The Effect of Curvature of the Equilibrium Line on the Film Resistances in Gas Absorption (II)

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INTRODUCTION

A study of the gas absorption process, the evaluation of the number of transfer units—N.T.U. which relate in tie-line slope, was reported in the *Tunghai Journal*, Volume VI, Number II, pp. 29-58, December, 1964. There is a critical tie-line slope equal to the operating line slope and of opposite sign. These phenomena easily showed from the Figures 10, 14 of the previous report (pp. 47, 55) for the system of sulfuric acid-water-air and water-ammonia-air respectively. These two systems were used in the exploratory calculations in that earlier report. The experiment now being carried on is the water-acetone-air system, which uses water to wash out acetone from the air containing acetone.

Most of the experimental data on absorption in packed towers have been interpreted in terms of the two-film theory first proposed by Whitman (1). In applying the theory it is considered that the resistance to mass transfer is due to a film of gas and a film of liquid and that a state of dynamic equilibrium exists at the interface. The previous report's graphical stepwise analysis showed that White's method (2) is very quick to get the number of transfer units. In this way much insight can be gained into the operation of gas absorption towers. It is also applicable to all tie-line slopes between zero and infinity. There is a critical tie-line slope equal to the operating line slope and of opposite sign. This critical tie-line slope divides the White method into two kinds of ways which are related to the cases in which either the gas-film resistance or the liquid-film resistance is most important. Of all cases which were taken, half of all tie-line slopes, those between the critical tie-line slope to zero side, belonged to the case where the liquid-film is more important. The other half of all tie-line slopes, those between the critical tie-line slope to infinity side belonged to the case where the gas-film resistance is more important. At the critical tie-line slope the number of transfer units reached a maximum and the absorption tower height a maximum. This is applicable to the equilibrum curve exhibits in any type. An equilibrium curve of the sulfuric acid-water-air system is S-shaped type and the water-ammoni-aair system is the concave upward type.

The scheme proposed in the previous report is to divide the gas absorption system into identical towers in series-counterflow. The gas and liquid compositions at the half way point would be determined as well as those at the top and bottom of the system. A tie-line slope would be assumed and the integration for the number of transfer units would be determined by White's method. This would also give the half way point on the operating line. If the half way points did not agree, a new tie-line slope would be tried. The correct tie-line slope would make the half way point identical. This gives an idea of the probable accuracy in estimating the true tie-line slope.

Choice of System. Theoretical considerations indicate that in the absorption of very slightly soluble gas the liquid-film might be expected to offer most of the resistance to mass transfer. Sherwood and Holloway (3) have shown that this is the case in the absorption of hydrogen, oxygen, etc. by water. Theoretical considerations also indicate that in absorption of highly soluble vapors the gas-film might be expected to offer most of the resistance to mass transfer. In this paper the water-acetone-air system has been selected to investigate the relation between tie-line slope and number of transfer units and also check the effectiveness of curvature of different equilibrium lines.

Othmer and Scheibel (4) studied the recovering of acetone vapor from air by absorption in water using a 10-inch diameter column packed with 1-inch rings to a height of 19 feet. Acetone absorption was essentially a two-film resistance phenomenon. Othmer and Scheibel calculated the mean driving force from the concentration at the top and bottom of the tower. Sherwood and Pigford (5) have shown that this method is inaccurate owing to temperature changes caused by the absorption of acetone and evaporation of water, and the true mean driving force is considerably lower than the logarithmic mean calculated from the terminal values. Scheibel and Othmer (6) investigated the absorption of acetone by water in a 4-inch diameter column packed with 10 mm. rings. Huchings, Stutzman and Koch (7) studied acetone vapor absorbed by water using three packed towers of 3/8, 1/2, 3/4 inches and $1\frac{1}{4}$-inch rings. White and Othmer (8) atudied the absorption of acetone vapor by water in a Stedman packing, which consists of sheets of wire cloth indented and perforated with gas passages. Larson (9) studied the effect of molecular diffusivity on gas-film coefficient using acetone absorbed from air by means of water.

PRESENTATION OF RESULTS

Graphical Stepwise Method

Calculations of Number of Transfer Units. In order to investigate the number of transfer units the system water-acetone-air was chosen. The equilibrium data for this system were taken from Scheibel and Othmer (6). The equilibrium curve of this system is nearly straight. The following four different terminal conditions are taken, which under the isothermal process at room temperature and atomosphere pressure. Air velocity was 430 pounds per hour per square foot accompanied by 6.97 volume per cent acetone. Now it is expected to wash out 70 per cent of aceton by pure water. Water velocities were adjusted in four different cases to 860, 720, 560, and 500 pounds per hour per square foot. These become the following terminal conditions: inlet gas contains 0.15 pounds acetone per pound air and leaves at 0.045 pounds acetone per pound air; inlet liquid is pure water, acetone free, and leaves at in four different cases, 0.0523, 0.0667, 0.0800, and 0.0933 pounds acetone per pound water. The idea is to try to find the inlet and outlet gas and liquid compositions to get the four different operating lines; that is, the four different operating line slopes. Calculations of number of transfer units was carried about these four operating lines to the almost straight line equilibrium curve and in each case also try to change tie-line slope from zero to infinite. Figure 1 shows the equilibrium curve and the four different operating lines for this system under isothermal conditions, and 1 atmosphere pressure.

