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AIR LIFT PERFORMANCE AT LOW LIQUID RATES USING
OVERSIZED PIPING AND LATERAL RUNS

H. V. Chamberlain

October 10, 1961

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A B S T R A C T

The use of oversized piping in an air lift for transferring solutions at rates less than 5 liters per hour was proven feasible with certain limitations. Reliable operation was also obtained with air lifts containing a lateral run inserted between the point of air injection and the final discharge point. Discharge of the air lifts, especially at low liquid flows, was very erratic under the conditions studied.

Work done under Contract AT(10-1)-205 to the U.S. Atomic Energy Commission

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I. SUMMARY

An investigation of the operation of air lifts was undertaken to determine the effects of the following items on lift performance: air inlet position, use of oversized piping for transferring liquids at low rates (<5 liters per hour), and a lateral displacement of the discharge from the inlet. Water was used as the transferred liquid for all tests in this study. Use of a high air inlet position (ten inches above the liquid inlet) generally produced more stable and more efficient operation. When a low air inlet position (at the liquid inlet) was used, air sometimes backed up into the feed tank causing the lift to become inoperative. Satisfactory air lift operation was obtained in most cases with $1/4$ - and $1/2$ -inch diameter tubing; satisfactory operation was rarely achieved with $3/4$ -inch diameter tubing at the low flow rates. Inclusion of a lateral run in the lift decreased the capacity by as much as 90 per cent with a lateral run of 75 feet; increasing the lateral run decreased the capacity, other conditions being the same. Also, a downward slope of five degrees in the lateral run (in the direction of flow) produced slightly higher flows than either a horizontal or an upward sloping (five degrees) line. The discharge of the air lift, especially at low average liquid flows, was very erratic under the conditions studied. The quantity of liquid holdup in the system varied considerably and was dependent on tubing size, air rate, and the length of lateral run used.

II. INTRODUCTION

A continuing problem in the operation of the Idaho Chemical Processing Plant (ICPP) has been the plugging of the inter-cycle transfer pumps. These pumps transfer concentrated uranyl nitrate solutions at rates up to five liters per hour. Since the use of air lifts as suitable replacements for many of the pumps originally installed in the ICPP has been adequately demonstrated, serious consideration has been given to replacement of the inter-cycle transfer pumps with air lifts. Because of the problem of line plugging, it was deemed desirable to use oversized piping for the lifts.

The air lift as a device for transferring solutions is used extensively in nuclear fuel reprocessing operations. The simplicity, the reliability (especially at relatively low flow rates) and the non-plugging characteristics when handling slurries are all very desirable features. Of course there are some inherent disadvantages of air lifts, such as low efficiencies and de-entrainment problems, but the advantages frequently far outweigh the disadvantages.

It is still impossible to predict precisely the operation of air lifts, even though the first recorded use was in 1782, when one was used in Chemnity, Hungary, to pump water from a flooded mine shaft (7). Various models and mathematical treatments have been proposed to describe the behavior of air lifts (1,2,4,6,10,11). Many works deal with generalized correlations of pressure drop (3,6,8,10) and heat transfer (10,11) in air lifts; other works have concerned specific applications (5,9,12). The published work still leaves major gaps in the knowledge of air lift parameters and, in the particular design problem at hand, these gaps prevented the direct design of air lifts to replace the inter-cycle transfer pumps.

The objectives of this investigation were the determination of air lift characteristics when using oversized piping for transferring at low liquid rates and the determination of the effect on lift capacity of a lateral displacement of the lift between the point of air injection and the discharge point. The latter information is pertinent to the design of intercell transfer lines using air lifts.

III. EXPERIMENTAL EQUIPMENT

Figure 1
Schematic Diagram of Experimental
Air Lift Setup

The liquid flowed in line AB for Study 1 and flowed in line CDB for Studies 2 and 3. The air-lifted stream followed path EFHJ in Studies 1 and 2 and path EFGJ in Study 3. For Study 3, line EF was of two lengths--10 and 17 feet, and line FG was of two lengths--25 and 75 feet. Line FG was constructed so that it could be positioned at three different slopes--horizontal, up five degrees (in the direction of flow), and down five degrees. Lines AB, CDB, and the lines from point E through to the discharge were constructed of Tygon tubing; visual observation of the flow behavior was necessary to evaluate properly the flow characteristics. The Tygon tubing was top-supported to maintain the line vertical, and Unistrut channels with stainless tubing U-bends for the turnarounds were used to support the tubing in the lateral runs.

