

Performance of Agitated

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GAS-LIQUID CONTACTORS

A method of studying the design variables pertinent to agitated gas-liquid reactors has been developed; the catalyzed rate of air oxidation of aqueous sodium sulfite and the agitator power consumption are measured. Volumetric absorption coefficients for agitated contactors are shown to vary with (agitator power)^{0.95} and with (gas velocity)^{0.67}, giving rise to a new function, absorption number, defined as $K_v/V_s^{0.67}$, where K_v is the absorption coefficient and V_s is the average gas velocity based on the cross section of the reactor. When plotted against agitator power input per unit volume of liquid, this function is shown to correlate data for vaned-disk impellers and flat paddles covering, respectively, three- and tenfold variations of scale size; it thus becomes a satisfactory basis for the design of plant equipment. Power magnitudes ranging from 10 to 3000 ft.-lb./(min.)(cu.ft.) and gas rates ranging from 20 to 360 feet/hour are reported. Application of this correlation to the study of design variables is illustrated by data relating the performance of a laboratory reactor to liquid depth. A no-gas power correlation of the familiar power function-Reynolds number type is presented for the vaned disk operating in a baffled tank.

FOR absorption applications to which conventional plate or packed columns are not well suited, such as gas-liquid reactions involving more than two phases, agitated gas-liquid contactors are useful. Outside of a few laboratory studies of specific reactions carried on in agitated flasks, no investigations of mechanical gas dispersers have been reported, and no rational basis for the design of this important type of equipment exists. This paper describes a laboratory method of evaluating the variables pertinent to such equipment and proposes a basis for the design of plant gas-liquid reactors.

The rate of solution of a gas in a liquid is a function of the following factors: area of gas-liquid interface, temperature, time of contact, magnitude of driving force, and intensity of agitation. If simultaneous absorption (physical) and reaction (chemical) are occurring, such additional factors as solute or catalyst concentration, pH, and light intensity may be involved. In a given system, these reaction factors and the items of temperature and driving force are usually either fixed or easily controllable to give the optimum conditions; area of contact, time of contact, and agitation thus become the variables most important to the design of gas-liquid contacting equipment.

Strictly speaking, gas dispersers are concerned only with the variables of area and time of contact, since it is their function to divide the gas into bubbles and to disperse these bubbles through the liquid phase. In so doing, however, they always produce within the liquid phase a degree of turbulence which may vary from that produced by the gas stream emanating from a sparger into an unagitated reactor, to that developed by a high-speed impeller operating in a baffled vessel. Liquid turbulence is in itself not undesirable, since most absorptions are controlled partially or entirely by the liquid-film resistance, and agitation of the liquid phase therefore enhances the rate of mass transfer. Also, eddy currents in the body of the liquid may improve contactor performance by directly increasing the liquid shear on the

dispersed bubbles and by lengthening the average retention time of the bubbles.

The most direct method, then, of evaluating disperser performance is by count and measurement of the bubbles produced, obviously not a practical scheme. An indirect but more practical procedure is to measure the rate of gas solution for some system in which the gas-film resistance entirely controls. Such measurement does not differentiate between area of contact and retention time, but it does largely eliminate the variable of agitation intensity. Unfortunately systems whose resistance is primarily in the gas film are not susceptible to simple, dependable measurement; the easiest, most reliable, batch laboratory determinations of absorption rate must be made on systems in which the liquid-film resistance is considerable. Such a system provides a third means of disperser evaluation which, although less desirable from the standpoint of developing fundamental knowledge, should be satisfactory when applied to commercial designs operating in systems with the usual high liquid-film resistance.

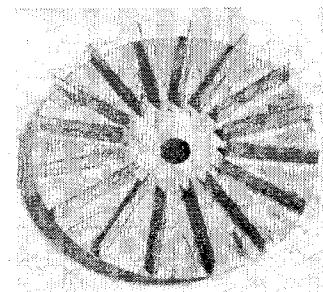


Figure 1. Vaned Disk

SULFITE-OXYGEN REACTION

The system oxygen-aqueous sodium sulfite was shown by Miyamoto, Kaya, and Nakata (12) to involve negligible gas-film resistance. The rate of the sulfite-oxidation reaction depends on the pH of the sulfite solution, and has been reported to proceed most rapidly in neutral or slightly alkaline media (8, 9, 10). The effect of temperature is not unusual, the reaction rate doubling as the temperature is increased from 0° to 10° C. (14), and increasing more slowly in the range 20° to 40° C. (10). The most remarkable characteristic of the reaction is that it proceeds at a rate independent of sulfite-ion concentration over wide concentration ranges. This phenomenon, observed by a number of investigators (2, 8, 11, 12), was most satisfactorily explained by

Table I. Effect of Sulfite- and Sulfate-Ion Concentration on Rate of Oxidation of Aqueous Sodium Sulfite