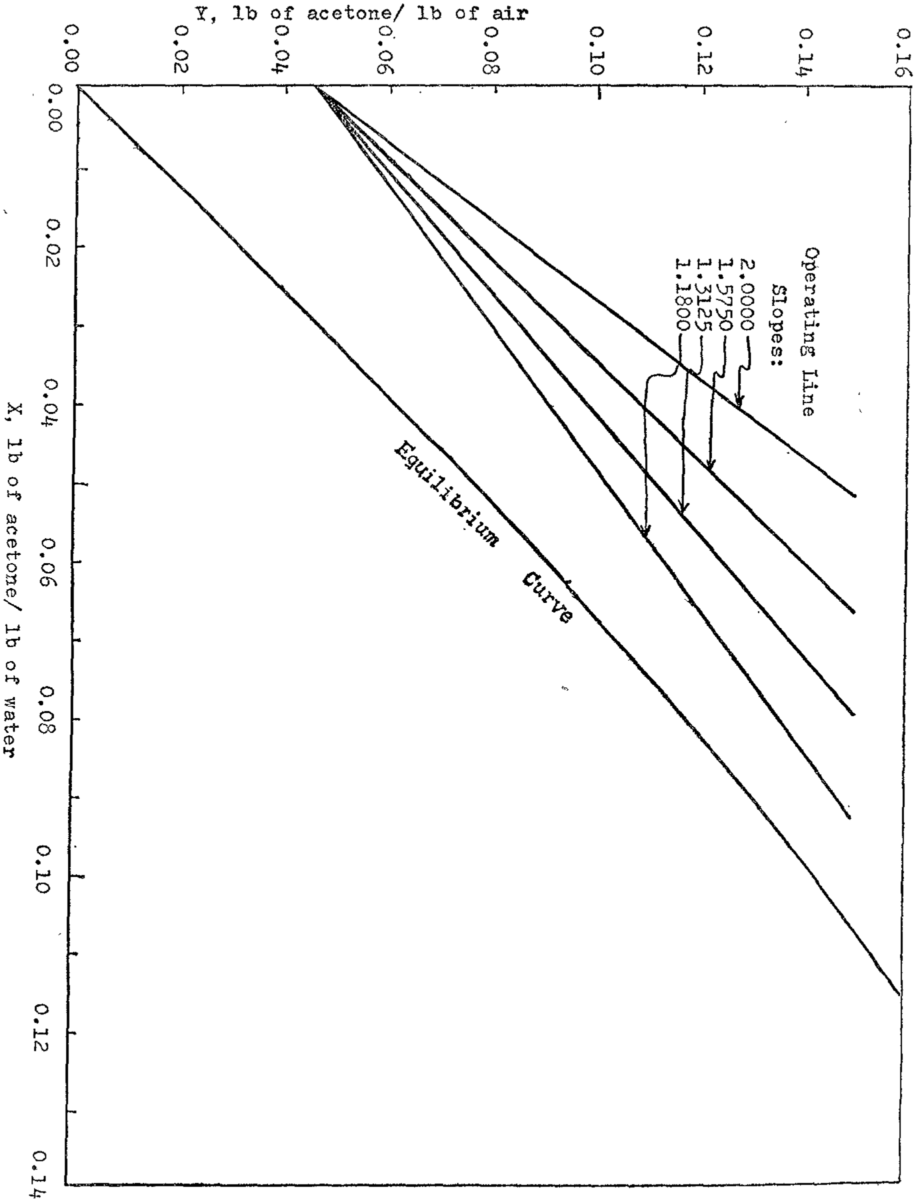

Fig. 1. Various operating line slopes in the system of water-acetone-air at 25°C. and 1.0 atmosphere pressure. Isothermal operation.

The results of the graphical stepwise constructions for the case in which the liquid film is more important and for the case in which the gas film is more important to different tie-line slopes from zero to infinite was calculated.

Table 1 shows what happens when the operating line slope is 2.000, with air containing acetone vapor entering at 0.15 pounds of acteone per pound of air and leaves at 0.045 pounds of acetone per pound of air. Water enters at 0.0 and leaves at 0.0523 pounds of acetone per pound of water.

Table 2 shows what happens when the operating line slope is changed to 1.5750, with air containing acetone vapor entering and leaving at the same compositions as before. Liquid leaves at 0.0667 pounds acetone per pound of water.

Table 3 shows what happens when the operating line slope is further decrease to 1.3125, with air containing acetone vapor entering and leaving at the same compositions as the first case. Liquid leaves at 0.0800 pounds acetone per pound of water.

Table 4 shows what happens when the operating line slope is more decrease to 1.180, with air containing acetone vapor entering and leaving at the same composition as the first case. Liquid leaves at 0.0933 pounds acetone per pound of water.

One of the graphical stepwise constructions for the case of a tie-line slope of minus 1.1800 is shown in Figure 2.

The results obtained in Table 1, 2, 3, and 4 were comebined in Table 5 and plotted in Figure 3. The N. Y. U. was the largest in each case when the tie-line slope was equal to the operating line slope and of opposite sign as reported in the previous article. Figure 3 shows the N. T. U. values vs. the tie-line slopes. The critical point corresponds to the largest N. T. U. values.

Table 1. Calculation of N. T. U. for Various Tie-Line Slopes. The system is water-acetone-air at 25° C. and 1.0 atmosphere pressure. The operating line slope is 2.0000. Air containing acetone vapor (6.97 volume per cent). enters at 0.51 and leaves at 0.045 pounds of acetone per pound of air. Water enters at 0 and leaves at 0.0523 pounds of acetone per pound of water. Isothermal operation.

Operating line slope $\frac{L'}{V'}=\frac{0.150-0.045}{0.0523-0.0}=2.0000$

Liquid film more important:

Tie-line slope $-\frac{k_X}{k_Y}$	s_X	t_X	N. T. U. graphical stepwise method
0.0000	+0.6677	− 2.0000	2.103
0.01	+0.6600	− 2.0200	
0.02	+0.6533	− 2.0400	2.105
0.05	+0.6333	− 2.1000	2.11
0.10	+0.6000	− 2.2000	2.14
0.20	+0.5333	− 2.4000	2.26
0.50	+0.3333	− 3.0000	2.34
1.00	0.0000	− 4.0000	2.50
2.00	−0.6667	− 6.0000	3.37

Gas film more important:

	s_Y	t_Y	
2.00	−0.6667	− 6.0000	3.37
5.00	−1.1111	+30.0000	1.20
10.00	−1.4286	+10.0000	0.66
20.00	−1.6667	+ 7.5000	0.28
50.00	−1.8519	+ 6.5217	+
100.00	−1.9231	+ 6.2500	+
200.00	−1.9608	+ 6.1224	+
500.00	−1.9841	+ 6.0484	+
1000.00	−1.9920	+ 6.0241	+
	−2.0000	+ 6.0000	+

Table 2. Calculation of N. T. U. for Various Tie-Line Slopes. The system is water-acetone-air at 25°C. and 1.0 atmosphere pressure. The operating line slope is 1.5750. Air containing acetone vapor (6.97 volume per cent) enters at 0.15 and leaves at 0.045 pounds of acetone per pound of air. Water enters at 0 and leaves at 0.0667 pounds of acetone per pound of water. Isothermal operation.

Operating line slope $\frac{L'}{V'}=\frac{0.150-0.045}{0.0667-0.0}=1.5750$

Liquid film more important:

Tie-line slope $-\frac{k_X}{k_Y}$	s_X	t_X	N. T. U. graphical stepwse method
0.0000	+0.5250	− 1.5750	2.92
0.01	+0.5180	− 1.5950	2.78
0.02	+0.5120	− 1.6150	2.77
0.05	+0.4920	− 1.6750	2.77
0.10	+0.4580	− 1.7750	2.80
0.20	+0.3920	− 1.9750	2.88
0.50	+0.1919	− 2.5750	3.00
1.00	−0.4119	− 3.5750	4.02
1.20	−0.2750	− 3.9750	4.19
1.50	−0.4750	− 4.5750	4.72
1.5750	−0.5250	− 6.3000	5.07

Gas film more important:

	s_Y	t_Y	
1.5750	−0.5250	− 6.3000	5.07
2.0	−0.6120	− 8.2250	3.95
5.0	−0.9660	+12.7500	1.50
10.0	−1.1980	+ 6.9000	0.57
20.0	−1.3600	+ 5.6100	0.20
50.0	−1.4800	+ 5.0450	+
100.0	−1.5300	+ 4.8800	+
200.0	−1.5500	+ 4.8000	+
500.0	−1.5650	+ 4.7550	+
1000.0	−1.5700	+ 4.7450	+
∞	−1.5750	+ 4.7250	+

Table 3. Calculation of N. T. U. for Various Tie-Line Slopes. The system is water-acetone-air at 25° C. and 1.0 atmosphere pressure. The operating line slope is 1.3125. Air containing acetone vapor (6.97 volumne per cent) enters at 0.15 and leaves at 0.045 pounds of acetone per pound of air. Water enters at 0 and leaves at 0.0800 pouds of aceton per pound of water. Isothermal operation.

