much less effective under ungassed conditions, since it reduces the power drawn by the impeller far more than the sparge ring does, and coupled with its inherent lower performance at gassed power, it shows a 20 to 30% lower value.

While it is not a prime feature of this discussion, the K factor is defined as the horsepower drawn by an impeller at a given gas rate compared to the horsepower drawn by the impeller at the same speed and no gas rate. Equipment can be designed either for ungassed operation, or with suitable controls of gas flow or mixer speed, can be operated at the gas rate and protected against possible overloads at reduced gas rates.

These data indicate the necessity of evaluating process performance under the mode that is going to be used to operate the mixing equipment. The gas inlet design affects the mass transfer coefficient, it affects the K factor, as well as the mechanical design.

The big advantage for the open pipe is its ease of cleaning and usual freedom from plugging.

Figure 7 shows the absorption rate at constant gassed horsepower between various designs of sparge rings. The sparge rings have two different hole sizes of the same total cross-section area and one different cross-section area. Under this condition which, in the main, is under a mixer-controlled flow pattern, there is very little difference in the sparge ring designs.

Other observations not reported here show, in general, that sparge ring design has more effect on performance in terms of the overall gas-liquid mass transfer rate when the *gas controls the flow pattern* than it does in the case illustrated here, where the mixer controls the flow pattern.

Tests with center inlet pipe

Figures 5, 6, 8, and 9 show successively the absorption coefficient with 4-, 6-, and 8-in. impellers at gas rates of 0.20-, 0.04-, 0.08-, 0.13-ft./sec. It can be seen that at the low gas rate the 4-in. diameter impeller is more effective. At the 0.04-ft./sec. gas rate, the 8-in. impeller is somewhat more effective than the 6-in. impeller at low impeller power, while at the 0.08-ft./sec. gas rate the 6-in. impeller has become more effective than the 4-in. impeller at low horsepower; with the 4-in. impeller still more effective at the higher horsepower.

At the high gas rate, the 8-in. impeller is more effective at the low power levels, while the 6-in. impeller is more effective at the higher horsepower levels, and the 4-in. impeller is inferior over most of the range.

This might sound very confusing, but in reality, it is a further illustration of the concepts presented in another paper 10 years ago. (*2*) At low horsepower levels, compared with gas flow, the mixer has difficulty in providing sufficient pumping capacity to physically control and handle the gas rates. Under these circumstances, typified by Figures 8 and 9, the larger diameter impeller is more effective until the power level rises to where the mixer can easily control the flow pattern at a smaller D/T.

As the mixer horsepower rises relative to the gas rate, smaller and smaller impellers become more effective, because the system requires a higher level of fluid shear rate to obtain the optimum combination of gas-liquid mass transfer. Figures 5, 6, 8, and 9 were all based on gassed horsepower.

Again, it should be emphasized that these are based on mass transfer considerations; they do not, at this point, take into account different appearances of surface level, size of bubbles passing through the system, or other variables that may affect both the physical appearance and performance of the tank, as well as the fluid force imposed on the impellers as it affects the fluid or shaft design of the equipment.

Comparing a sparge ring with a center inlet pipe, at equal gassed horsepower, the center inlet is about 10% less effective in terms of $K_G a$ and gassed horsepower than a sparge ring with $0.8D$ diameter.

Looking at ungassed horsepower, if a mixer is installed at a given speed and rated at horsepower to be run ungassed and then the gas is turned on to a design condition, the center inlet normally has a lower power consumption than a sparge ring and the 10% reduction in performance becomes almost 30% because of the additional drop in horsepower consumed by the impeller.

The experimental procedure for mass transfer runs is outlined below: The tank was filled with tapwater at about 68°F, to heights of 18 and 36 in., respectively, for use with single or dual turbines. Sufficient C.P. anhydrous sulfite to make a solution of approximately 0.2N in sulfite ion and C.P. anhydrous cupric-sulfate to produce a Cu^{++} ion concentration of at least 10^{-3} molar were added.

The rate of oxygen absorption was measured by determination of the unoxidized sulfite ion content of the solution before and after gassing. The analysis was done by the usual idiometric procedure of back-titration with standard thiosulfate solution to a starch indicator end point.