Temperature, ° C.	Na ₂ SO ₃ Normality	Absorption
		Coefficient, Lb. Moles/(Hr.) × (Cu. Ft.) (Atm.)
24.2	0.93 - 0.84	0.0188
24.5	0.84 - 0.76	0.0175
25.0	0.76 - 0.63	0.0175
25.5	0.63 - 0.52	0.0182
26.0	0.52 - 0.42	0.0185
26.0	0.42 - 0.34	0.0187
26.0	0.34 - 0.24	0.0185
26.0	0.095 - 0.035	0.0182

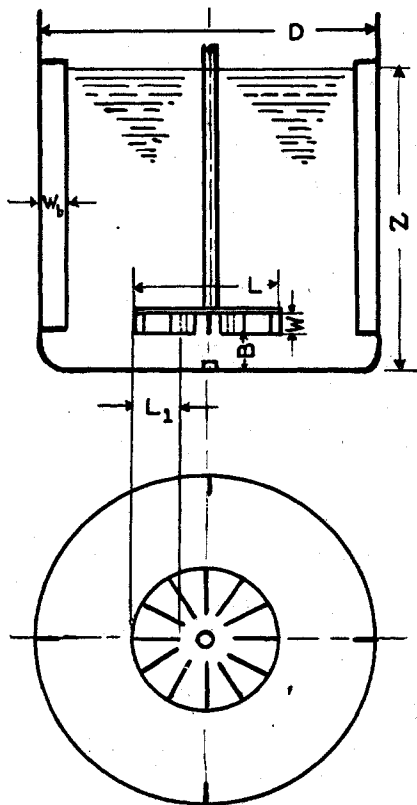


Figure 2. Proportions and Arrangement of Apparatus

$L/D=2.5$; Z/D =variable; $W/L=0.1$; $B/D=0.3$,
 $L_1/L=0.35$; $W_b/D=0.08$ to 0.10 .

which results are reported lay within the limits of the table; for the purpose of this study, therefore, the sulfite oxidation reaction may be considered of zero order with respect to both sulfite and sulfate concentration.

APPARATUS AND PROCEDURE

The experimental absorptions were carried out in geometrically similar, straight cylindrical tanks of the sizes listed in Table II. The four smaller vessels were made of Pyrex; the largest was of smooth steel plate. Four vertical wall baffles, extending from top to bottom of each tank, were clamped at equal intervals about the top edge of each container. For the glass tanks, the baffles were brass; for the steel tank, wood timbers of the proper size were used.

Table II. Summary of Equipment Dimensions (in Inches)

D"	Agitator	L"	W"	L ₁ "	B"	W _b "
6.0	Vaned disk	2.44	0.25	0.88	1.8	0.50
8.3	Vaned disk	3.31	0.31	1.19	2.5	0.75
9.5	Vaned disk	3.88	0.38	1.38	2.9	0.75
9.5	Flat paddle	2.38	0.41	...	3.2	0.75
17.3	Vaned disk	6.88	0.70	2.41	5.2	1.50
96	Flat paddle	24	4	...	30	8

Two types of agitators were tested. The first, a modification of the stirrer suggested by Huber and Reid (6), consisted of a flat disk bearing on its lower face sixteen radial vanes; each vane originated at the disk periphery and extended inward for a distance of about one third the disk diameter. Figure 1 shows a typical vaned disk viewed from its lower surface. The vaned disk was tested in the four smaller tanks; the proportions of the disk were held constant for all scale sizes of equipment, as indicated in Table II and Figure 2. The other agitator, tested in the 9.5- and 96-inch tanks, was a simple flat paddle whose length was one fourth the tank diameter. The agitators were fastened to

the shafts by hubs and setscrews. The shafts for the four smaller tanks were held in the chuck of an ordinary drill-press head, driven by a motorized Reeves variable-speed transmission and step-cone pulleys (Figure 3). The shaft for the 96-inch tank was coupled to the output stub of a variable-speed reducer. Clean air from the laboratory pressure line (100 pounds per square inch) was metered by a sharp-edged orifice and was introduced into the tank through a single open-end pipe directly beneath the center of the agitator. The air was delivered from the sparger in a vertical stream. A needle valve made it possible to control air rates closely. The procedure of making a run follows: Tap water at about room temperature was placed in the tank and the agitator was started. Sufficient c.p. sodium sulfite crystals to make the solution approximately 1 normal in sulfite ion and c.p. cupric sulfate to produce a Cu^{++} concentration of at least 10^{-3} molar were added and allowed to dissolve. The air was then turned on, and a timer was started when the first bubbles of air emerged from the sparger. With practice it became possible to open the valve quickly to approximately the correct degree, and the air rate could be adjusted to the desired value in a few seconds. The oxidation was allowed to continue for 4-20 minutes, after which the air stream, agitator, and timer were stopped at substantially the same instant. During the aeration interval, the agitator power was measured several times. Normally the power requirement was quite constant for a given run. Rate of oxygen absorption was measured by determination of the unoxidized sulfite-ion content of the solution before and after each run, in the manner developed by Bellas and Flinn (1). Samples of 5-100 ml., depending on the size of the tank, were pipetted from the solution before and after each run. Each sample was run immediately into an excess of freshly pipetted standard iodine reagent, the tip of the sulfite pipet being held not more than 0.5 inch from the iodine solution surface. Analysis was completed by the usual iodometric procedure of back-titration with standard thiosulfate solution to a starch indicator end point (7). Preliminary experimentation showed that the only