Operating line slope $\frac{L'}{V'}=\frac{0.150-0.045}{0.080-0.0}=1.3125$

Liquid film more important:

Tie-line slope $-\frac{k_X}{k_Y}$	s_X	t_X	N. T. U. graphical stepwise method
0.0000	+0.4375	− 1.3125	3.68
0.01	+0.4320	− 1.3325	3.71
0.02	+0.4240	− 1.3525	3.44
0.05	+0.4040	− 1.4125	3.73
0.10	+0.3710	− 1.5125	3.81
0.20	+0.3040	− 1.7125	3.93
0.50	+0.1035	− 2.3125	4.40
1.00	−0.2290	− 3.3125	5.29
1.3125	−0.4375	− 3.9375	6.65

Gas film more important:

	s_Y	t_Y	
1.3125	−0.4375	− 3.9375	6.65
1.50	−0.4775	− 5.2800	5.95
2.0	−0.5675	−12.6000	4.62
5.0	−0.8600	+ 8.2900	1.80
10.0	−1.0400	+ 5.3500	0.81
20.0	−1.1600	+ 4.5300	0.23
50.0	−1.2500	+ 4.1600	+
100.0	−1.2800	+ 4.0400	+
200.0	−1.2950	+ 3.9400	+
500.0	−1.3050	+ 3.9600	+
1000.0	−1.3100	+ 3.9500	+
∞	−1.3125	+ 3.9500	+

Table 4. Calculation of N. T. U. for Various Tie-Line Slopes. The system is water-acetone-air at 25° C. and 1.0 atmosphere pressure. The operating line slope is 1.1800. Air containing acetone vapor (6.97 volume per cent) enters at 0.15 and leaves at 0.045 pounds of acetone per pound of air. Water enters at 0 and leaves at 0.0933 pounds of acetone per pound of water. Isothermal operation.

Operating line slope $\frac{L'}{V'}=\frac{0.150-0.045}{0.0933-0.0}=1.1800$

Liquid film more important:

Tie-line slope $-\frac{k_X}{k_Y}$	s_X	t_X	N. T. U. graphical stepwise method
0.0000	+0.3935	− 1.1800	5.70
0.01	+0.3860	− 1.2000	5.72
0.02	+0.3800	− 1.2200	5.87
0.05	+0.3600	− 1.2800	5.85
0.10	+0.3260	− 1.3800	6.00
0.20	+0.2600	− 1.5800	6.29
0.50	+0.0600	− 2.1800	7.01
1.00	−0.2735	− 3.1800	8.34
1.180	−0.3935	− 3.5400	9.00

Gas film more important:

	s_Y	t_Y	
1.180	−0.3935	− 3.5400	9.00
1.20	−0.3980	− 3.6500	8.80
1.50	−0.4575	− 6.1750	7.33
2.00	−0.5310	−19.7000	5.42
5.00	−0.8025	+ 5.4750	1.80
10.00	−0.9575	+ 4.6400	1.01
20.00	−1.0550	+ 4.0150	+
50.00	−1.1280	+ 3.7180	+
100.00	−1.1520	+ 3.6300	+
200.00	−1.1680	+ 3.5800	+
500.00	−1.1750	+ 3.5600	+
1000.00	−1.1790	+ 3.5450	+
∞	−1.1800	+ 3.5400	+

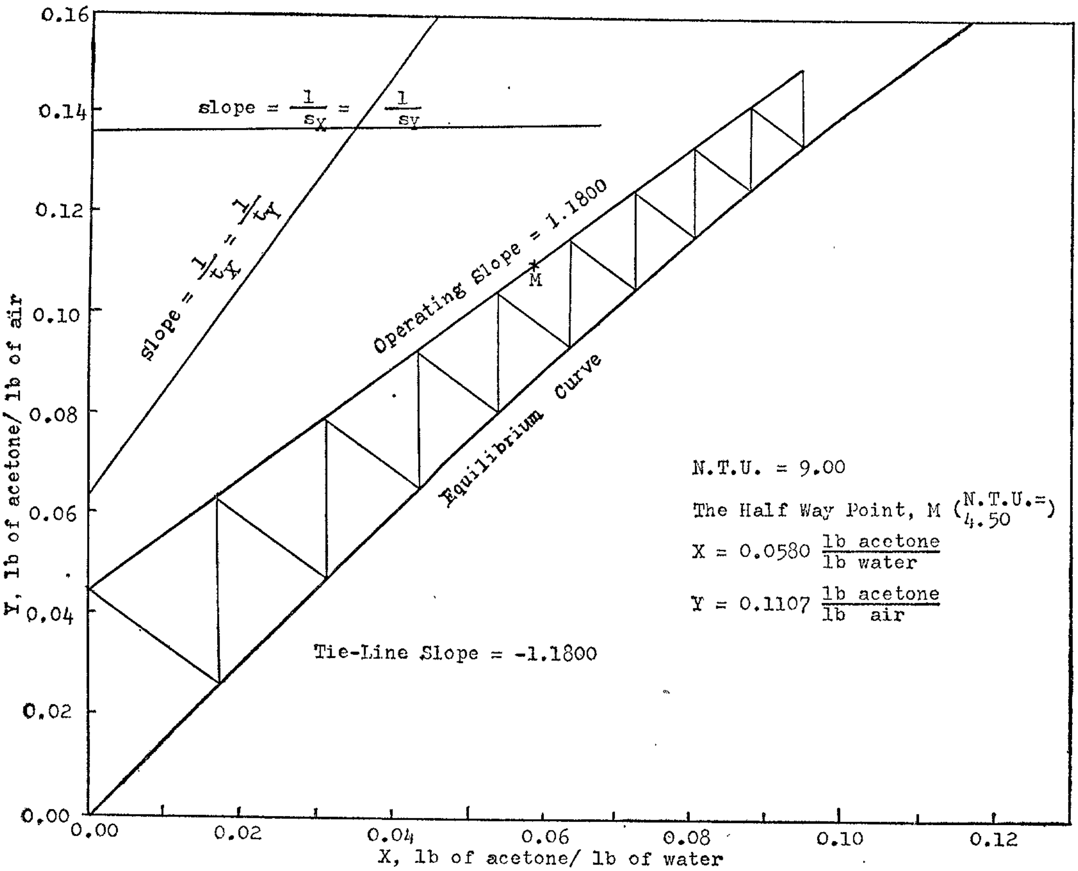

Fig. 2. Graphical stepwise construction for gas absorption. The system is water-acetone-air at 25°C. and 1.0 atmosphere pressure. The operating line slope is 1.1800 and the tie-line slope is -1.1800. Gas enters at 0.15 and leaves at 0.045 pounds of acetone per pound of air. Liquid enters at 0.0 and leaves at 0.0933 pounds of acetone per pound of water. Isothermal operation.