Visual observation studies

We now turn our attention to a completely different type of gas-liquid process. In this case, we are interested in keeping surface phenomena below the point where they will cause problems with splashing, geysering, and foaming, typified by the situation where the mixer has no effect on mass transfer and the operator wishes only to blend, to obtain solids suspension, or to allow a flotation type of foam separation to take place in the system.

Measurements were made of many different parameters, including the height of geysers coming out of the surface and the diameter of the swell created by a gas-controlled flow pattern. When the height of the geysers approaches zero, the condition is such that the flow pattern is about to become mixer-controlled. At this point, we have a measure of the horsepower required to achieve this condition.

Similarly, when the diameter of a swell due to the gas bubbles passing through the tank approaches the tank diameter (in this case 30 in.), we have another condition that gives the same horsepower; this is another definition of the horsepower required to change from a gas-controlled to a mixer-controlled flow pattern. Other observations, such as frequency of geysering and percentage of bubbles in the tank, can also be used as a physical measure of the performance of different kinds of systems.

Information like this can be used to evaluate the effect of various impeller types and also substantiates the basic fluid mechanics principles involved in contolling gas dispersion and the condition when changing from a gas-controlled to a mixer-controlled flow pattern.

Figure 10 shows that in terms of the height of geysers coming off the 30-in. tank (in this case the impeller is used with a sparge ring) the 8-in. diameter impeller of the standard flat-blade turbine design gives a result at lower horsepower, as does the 6-in. diameter impeller. This indicates that pumping capacity is the primary phenomenon governing the dispersion of gas in terms of surface phenomena and the horsepower required to attain a mixer-controlled flow pattern.

This does not mean that this would be compatible with the effect of these variables on gas absorption.

In Figure 10 is also plotted the horsepower required for a narrow-bladed, high-shear impeller. This again corroborates the foregoing statement that high shear is inferior in horsepower requirements for this criterion.

Using a different criterion, Figure 11 shows the diameter of the swell of the gas bubbles rising up to the tank, and it can also be seen that the higher pumping capacity and lower shear rate requires less horsepower for any given situation, including that required to change to a mixer-controlled flow pattern. This indicates that the conclusion drawn in the previous paragraph is shown by this phenomenon also.

Hysteresis is always a possibility with gas-controlled flow patterns. An impeller operating with no gas sets up a flow pattern and draws a certain level of power; when the gas is turned on, the power is reduced but it can be a different value than if the gas and the mixer were turned on initially at the same time. This is the cause of occasional abnormalities in the field when power does not correspond to predicted power levels.

Some suggestions

The following list contains some suggestions for evaluating gas-liquid contacting applications:

1. Define the various types of mass transfer requirements, physical gas dispersion, and flow pattern requirements.
2. Consider and discuss the effect of mixer variables on the overall mass transfer rates required, and the various possible combinations.
3. Look at the physical effect of the gas dispersion under these various conditions that are suitable for the mass transfer requirement.
4. Evaluate different mixers that may be suitable for various combinations of performance variables, all of which yield the desired mass transfer result.
5. In the event that mass transfer is not at all a part of the process, evaluate the effect of physical dispersions on the appropriate criteria.
6. Avoid using the wrong criteria or irrelevant criteria to evaluate a given potential process performance. #

Literature cited

1. Oldshue, J. Y., *Ind. Eng. Chem.*, **61**, 79–89 (1969).
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Nomenclature

C = Off-bottom position
D = Impeller diameter
D_b = Blade length
D_d = Disc diameter
D_w = Blade height
F = Ft./sec. gas velocity
$K_G a$ = Absorption coefficient, lb. mol./(hr.) (cu. ft.) (atm.)
N = Speed
Z = Liquid level

J. Y. Oldshue is vice president, mixing technology, Mixing Equipment Co., Inc. The author of numerous articles on the role of mixing in such diverse areas as chemical processing, paper manufacture, mining operations, food processing, petroleum processing and waste and water treatment, Oldshue is the recipient of B.S., M.S. and Ph.D. degrees in chemical engineering from Illinois Institute of Technology. A registered professional engineer in New York State, he chairs the metric commission of Engineers Joint Council.

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