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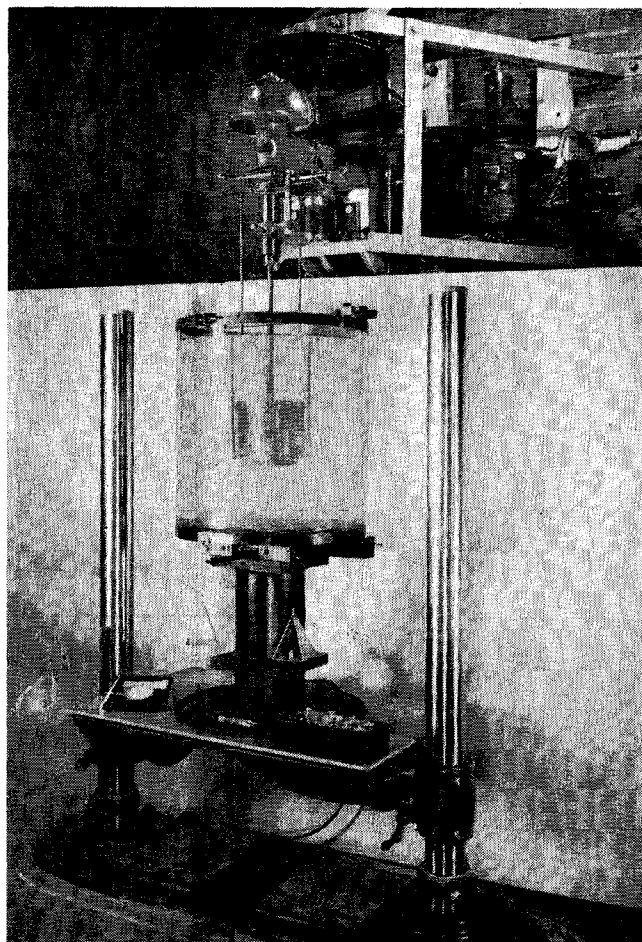


Figure 3. Experimental Agitation Equipment

Table III. Vaned Disk Performance Data When $Z/D = 1$

Vol. of Soln., Cu. Ft.	n , R.P.M.	P_s , Ft.-Lb./ (Min.) \times (Cu. Ft.)	Absorption Rate, Lb. Moles/ (Cu. Ft.) \times (Hr.)	Oxygen Efficiency, %	K_s , Lb. Moles/ (Cu. Ft.) \times (Hr.) (Atm.)	V_s , Ft./Hr.	$\frac{K_s}{V_s^{0.67}}$
$L^* = 2.44$ Inches							
0.104	396	202	0.00144	2.71	0.00694	46.1	0.000538
0.104	396	156	0.00299	1.05	0.0143	248	0.000362
0.104	602	765	0.00388	7.34	0.0192	46.1	0.00149
0.104	607	429	0.00548	1.93	0.0264	248	0.000668
0.104	893	2740	0.0129	24.2	0.0706	46.1	0.00547
0.104	893	1370	0.0144	5.07	0.0702	248	0.00178
$L^* = 3.31$ Inches							
0.255	411	292	0.00386	2.29	0.0186	199	0.000547
0.255	411	336	0.00284	3.85	0.0138	86.6	0.000705
$L^* = 3.88$ Inches							
0.394	419	946	0.00278	19.9	0.0149	19	0.00209
0.394	419	754	0.00414	8.74	0.0206	65	0.00127
0.394	419	603	0.00480	7.00	0.0236	93.5	0.00115
0.394	419	460	0.00502	4.58	0.0246	149	0.000869
0.394	419	427	0.00600	3.85	0.0291	212	0.000813
0.394	296	298	0.000886	6.32	0.00436	19.0	0.000612
0.394	296	222	0.00152	3.20	0.00734	65.0	0.000453
0.394	296	213	0.00159	3.23	0.00766	66.7	0.000464
0.394	296	180	0.00172	2.57	0.00832	91.0	0.000410
0.394	296	200	0.00170	2.48	0.00818	93.5	0.000397
0.394	286	203	0.00217	1.98	0.0104	149	0.000369
0.394	173	55.2	0.000267	1.91	0.00128	19.0	0.000180
0.394	173	62.2	0.000768	1.12	0.00367	93.5	0.000173
0.394	173	62.2	0.00102	0.93	0.00488	149	0.000178
0.394	172	63.7	0.00150	0.96	0.00750	212	0.000209
0.394	598	2870	0.00591	42.2	0.0367	19.0	0.00515
0.394	598	2060	0.0135	19.6	0.0715	93.5	0.00347
0.394	598	1300	0.0252	16.1	0.130	212	0.00364
0.394	306	224	0.00578	1.21	0.0277	646	0.00037
0.383	480	583	0.0118	2.40	0.0570	650	0.00076
0.317	644	1030	0.0257	4.33	0.125	650	0.00167
0.394	0	0	0.000368	0.54	0.00176	65
$L^* = 6.88$ Inches							
2.33	63	10.9	0.000107	1.32	0.000514	19.8	0.000070
2.33	182	299	0.00109	9.35	0.00542	28.5	0.000580
2.33	182	276	0.00140	7.57	0.00686	45.5	0.000536
2.33	182	251	0.00162	6.16	0.00798	64.8	0.000492
2.30	178	206	0.00209	2.60	0.0101	194	0.000302
2.27	178	66.2	0.00153	1.88	0.00805	194	0.000240
2.26	262	925	0.00582	7.16	0.0288	194	0.000860