Table 5. N. T. U. vs. Tie-Line Slope for Various Operating Line Slopes. The system is water-acetone-air at 25°C. and 1.0 atmosphere pressure. Isothermal operation.

Operating line					Tie-line slope	N. T. U. graphical stepwise method
Slope $\frac{L'}{V'}$	X-axis liquid enter $\frac{\text{lb acetone}}{\text{lb water}}$	Y-axis gas leave $\frac{\text{lb acetone}}{\text{lb air}}$	X-axis liquid leave $\frac{\text{lb acetone}}{\text{lb water}}$	Y-axis gas enter $\frac{\text{lb acetone}}{\text{lb air}}$	$-\frac{k_X}{k_Y}$	
2.0000	0.0	0.045	0.0523	0.15	0.0000	2.103
					0.02	2.105
					0.10	2.14
					0.50	2.34
					2.00	3.37
					5.00	1.20
					10.00	0.66
					20.00	0.28
					50.00	+
					100.00	+
1.5750	0.0	0.045	0.0667	0.15	0.0000	2.92
					0.02	2.77
					0.10	2.80
					0.50	3.00
					1.20	4.19
					1.5750	5.07
					2.0	3.95
					5.0	1.50
					10.0	0.57
					20.0	0.20
					50.00	+
					100.0	+
1.3125	0.0	0.045	0.0800	0.15	0.0000	3.68
					0.02	3.44
					0.10	3.81
					0.50	4.40
					1.00	5.29
					1.3125	6.65
					1.5	5.95
					2.0	4.62
					5.0	1.80

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					10.0	0.81
					20.0	0.23
					50.0	+
					100.0	+
1.1800	0.0	0.045	0.0933	0.15	0.0000	5.70
					0.02	5.87
					0.10	6.00
					0.50	7.01
					1.00	8.34
					1.1800	9.00
					1.20	8.80
					1.50	7.33
					2.00	5.42
					5.00	1.80
					10.00	1.01
					20.00	+
					50.00	+
					100.00	+

The Half Way Points. A possible method for estimating the tie-line slope, $-\frac{k_X}{k_Y}$, depends upon the determination, at some intermediate point in the tower, of corresponding values of X and Y. The gas and liquid compositions at the half way point would be determined. A tie-line slope would be assumed and the integration for the number of transfer units would be determined by White's method. This would also give the half way point on the operating line. If the half way points did not agree a new tie-line slope would be tried. The correct tie-line slope would make the half way point identical.

For the case in which the operating line slope is 1.1800 in the system using water-acetone-air, the N.T.U. is 9.00 as shown in Table 4, 5 and Figure 2. The half number of N.T.U. is 4.50: this point designated as M, is shown in Figure 2 also. The point M will fall on the operating line at the composition: $X=0.0580\ \frac{\text{lb acetone}}{\text{lb water}}$, $Y=0.1107\ \frac{\text{lb acetone}}{\text{lb air}}$. For the same operating line slope and other different tie-line slopes, the mean value of X and Y are $0.0576\ \frac{\text{lb acetone}}{\text{lb water}}$ and $0.1097\ \frac{\text{lb acetone}}{\text{lb air}}$ respectively. The calculated half way points indicate differences of -0 to -10.0, the half way point changes by amount equivalent to only 1.07 per cent of the change in liquid composition and 1.80 per cent of the change in gas composition. The other operating line slopes also indicate a similar conclusion. These results are shown in Table 6.

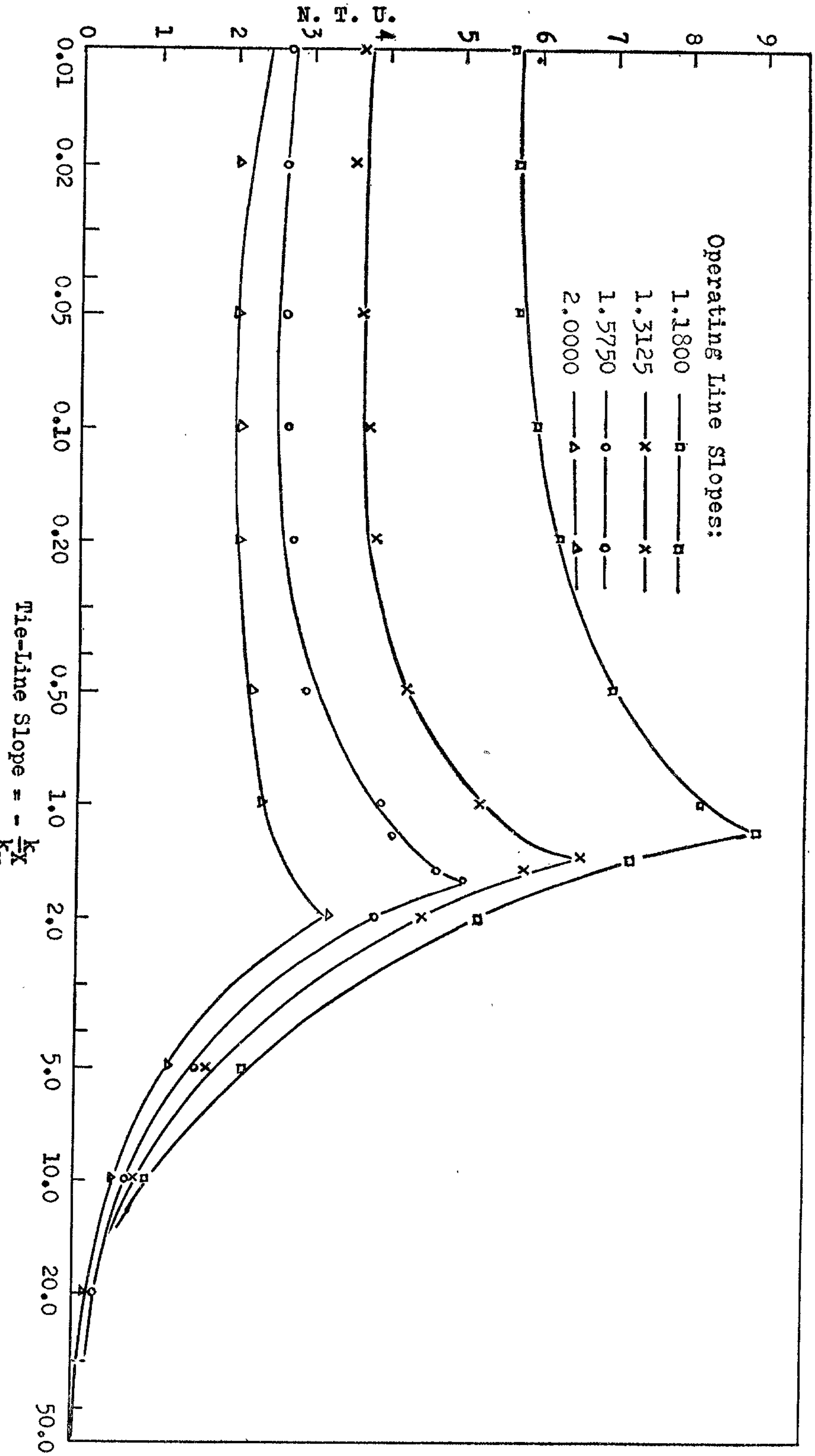

Fig. 3. N.T.U. vs. tie-line slope for various operating line slopes. The system is water-acetone-air at 25°C. and 1.0 atmosphere pressure. Isothermal operation.

Table 6. The Half Way Points of Various Operating Lines for Various Tie-Line Slopes. The system is water-acetone-air at 25°C. and 1.0 atmosphere pressure.

Operating Line Slope $\frac{L'}{V'}$	Tie-Line Slope $-\frac{k_X}{k_Y}$		Half Way Points X $\frac{\text{lb acetone}}{\text{lb water}}$	Half Way Points Y $\frac{\text{lb acetone}}{\text{lb air}}$
2.0000	0.0000		0.0225	0.0906
	0.01		0.0230	0.0911
	0.02		0.0231	0.0919
	0.05		0.0242	0.0915
	0.10		0.0232	0.0918
	0.20		0.0225	0.0903
	0.50		0.0230	0.0910
	1.00		0.0226	0.0908
	2.00		0.0233	0.0914
	5.00		0.0250	0.0928
	10.00		0.0263	0.0943
	20.00		0.0265	0.0952
		Mean Value:	0.0238	0.0927
1.5750	0.0000		0.0380	0.0987
	0.01		0.0321	0.0957
	0.02		0.0326	0.0959
	0.05		0.0323	0.0962
	0.10		0.0320	0.0958
	0.20		0.0333	0.0959
	0.50		0.0327	0.0960
	1.00		0.0320	0.0955
	1.20		0.0323	0.0958
	1.50		0.0343	0.0991
	1.5750		0.0328	0.0961
	2.00		0.0328	0.0963
	5.00		0.0332	0.0969
	10.00		0.0335	0.0975
	20.00		0.0338	0.0980
		Mean Value:	0.0332	0.0966

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1.3125	0.0000	0.0428	0.1012
	0.01	0.0428	0.1010
	0.02	0.0426	0.1008
	0.05	0.0422	0.1000
	0.10	0.0475	0.1009
	0.20	0.0422	0.1008
	0.50	0.0430	0.1019
	1.00	0.0429	0.1014
	1.3125	0.0427	0.1012
	1.50	0.0430	0.1013
	2.00	0.0430	0.1016
	5.00	0.0432	0.1029
	10.00	0.0435	0.1015
	Mean Value:	0.0432	0.1013
1.1800	0.0000	0.0580	0.1103
	0.01	0.0579	0.1100
	0.02	0.0578	0.1100
	0.05	0.0577	0.1108
	0.10	0.0570	0.1096
	0.20	0.0570	0.1090
	0.50	0.0576	0.1093
	1.00	0.0568	0.1090
	1.1800	0.0580	0.1107
	1.20	0.0578	0.1095
	1.50	0.0579	0.1095
	2.00	0.0577	0.1096
	5.00	0.0575	0.1090
	10.00	0.0570	0.1090
	Mean Value:	0.0576	0.1097

One practical proposed experimental arrangement is to divide the tower into up and down sections of equal packed height, providing in effect two identical towers in series-counterflow. The gas and liquid compositions at the half way point would be determined. Obviously, this point corresponding to the intermediate analysis will fall on the operating line, and there will be an equal number of transfer units in the two sections. The true half way point will be got, and to give an idea of the probable accuracy in estimating the true tie-line slope in gas absorption tower.

EXPERIMENTAL PART

Apparatus

Absorber Tower. The flow diagram of the apparatus is presented in Figure 4. Two identical towers in series-counterflow, each with an inside diameter of 4 inches and 4 foot high glass tubing as the absorber tower, were packed with ½-inch Intalox Saddles. The measured height of 3.75 feet in each tower means total height of packing was 7.50 feet. The dry void was 78 per cent. For keeping the isothermal states each tower was equipped with a cooling jacket to maintain the desired temperature.

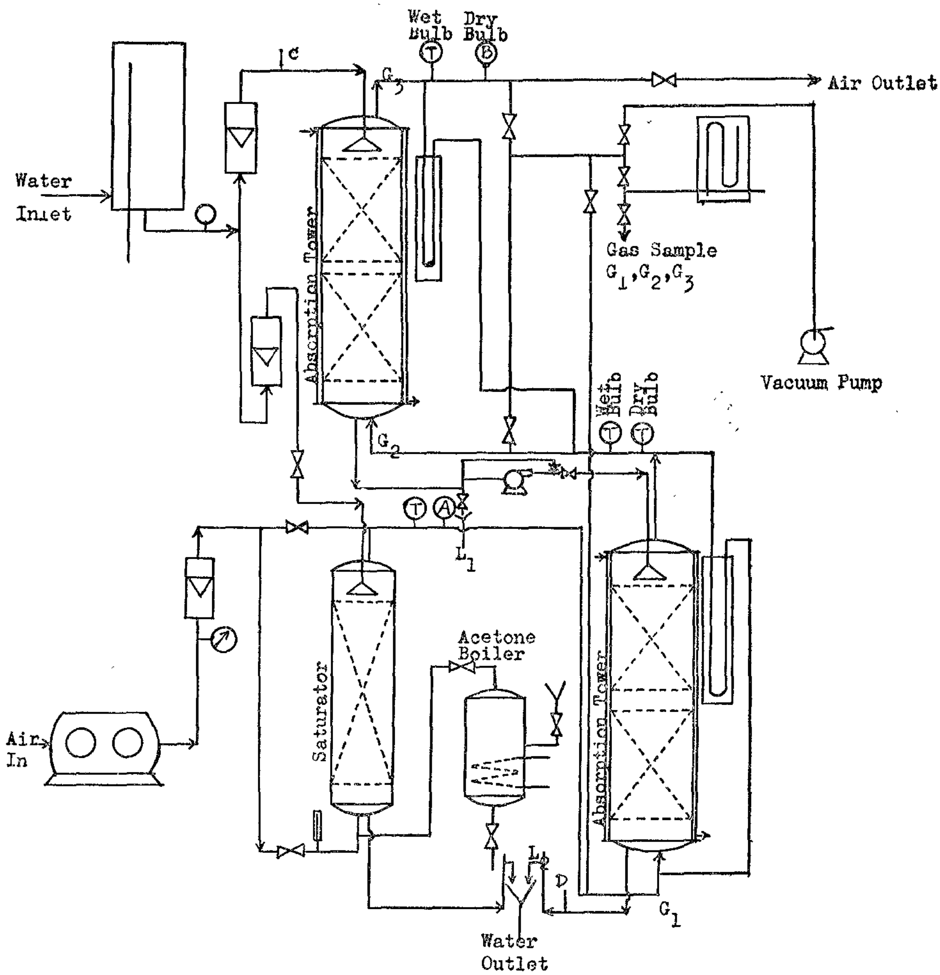

Fig. 4. Gas Absorption Apparatus for the system water-acetone-air.