Table IV. Effect of Liquid Depth on a Vaned-Disk Agitator

L^* , In.	Vol. of Soln., Cu. Ft.	Z/D	n , R.P.M.	P_s , Ft.-Lb./ (Min.) \times (Cu. Ft.)	Absorption Rate, Lb. Moles/ (Cu. Ft.) \times (Hr.)	Oxygen Efficiency, %	K_s , Lb. Moles/ (Cu. Ft.) \times (Hr.) (Atm.)	V_s , Ft./Hr.	$\frac{K_s}{V_s^{0.67}}$
2.44	0.0926	1	716	904	0.0102	2.50	0.0496	349	0.000973
			608	795	0.00593	2.92	0.0287	174	0.000905
			608	422	0.00626	1.16	0.0299	459	0.000490
			608	398	0.00633	0.93	0.0303	582	0.000427
			890	4220	0.00980	17	0.0510	49.3	0.00372
			610	1380	0.00423	7.52	0.0209	49.3	0.00153
			782	3230	0.00794	13.5	0.0405	50.6	0.00291
746	1210	0.0127	3.34	0.0614	325	0.00128			
2.44	0.197	2	836	1475	0.00580	1.91	0.0279	51.8	0.00198
			830	905	0.0116	7.56	0.0569	262	0.00185
			340	83.5	0.00119	1.04	0.00567	194	0.000167
2.44	0.298	3	296	44.0	0.00113	1.48	0.00548	196	0.000160
			593	382	0.00157	11.1	0.0079	36.1	0.000712
			656	451	0.00245	1.23	0.0117	51.2	0.000843
			836	1000	0.00493	2.47	0.0238	61.2	0.00171
2.44	0.413	4	785	398	0.00563	9.77	0.0281	198	0.000815
			296	37.6	0.00121	2.10	0.00582	198	0.000169
3.88	0.195	0.5	325	381	0.00232	12.6	0.0118	125	0.000472
			588	1820	0.0114	6.19	0.0562	125	0.00225

Table V. Paddle Performance Data

n , R.P.M.	P_s , Ft.-Lb./ (Min.) \times (Cu. Ft.)	Absorption Rate, Lb. Moles/ (Cu. Ft.) \times (Hr.)	Oxygen Efficiency, %	K_s , Lb. Moles/ (Cu. Ft.) \times (Hr.) (Atm.)	V_s , Ft./Hr.	Z/D	Depth Cor. Factor	Cor. K_s	$\frac{K_s}{V_s^{0.67}}$
2.38-In. Paddle, Absorbent Solution Volume = 0.38 Cu. Ft.									
411	12.7	0.000307	0.69	0.00146	65	1	1	0.00146	0.000902
691	63.8	0.000885	1.98	0.00426	65	1	1	0.00426	0.000283
1076	254	0.00180	4.03	0.00875	65	1	1	0.00875	0.000541
1254	451	0.00239	5.35	0.0117	65	1	1	0.0117	0.000723
24-In. Paddle, Absorbent Solution Volume = 300 Cu. Ft.									
105	57.9	0.000498	7.66	0.00247	69.6	0.75	0.81	0.00305	0.000180
142	174	0.000974	22.4	0.00525	44.6	0.75	0.81	0.00648	0.000518
238	567	0.00235	22.6	0.0127	106	0.75	0.81	0.0156	0.000698
276	808	0.00519	25.1	0.0286	212	0.75	0.81	0.0354	0.000998

precaution necessary to prevent further oxidation of the solution during transfer was to flush the sampling pipet with nitrogen for a few minutes previous to sampling. Accordingly, the pipet was rinsed with distilled water after each use and nitrogen was passed through it continuously between sampling times. Determinations were made in duplicate and usually agreed within 2%. This analytical method was considered sufficiently reliable to obviate the necessity of an oxygen balance on the system.

Power requirements of the agitators were observed for all except the largest equipment by measuring the resisting torque of the tanks; a torque-table dynamometer (Figure 3) was employed, similar to the one described by Hixson and Luedeke (5). In the 96-inch tank, power was measured by the shaft dynamometer developed by F. D. Miller and described by Riegel (13).