Acetone Boiler. Variac controlled electric heaters in the boiler provided heat to vaporize acetone, with mixed with the saturated air from the saturator before entering the absorber tower. The power input was measured by a wattmeter. A 600-watt electric heater in a cooper coil was installed in order to keep the temperature constant during a run.

Air System. The air flow was measured by a rotameter and controlled by changing the blower speed via a variable speed drive. The air was saturated with water by passing it countercurrent to water in a packed saturator, with a 2 foot height of 4-inch pipe. The saturated air then mixed with vaporized acetone in a fixed proportion and entered the bottom of the lower absorption tower.

Water System. The water can be admitted to the absorption tower and saturator through separate rotameters. Water was sprayed over the packing by means of a liquid distributor, passed through the top column and then into the spray distributor same above of the top of tower, then passed through the bottom column and then into a drain. Water rates were determined by means of a rotameter, calibrated by means of a rotameter by measuring the time required for a definite volume of water to pass through the meter.

Experimental Procedure

600 watts were used to bring acetone to its boiling point, 56.2°C. When the temperature reached the boiling point, the boiler input was reduced to 360 watts to maintain the desired 6.97 volumetric per centage of acetone to the air flow rate 430 pounds per hour per square foot. The air flow rate was fixed. Four different water rates to the tower were used: 860, 720, 560, and 500 pounds of water per hour per square foot, reading by rotameter. The water and air should be at the same temperature to minimize water transfer and maintain single component diffusion. Water rates were maintained constant by manual control of the valve on the discharge side.

After steady state conditions were reached, gas and liquid samples were taken at the points indicated in Figure 4. Temperatures were measured with thermometers at positions (A), (B), (C), and (D) shown in Figure 4. The gas samples were obtained in previously evacuated brown bottles. The vacuum was created by means of a vacuum pump. Three gas samples were taken at the points marked G_1, G_2, and G_3, on Figure 4. The analytical procedure for acetone used was the Messinger method, in which iodoform is produced. The quantity of iodine solution absorbed in the analysis bears a direct relation to the acetone in the sample. By adding an excess of iodine and then later backtitrating, the equivalent quantity of acetone may be determined.

The two liquid samples were obtained at the points marked L_1 and L_2 on Figure 4. The analytical procedure for acetone used was the Pycnometer method using an Osward Pycnometer. A semi-micro-balance was used to weigh the Pycnometer and calculate its specific gravity compared with the physical data.

In all runs at least 30 minutes of steady-state operation were observed before taking samples.

Results of Experiment

Experimental data recorded for each run included the gas and liquid rates, the composition of gas mixture entering the bottom and top of the lower tower and leaving the upper tower, the composition of the liquid leaving the bottom of the upper tower and the composition of the liquid leaving the bottom of the lower tower. The liquid let into the upper tower was pure water and acetone-free. Table 7 shows the experimental results.

Data used for this investigation consisted of 24 experiments for each case and a total 96 runs which are summarized in Table 7. The gas rate remained around 430 pounds per hour per square foot for all runs and the liquid rates employed in this investigation were from 500 to 860 pounds per hour per square foot. Table 7 also indicates the deviation from the mean value of the graphical method of the half way point. Sufficient runs were available to permit correlation of the half way point.

Table 7 Experimental Data For Runs With The System Water-Acetone-Air.

Run	Inlet Gas Rate lb/hr/ft2	Ilnet Liquid Rate lb/hr/ft2	Temperature, °C.				Concentration of Acetone in water X, lb acetone/lb water			Concentration of Acetone in air Y, lb acetone/lb air			Deviation from the mean value of graphical method Half Way Point	
			T_1 Gas in	T_2 Gas out	t Liquid in	t_2 Liquid out	Top	Half-Way	Bottom	Bottom	Half-Way	Top	X, %	Y, %
1	430	501	28.2	27	25.5	26	0.0	0.0578	0.0930	0.1540	0.1108	0.0447	+0.35	+1.01
2	429	506	27.5	26.5	25	25.8	0.0	0.0587	0.0929	0.1537	0.1058	0.0438	+1.91	−3.75
3	430	505	28	26.2	25.4	26	0.0	0.0574	0.0949	0.1542	0.1090	0.0449	−0.36	−1.21
4	431	505	27	26	26	26.4	0.0	0.0580	0.0948	0.1545	0.1093	0.0445	+0.75	−0.37
5	430	505	28	26.5	25	26	0.0	0.0575	0.0949	0.1549	0.1099	0.0448	−0.17	+0.18
6	431	507	29.3	27	26.2	26.9	0.0	0.0634	0.0949	0.1547	0.1101	0.0445	+1.02	+0.37
7	430	506	28.2	26	26	26.5	0.0	0.0573	0.0947	0.1548	0.1098	0.0449	−0.52	−0.09
8	429	505	27.5	26.5	26	26.5	0.0	0.0575	0.0930	0.1548	0.1106	0.0446	−0.17	+0.91
9	430	506	28	26.5	26	26.8	0.0	0.0574	0.0934	0.1549	0.1099	0.0447	−0.34	+0.18
10	431	506	27	25.5	26	26.6	0.0	0.0581	0.0929	0.1546	0.1110	0.0435	+1.00	+1.19
11	430	502	26.8	25.3	25.7	26.5	0.0	0.0567	0.0931	0.1547	0.1098	0.0449	−1.56	+0.09
12	431	508	28.5	26.3	25.5	26.5	0.0	0.0586	0.0932	0.1550	0.1105	0.0451	+1.57	+0.73
13	430	505	27.8	26.2	25.3	26.7	0.0	0.0580	0.0934	0.1551	0.1106	0.0449	+0.75	+0.82
14	429	506	27.8	25.9	25	26.5	0.0	0.0568	0.0931	0.1549	0.1088	0.0450	−1.39	−0.82
15	430	507	28	26.8	25.3	26.6	0.0	0.0585	0.0929	0.1547	0.1084	0.0452	+1.56	−1.10
16	432	507	28	26.7	25.3	27	0.0	0.0571	0.0931	0.1552	0.1109	0.0448	−0.87	+1.10
17	430	508	27.5	26.2	25	26.5	0.0	0.0570	0.0930	0.1549	0.1099	0.0449	−1.04	+0.18
18	431	508	27.8	26.4	25.5	26	0.0	0.0557	0.0929	0.1539	0.1083	0.0445	−3.30	−1.28
19	429	505	27.8	26.5	25.6	26.8	0.0	0.0573	0.0924	0.1547	0.1089	0.0451	−0.52	−0.73
20	428	499	27	26.2	25.7	27	0.0	0.0580	0.0930	0.1548	0.1111	0.0449	−0.75	+1.28
21	429	504	27.8	26.3	25.5	26.5	0.0	0.0571	0.0928	0.1510	0.1109	0.0451	+1.04	+1.10
22	433	509	28	27	26.2	27.7	0.0	0.0588	0.0930	0.1509	0.1110	0.0450	+2.08	+1,19

(Continued)

40	432	564	28.8	27	25.5	26.4	0.0	0.0453	0.0810	0.1549	0.1017	0.0452	+2.79	+0.39
41	430	566	28.5	27	25	26	0.0	0.0420	0.0813	0.1548	0.1010	0.0448	−2.78	−0.30
42	432	565	27.8	26.5	25.3	26.7	0.0	0.0424	0.0809	0.1560	0.1009	0.0451	−1.62	−0.39
43	430	567	27.8	26.2	25.6	26.7	0.0	0.0428	0.0811	0.1553	0.1007	0.0455	−0.93	−0.59
44	435	567	28.5	26.8	25	26.3	0.0	0.0440	0.0815	0.1552	0.1020	0.0456	+1.56	+0.68
45	431	568	29	27.2	24.7	26.5	0.0	0.0433	0.0805	0.1549	0.1020	0.0458	+0.02	+0.68
46	430	566	28.7	26.8	25	26.3	0.0	0.0425	0.0799	0.1551	0.1009	0.0451	−1.62	−0.39
48	429	570	27.9	26	25	26.2	0.0	0.0430	0.0798	0.1549	0.1010	0.0453	−0.46	−0.30
49	431	721	28.3	27.2	25.8	26.8	0.0	0.0338	0.0668	0.1503	0.0959	0.0445	+1.80	−0.73
50	429	720	28.5	27.5	25.3	26.9	0.0	0.0329	0.0670	0.1508	0.0963	0.0449	−0.91	−0.31
51	431	722	27.4	26	25	26.3	0.0	0.0322	0.0666	0.1509	0.0957	0.0448	+1.50	−0.93
52	430	723	27.8	26.4	25.4	26.2	0.0	0.0337	0.0671	0.1510	0.0987	0.0450	+1.50	+2.17
53	429	722	28.6	26.8	25.8	26.5	0.0	0.0327	0.0669	0.1511	0.0957	0.0448	−1.50	−0.93
54	431	724	28.7	27	25.6	26.3	0.0	0.0326	0.0670	0.1501	0.0958	0.0449	−1.80	−0.83
55	429	720	28.5	27.3	25	26.2	0.0	0.0338	0.0669	0.1508	0.0963	0.0448	+1.80	−0.31
56	427	726	28	27	25.4	26.6	0.0	0.0339	0.0666	0.1509	0.0958	0.0449	+2.11	−0.83
57	432	719	27.7	26.8	25	26.2	0.0	0.0328	0.0669	0.1510	0.0960	0.0450	−1.20	−0.62
58	433	720	28.3	27	25	26	0.0	0.0340	0.0658	0.1511	0.0987	0.0448	+2.11	+2.18
59	429	722	28.5	27.2	25.3	26.7	0.0	0.0330	0.0660	0.1501	0.0958	0.0447	−0.06	−0.83
60	427	724	28	26.8	24.8	26	0.0	0.0342	0.0670	0.1500	0.0943	0.0451	+3.00	−2.34
61	423	721	28.6	27.2	25	26.3	0.0	0.0336	0.0669	0.1503	0.0969	0.0448	+1.21	+0.31
62	429	722	28	26.8	25.5	26.4	0.0	0.0342	0.0672	0.1509	0.0971	0.0451	+3.00	+0.52
63	428	721	28	26.6	25	26.3	0.0	0.0328	0.0664	0.1513	0.0959	0.0449	−1.20	−0.73
64	429	723	28.2	27	25	26.2	0.0	0.0326	0.0680	0.1515	0.0960	0.0451	−1.80	−0.62
65	432	726	28	27	24.8	26	0.0	0.0328	0.0667	0.1505	0.0960	0.0448	−1.20	−1.80
66	430	728	27.8	26.9	25	26.3	0.0	0.0339	0.0669	0.1507	0.0973	0.0449	+2.11	+0.73
67	433	729	28	26	24.7	26.2	0.0	0.0344	0.0673	0.1511	0.0972	0.0451	+3.62	+0.62
68	435	731	29	27.8	24.6	26.8	0.0	0.0322	0.0670	0.1508	0.0969	0.0449	+3.00	+0.31
69	430	728	28.6	27	25	26.3	0.0	0.0335	0.0669	0.1512	0.0975	0.0453	+0.91	+0.93
70	431	722	28.9	26.9	25	26.2	0.0	0.0340	0.0673	0.1510	0.0969	0.0451	+2.41	+0.31
71	432	721	27	26.6	25.2	26.5	0.0	0.0342	0.0669	0.1515	0.0962	0.0454	+3.00	−0.91
72	434	725	29	27.3	25	26.3	0.0	0.0333	0.0673	0.1510	0.0967	0.0450	+0.30	+0.10
73	429	856	28.7	26.5	25	26	0.0	0.0250	0.0524	0.1509	0.0918	0.0449	+5.05	−0.97
74	430	859	29	27.4	24.5	26.8	0.0	0.0229	0.0528	0.1509	0.0922	0.0445	−3.78	−0.54
75	431	861	28	26.6	24.7	26.5	0.0	0.0234	0.0530	0.1511	0.0925	0.0449	−1.68	−0.22
76	433	869	29	28	25.2	26.8	0.0	0.0242	0.0526	0.1513	0.0933	0.0451	+1.68	+0.65
77	431	850	28.5	26.8	24.3	26.6	0.0	0.0240	0.0528	0.1510	0.0929	0.4448	+0.84	+0.22
78	429	858	29.2	27.4	25	26.2	0.0	0.0229	0.0525	0.1517	0.0920	0.0450	−3.78	−0.75
79	433	859	29	27.5	25.5	26.6	0.0	0.0230	0.0529	0.1512	0.0919	0.0449	−3.36	−0.86
80	431	857	28.5	27	24.3	26	0.0	0.0229	0.0529	0.1511	0.0920	0.0452	−3.78	−0.97
81	434	857	28.7	27.2	25	26.7	0.0	0.0245	0.0524	0.1518	0.0934	0.0448	+2.95	+0.76
82	435	859	29	27.7	25	26.8	0.0	0.0233	0.0525	0.1519	0.0923	0.0449	−2.10	−0.32
83	430	859	28.8	27	24.6	26.8	0.0	0.0227	0.0529	0.1505	0.0920	0.0450	−4.61	−0.76
84	429	862	29	27.4	24.5	26.6	0.0	0.0230	0.0531	0.1511	0.0922	0.0449	−3.36	−0.54