CORRELATION OF DATA

Absorption coefficients, (lb. moles oxygen absorbed)/(cu. ft. sulfite solution) (atm. oxygen partial pressure) (hr.), and oxygen efficiencies were calculated for each run. In computation of the driving force, there was assumed to be zero back-pressure of oxygen from sodium sulfate solution, and the logarithmic mean of inlet and outlet oxygen partial pressures was used. The data for the vaned disk operating in liquid equal in depth to the vessel diameter are shown in Table III. Surprisingly high absorption efficiencies were obtained at high power inputs, the value varying from less than 1% with the agitator stationary to 42% with a power input of 2870 ft.-lb./ (min.) (cu. ft.)¹.

Absorption coefficients obtained with a given agitator and constant air rate were found to plot as a straight line against agitator power on log-log paper. In accordance with Büche's suggestion (3) that the rate of solution of solids in an agitated tank is a function of power input per unit volume of liquid, cross plots of absorption coefficients against agitator power per unit volume, ft.-lb./ (min.) (cu. ft.), were made to give interpolated curves at such air rates as to provide equal superficial gas velocities (based on incoming gas volumes and tank cross sections) in all sizes of equipment. The data from the 6.0-, 9.5-, and 17.3-inch vessels were thus found to correlate to a single straight

¹ To convert these units to horsepower/1000 gal., multiply by 0.00405.

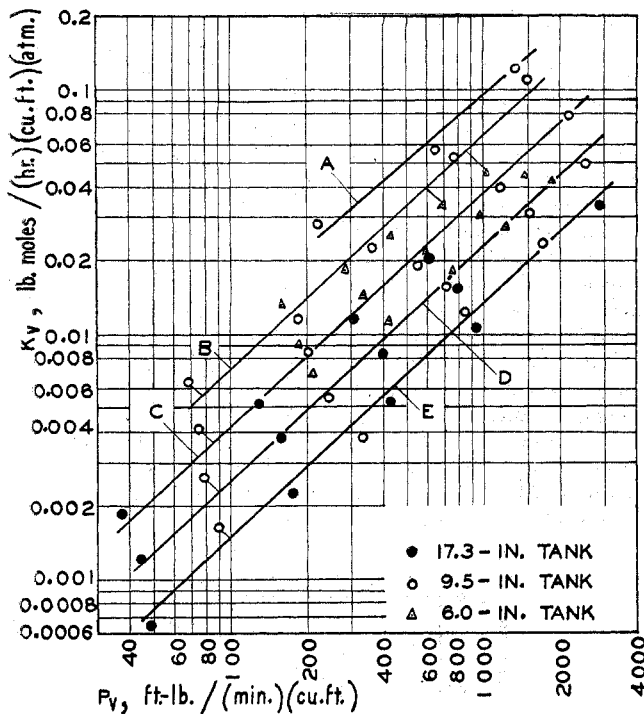


Figure 4. Effect of Agitator Power with a Vaned Disk and $Z/D = 1$
 A. $V_s = 642$ B. $V_s = 194$ C. $V_s = 89$ D. $V_s = 45$ E. $V_s = 18.6$

line for each air velocity. Figure 4 shows the lines for several air velocities. The slopes of the lines are virtually the same, indicating the relation:

$$K_v = kP_v^{0.95}$$

where P_v is the agitator power input per unit volume of liquid at a constant superficial gas velocity.

The spacing and almost constant slope of the curves of Figure 4 suggest that, at constant power input, the logarithm of absorption coefficient may be a linear function of the logarithm of superficial gas velocity. A cross plot of Figure 4 at various power ordinates (Figure 5) indicates this relation to be valid up to a "loading velocity" (velocity of about 400 feet per hour for the power magnitudes investigated); below this velocity,

$$K_v = k'V_s^{0.67}$$

From these two relations a general correlation has been evolved (Figure 6). Here all the data for the vaned-disk agitator from the four scale sizes of equipment tested are plotted in terms of an "absorption number", $K_v/V_s^{0.67}$, against P_v . The agreement is satisfactory for those determinations in which the air rate did not exceed the "loading point" defined in Figure 5. Data with air rates above this point, indicated as points with horizontal lines through them, fall below the line of correlation by different amounts that may be as great as 50%.

The loading point appears to be identified roughly with a change in visual appearance of the gas-liquid mixture. As gas rate is increased at constant agitator speed, a rate is finally reached above which the gas is no longer uniformly dis-

persed by the agitator, but instead much of the gas escapes around the edge of the impeller and rises in large bubbles or clusters close to the shaft. The break points in the curves of Figure 5 actually seem to occur at gas rates above those at which the appearance first begins to change.