23	431	504	27.2	26.5	25	26	0.0	0.0572	0.0931	0.1506	0.1078	0.0446	−0.88	−1.73
24	430	503	27	25.5	25	26.3	0.0	0.0569	0.0929	0.1534	0.1082	0.0461	−1.22	−1.37
25	430	565	28.5	26.8	25.5	26.4	0.0	0.0435	0.0801	0.1538	0.1029	0.0442	+0.70	+1.58
26	429	566	28.3	27.2	25	26	0.0	0.0442	0.0821	0.1539	0.1034	0.0451	+2.78	+2.26
27	431	567	28.7	27	25.7	26	0.0	0.0430	0.0802	0.1538	0.1012	0.0450	−0.46	−0.09
28	429	568	28	26.8	25.5	26.4	0.0	0.0444	0.0799	0.1541	0.1024	0.0449	+3.00	+1.08
29	431	567	27.9	26.2	25.4	26.2	0.0	0.0432	0.0798	0.1537	0.1015	0.0451	0.00	+0.29
30	429	566	27	25.9	24.9	26	0.0	0.0441	0.0803	0.1539	0.1014	0.0453	+2.09	+2.00
31	428	565	28	26.3	25	26.4	0.0	0.0426	0.0801	0.1538	0.1000	0.0449	−1.85	−1.28
32	429	564	28.3	26.7	25.4	26.3	0.0	0.0411	0.0801	0.1549	0.1015	0.0452	−4.85	+0.02
33	430	564	28.3	26.7	25.4	26	0.0	0.0422	0.0800	0.1551	0.1009	0.0451	−2.32	−3.94
34	431	568	28.5	26	25.5	26.2	0.0	0.0431	0.0804	0.1549	0.1018	0.0447	−0.02	+0.49
35	434	570	28.6	26.7	25.4	26.3	0.0	0.0442	0.0804	0.1551	0.1020	0.0499	+2.32	+0.69
36	430	567	27.4	25.3	25.4	26.2	0.0	0.0442	0.0818	0.1548	0.1021	0.0450	+2.32	+0.69
37	429	566	28.5	26.9	25.8	26	0.0	0.0439	0.0799	0.1549	0.1010	0.0452	+1.62	−0.29
38	431	568	27.9	26.7	25	26	0.0	0.0427	0.0802	0.1550	0.1019	0.0449	−1.16	+0.59
39	430	570	28.2	26.8	24.8	26	0.0	0.0439	0.0801	0.1551	0.1010	0.0452	−1.16	−0.29

(Continued)

85	431	864	28.7	26.5	25	26.2	0.0	0.0231	0.0532	0.1517	0.0924	0.0451	−2.94	−0.32
86	432	866	29	27.4	25.2	26.9	0.0	0.0243	0.0529	0.1507	0.0935	0.0452	+2.10	+0.86
87	431	862	28.6	27	25	26.3	0.0	0.0240	0.0527	0.1510	0.0936	0.0450	+0.84	+0.76
88	432	860	29	27.3	24.8	26.6	0.0	0.0243	0.0528	0.1513	0.0937	0.0448	+2.10	+1.07
89	429	863	28.5	27	25	26.8	0.0	0.0229	0.0527	0.1511	0.0919	0.0449	−3.78	−0.86
90	435	862	29	27.8	24.6	26.8	0.0	0.0232	0.0529	0.1517	0.0920	0.0452	−2.52	−0.76
91	434	861	29	27.4	25	26.4	0.0	0.0235	0.0530	0.1511	0.0933	0.0453	−1.26	+0.65
92	435	864	28.5	26.9	25	26.5	0.0	0.0236	0.0532	0.1509	0.0930	0.0449	−0.84	+0.32
93	430	864	28.9	26.8	24.6	26.5	0.0	0.0242	0.0529	0.1510	0.0923	0.0450	+1.68	−0.43
94	432	862	28.5	26.4	25	26.8	0.0	0.0240	0.0527	0.1513	0.0933	0.0449	+0.84	+0.65
95	430	863	29	27.8	25	26.7	0.0	0.0244	0.0529	0.1510	0.0935	0.0451	+2.52	+0.86
96	431	862	29	27.6	25	26.8	0.0	0.0240	0.0528	0.1508	0.0929	0.0453	+0.84	+0.22

Runs 2, 18, 22,......etc. were shifted too much from the calculation values. This means that the half way point does not fall on the operating line. This might be caused by some error in experiment or analytical procedure. Those with a deviation within one per cent were in good agreement on the half way point on the operating line.

For the conditions tried as shown in Table 6, the variation in the tie-line slope from minus zero to minus twenty changed the half way point on the operating line only 2 to 8.5% of its length. The true half way point must lie in this range, which is shown by experimental results in Table 7. This shows reasonable agreement both by calculation and experiment. This gives an idea of the probable accuracy of the true tie-line slope.

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Nomenclature

L'=lb inert liquid per unit time, lb/hr.

N.T.U.=number of transfer units.

s=slope of lower trace line in graphical construction of transfer unit.

t=slopee of upper trace line in graphical construction of transfer unit.

V'=lb inert gas per unit time, lb/hr.

X=lb ratio of solute to lb liquid.

Y=lb ratio of solute to lb inert gas.

Subscripts:

X=liquid, or liquid-film or based on X units.

Y=gas, or gas-film, or based on Y units.

Correction for Tunghai Journal, Vol. VI, No. II. Dec. 1964 "The Effect Of Curvature Of The Equilibrium Line On The Film Resistances In Gas Absorption pp. 29-58.
Figure 7 on pp. 40 and Figure 12 on pp. 52 should interchange.

氣體吸收時薄阻力對平衡線曲率之影響(II)

高 昭 仁

在氣體吸收過程中，操作線介於平衡曲線之上。要使操作線成爲直線，圖表應該用重量比表示。傳送值利用懷特法計算，可得到十分滿意的結果。利用此法，在氣體吸收塔的反應，許多現象可以了解並測得。用此法亦可適用於斜率零到無窮間的束線的斜率。其臨界束線的斜率，係等於操作線的斜率，但符號相反。依臨界束線，懷特法可分爲兩步驟，即以氣體及液體薄膜阻力最爲重要。在臨界束線斜率上，傳送值達到最大，同時吸收塔高度也達最大。

對于水—丙酮—空氣系予以計算與實驗探討。因此系的平衡曲線僅僅呈微小彎曲。探討四種不同反應狀況下，用 4 吋吸收塔裝 $\frac{1}{2}$ 吋的 Intarlox Saddles 的吸收介子，並在普通大氣壓與室溫下操作。

平衡曲線幾乎成一直線，有一種可以分析大約的束線斜率，在氣液體交界面上的液體與氣體薄膜間的相對阻力，很容易求得，此種資料對于設計氣體吸收塔將十分需要。

本實驗的吸收塔是用兩個同高塔同方向串聯使用。以純水吸收含丙酮汽的空氣的丙酮成份。對于空氣及液體的組成份，無論中段或上下段均容易測得。傳送值的測定，適用懷特法，並且擴大其範圍，使束線斜率自零到負無窮。中段點必介於傳送數目自零到無窮區域間之半，且必介於操作線上。

實驗結果與計算值呈滿意的接近。並由實驗得知斜率自零到負二十的變化對中段點的移動約爲操作線全長的百分之二到八點五。由此得一結論即正確的中段點由實驗結果得知應介於此一範圍，在氣體吸收塔內眞正的束線斜率有一較精確的概念。