The correlation of Figure 6 presents a convenient method of studying the variables affecting the performance of agitated gas-liquid contactors, since data at any two or three power values and at any gas rate below loading can be used to establish the absorption number line for each particular combination of variables being investigated. To illustrate this use, data were obtained for the effect of variable liquid depth on absorption rate (Table IV and Figure 7). The equipment employed was a vaned disk and a 6-inch Pyrex container, 27 inches high. Because the vessel

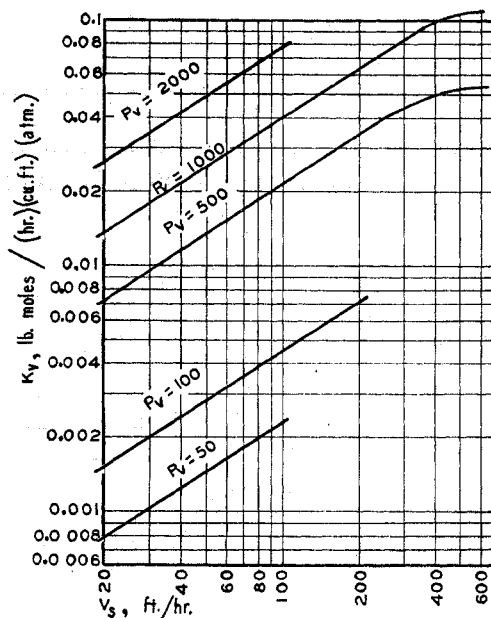


Figure 5. Effect of Air Rate with a Vaned Disk and $Z/D = 1$

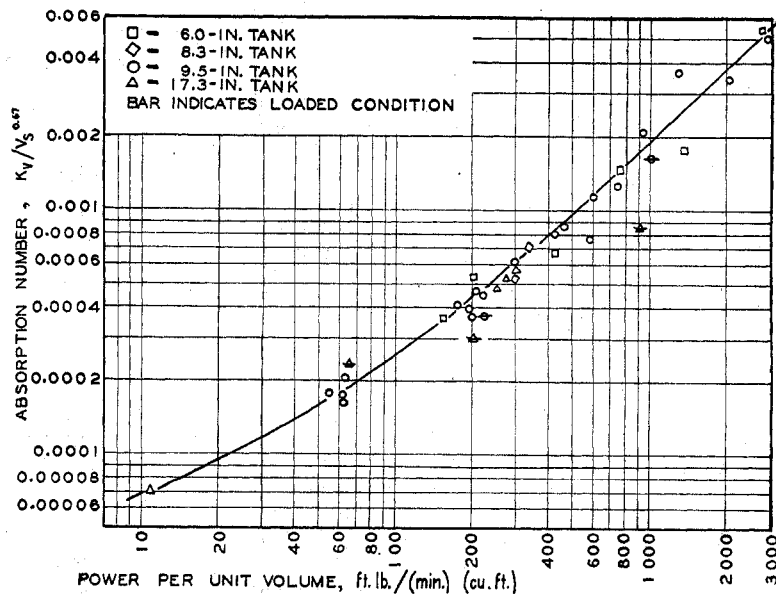


Figure 6. General Correlation of Data for a Vaned Disk When $Z/D = 1$

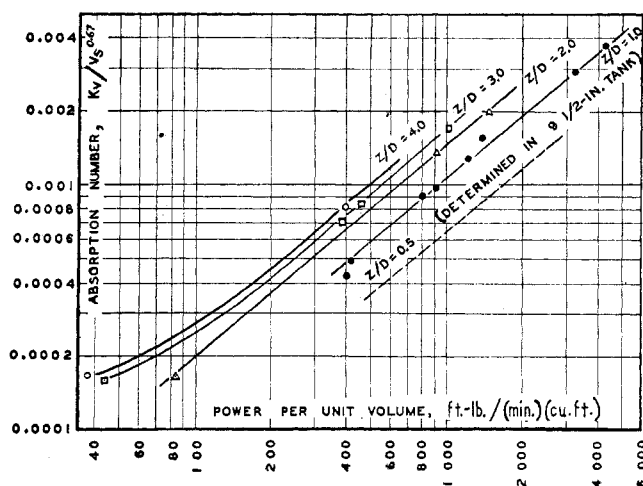


Figure 7. Effect of Liquid Depth on Absorption Rate

Table VI. Reduction of Agitator Power with Gas Rate

(Typical data for 3.88-in. vaned disk, $Z/D = 1$)

n , R.P.M.	V_{S_1} , Ft./Hr.	P , Ft.-Lb./Min.	% of No-Gas Power
419	0	439	100
	19.0	373	85
	65.0	294	67
	93.5	237	54
	149	181	41
	212	168	38
644	0	1742	100
	650	405	23

arrangement was slightly different from that of the tanks used in the tests described above, the curve for the ratio of depth to diameter (Z/D) of unity is displaced somewhat from the line of Figure 6. Values for Z/D of 0.5 were determined in the 9.5-inch tank with the corresponding disk. The dashed line for this depth ratio is drawn a distance below the line for $Z/D = 1$, proportional to the displacement of the data for the larger tank.

The near parallelism of the curves suggests that, over the power range investigated, the effect of depth on absorption number may be expressed as a depth factor, the ratio of the absorption number obtained at any depth to that for $Z/D = 1.0$. Figure 8 shows a plot of depth factors derived from Figure 7. The factors of Figure 8 are corrections to a volume coefficient at constant power per unit volume rather than to absolute quantities of mass transferred at constant agitator speed. Thus, to say that there is a 50% increase in absorption number or coefficient as Z/D increases from 1 to 2 indicates a threefold increase in quantity of oxygen absorbed per unit time in the batch with a corresponding increase in oxygen efficiency, accompanied by a doubling of agitator shaft power.

DESIGNING PLANT EQUIPMENT

The ability of the plot of absorption number against power per unit volume to correlate absorption data for equipment covering a threefold spread of scale size validates the application of laboratory results to larger installations and suggests a method of designing plant contactors from small-scale data. To test this application more completely over the range of scale factors likely to be encountered in carrying a design from semiworks to plant stages, runs were

made with two geometrically similar flat paddles in tanks, respectively, 9.5 and 96 inches in diameter. Agitator-to-bottom clearance was the same as in the disk experiments (Figure 2). The maximum liquid depth that could be used in the larger tank was 75 inches ($Z/D = 0.78$); the coefficients measured were adjusted, therefore, to a Z/D ratio of unity by use of the proper factor obtained from Figure 8. The data from these runs are listed in Table V and plotted in Figure 9. The agreement is excellent. The one point which falls considerably below the curve represents a badly loaded condition, as evidenced by a violent "boil" of the liquid surface at the agitator shaft. The slope of the curve is somewhat less than that for the vaned disk, nor surprising in view of the difference in the types of impeller. The coefficients measured indicate that in the lower range of power values, a paddle may be slightly superior to a disk. A compensating disadvantage lies in the fact that a paddle will load at lower gas velocities than will a disk consuming the same power. Thus, the loaded point of Figure 9 represents a gas velocity of 70 feet per hour, a flow which a disk at the same power input would be capable of dispersing completely.

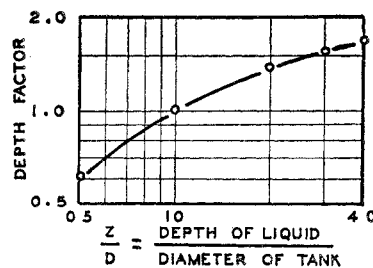


Figure 8. Plot of Depth Factors Derived from Figure 7

The procedure for designing an agitated gas-liquid contactor for a given process is now clear. The gas-liquid reaction should first be carried out in the laboratory and the variables established to produce the desired result in the form of cycle, yield, etc. From these data plant equipment may be designed. The plant installation is made geometrically similar to the laboratory setup in all points. Equal superficial gas velocities should be effected

Table VII. No-Gas Power Data for Vaned Disk When $Z/D = 1$

L^3 , In.	n , R.P.M.	P , Ft.- Lb./Min.	Fluid	ρ , Lb./ Cu. Ft.	μ , Lb./ (Ft.) (Min.)	$L^2 N \rho$ μ	$\frac{g_e P}{L^3 \rho n^4}$
2.44	607	130	Water	62.4	0.0360	43,400	3.12
	893	412	Water	62.4	0.0360	63,800	3.10
	232	6.56	Oil	54.8	6.87	76.2	3.20
	292	13.0	Oil	54.8	6.87	95.6	3.18
	426	39.6	Oil	54.8	6.59	146	3.13
	649	139	Oil	54.8	6.59	222	3.10
	754	222	Oil	54.8	6.59	258	3.17
3.31	411	193	Water	62.4	0.0360	55,300	3.04
	3.88	173	26.6	Water	62.4	0.0360	31,200
3.88	173	28.7	Water	62.4	0.0360	31,200	2.90
	286	133	Water	62.4	0.0360	51,700	2.98
	296	147	Water	62.4	0.0360	53,500	2.97
	306	163	Water	62.4	0.0360	55,100	3.01
	419	439	Water	62.4	0.0360	75,600	3.12
	419	449	Water	62.4	0.0350	73,600	3.20
	480	679	Water	62.4	0.0354	86,500	2.97
	598	1264	Water	62.4	0.0404	108,000	3.08
	644	1742	Water	62.4	0.0352	116,000	2.91
	142	14.4	Oil	54.8	5.45	148	2.99
	272	92.2	Oil	54.8	6.06	256	2.74
	430	368	Oil	54.8	6.38	384	2.77
	634	1170	Oil	54.8	6.38	566	2.75
	867	3080	Oil	54.8	6.06	815	2.83
6.88	63	25.5	Water	62.4	0.0360	36,400	2.91
	100	121	Water	62.4	0.0360	57,800	3.47
	118	208	Water	62.4	0.0360	67,500	3.61
	178	792	Water	62.4	0.0360	101,500	3.72
	182	854	Water	62.4	0.0360	105,500	4.06

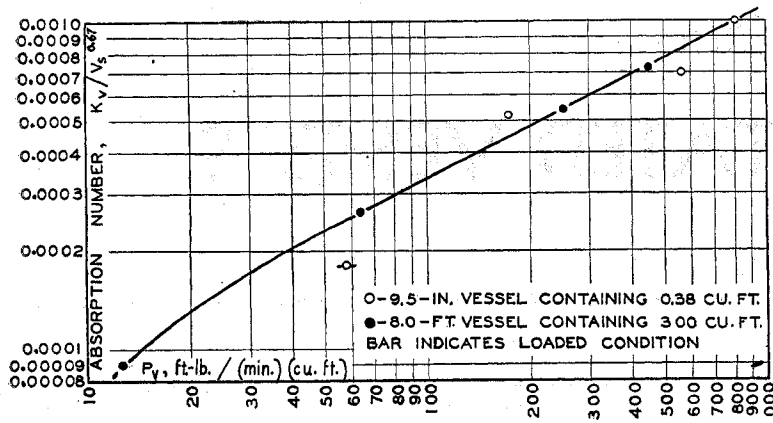


Figure 9. Scale-up of Paddle Data

in both sizes of equipment, and this point of design will usually fix the minimum tank size which can be used in the plant. To avoid the necessity of an excessively large agitator drive, it is believed that gas rates in excess of 500 or 600 feet per hour should not be considered.

The speed of the plant agitator should be so selected as to apply the same power per unit volume as in the laboratory. This will usually necessitate installation of a V-belt or chain-and-sprocket drive with final adjustment of the speed in the field, since the variation of agitator power with gas rate at a given speed is erratic and unpredictable, as shown by Table VI. Thus the power with a high gas rate may be as little as 25% of the no-gas value at the same speed. The drive should be large enough to handle the no-gas load, however, which may be predicted from power measurements of a small-scale model by use of a power function-Reynolds number plot, as first proposed by White and Brenner (15). No-gas power data correlated in this manner for the vaned disk described above, operating in a baffled tank, are given in Table VII and Figure 10. Attempts to correlate the power requirements of the agitators during gas dispersion have not yet been successful.

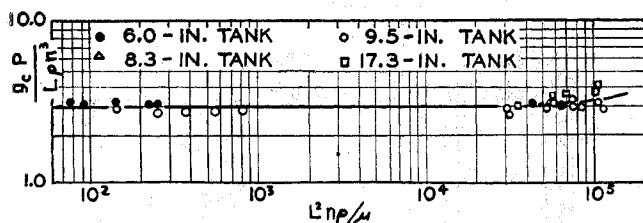


Figure 10. Vaned-Disk Power Data When $Z/D = 1$
(No Gas Flow)

It should be noted that, in scaling up a design, the volume of absorbent liquid and the agitator power per unit volume will increase as the cube of the scale factor, whereas the gas rate will increase as the square of this factor. That is, the space velocity in the plant reactor will be smaller than in the laboratory, varying as the inverse of the scale factor. Thus, although the proposed correlation predicts gas efficiencies in the plant higher than in the laboratory, it requires actual rates of absorption per unit volume of liquid much lower in the plant than in the laboratory. The plant cycle, based on a unit of reaction in the liquid phase, therefore will be longer than the corresponding laboratory cycle.

CONCLUSIONS

The oxidation by air of aqueous sodium sulfite solutions containing Cu^{++} ion is a useful reaction in the study of the design variables of agitated gas-liquid contactors.

Absorption coefficients for equipment agitated with a vaned-disk impeller vary with $P_v^{0.96}$ and with $V_s^{0.67}$ below loading gas rates.

The effect of liquid depth on absorption coefficient is defined for one type of design.

A method of correlation, involving absorption number, defined as $K_v/V_s^{0.67}$, and agitator power per unit volume of liquid, provides a reasonable basis for the scale-up of a mechanical gas-disperser design from laboratory to plant. Plant equipment thus may be designed by the determination in the laboratory of the proper conditions for the absorption and by the selection of a plant reactor geometrically similar to the laboratory equipment, to be operated with superficial gas velocity and agitator power per unit volume of liquid the same as on the laboratory scale.

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NOMENCLATURE

- B = distance from tank bottom to lower edge of agitator, ft. or in.*
- D = inside diameter of tank, ft. or in.*
- g_0 = gravitational conversion factor = 115,700 (ft./min.)/(min.)
- K_v = volumetric absorption coefficient, lb. moles/(cu. ft.) \times (hr.) (atm.)
- k, k' = constants of proportionality
- L = agitator length or diameter, ft. or in.*
- L_1 = length of vane on vaned disk, ft. or in.*
- n = angular speed of agitator, r.p.m.
- P = agitator shaft power, ft.-lb./min.
- P_v = agitator shaft power per unit volume of agitated liquid, ft.-lb./min. (cu. ft.)
- V_s = superficial gas velocity based on inlet gas volume and cross section of tank, ft./hr.
- W = agitator blade or vane width, ft. or in.*
- W_b = baffle width, ft. or in.*
- Z = liquid depth, ft.
- μ = abs. viscosity of unaerated liquid, lb./(ft.) (min.) = 0.0404 \times centipoises
- ρ = density of unaerated liquid, lb./cu. ft.

* Double prime indicates dimension in inches.

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