A schematic diagram of the experimental setup for these studies is shown in Figure 1. The air was normally admitted through Valve 3 with Valve 4 closed. The air, when admitted through Valve 3, entered the line EF at the point at which the liquid flowed from the feed tank through the line AB (or line CDB) and into the lift. When flowing through Valve 4, the air entered the lift ten inches above the point at which the liquid flowed into the lift. The air inlet nozzle consisted of a 1/4-inch diameter copper tube inserted into a pipe tee (the tip of the nozzle was at the centerline of the pipe); at the lower position the air entered vertically into the lift, and at the upper position the air entered horizontally into the lift. The detail of the air inlet is also shown in Figure 1.

The liquid flowed in line AB for Study 1 and flowed in line CDB for Studies 2 and 3. The air-lifted

IV. EXPERIMENTAL PROCEDURES AND RESULTS

A. Procedures

Two procedures were used in studying the lift characteristics. The first consisted of metering the liquid into the feed tank and allowing the air to lift the liquid at the rate it flowed over the side outlet. As a result, the submergence ratio (ratio of suction to discharge heights) did not remain constant, the liquid seeking a particular level in line AB of Figure 1 at each air and liquid rate. The second procedure, which was the only one used in the study of the effect of a lateral displacement, consisted of maintaining a constant liquid level in the feed pot and feeding out the bottom of the pot, thereby maintaining a constant submergence ratio. Water at 60° to 70° F was used as the flowing liquid in all experiments. Table 1 lists the pertinent conditions of the experiments.

Table 1

VALUES OF PRINCIPAL VARIABLES USED IN AIR LIFT STUDIES

Variable	Study		
	1	2	3
Water Rate (cc/min)			
33, 67, 500	x		
variable		x	x
Air Rate (scfm)			
1/4-inch Tygon tubing 0.05, 0.10, 0.20	x	x	x
1/2-inch Tygon tubing 0.3, 0.6, 1.0	x	x	x
3/4-inch Tygon tubing 0.4, 0.8, 1.0	x	x	x
Tygon Tubing I.D. (inches)			
0.25, 0.50, 0.75	x	x	x
Submergence Ratio (per cent)			
15, 20, 30		x	x
variable	x		
Total Lift (feet) 30	x	x	x
Lateral Displacement (feet)			
0	x	x	
25, 75			x
First Stage Lifts (feet)			
10, 17			x

The data presented herein were obtained with liquid temperatures of 60° to 70° F.

B. Results

1. Study of Low Volume Lifts Without Lateral Displacement

a. Variable Submergence Tests

The results of the first study (which had a variable submergence) showed that it is possible to pump at low liquid rates with oversized piping. However, careful adjustment of the valve in the outlet line from the tank (No. 5 in Figure 1) was often necessary to prevent air bubbling back into the feed pot, even with the air inlet ten inches above the water inlet (through Valve 4). It was evident that the back pressure exerted by the air-liquid mixture in the lift sometimes exceeded the head of liquid in the feed line, causing air to flow into the liquid inlet line. When the air backed up into the liquid feed line, it was necessary to turn off the air and allow the lines to fill with liquid; then the air could be turned on again. Modification of the air inlet might prevent this erratic behavior.

The data obtained in Study 1 indicated general trends for the Tygon tubing sizes studied. Although the position of the side-outlet of the feed tank allowed submergence ratios up to 30 per cent, considerably lower submergence ratios (10 to 15 per cent) were maintained at the low liquid rates (2 to 4 l/hr).

Figure 2
Effect of Air Rate and Water Rate
on Submergence Ratio for
1/4-inch I.D. Tubing

The data for the 1/4-inch tubing (Figure 2) indicated that these tests were made beyond the point of maximum liquid flow (i.e., that point beyond which an increase in air flow produces a decrease in liquid flow). The data for the 1/2-inch tubing (Figure 3) were obtained on both sides of the point of maximum liquid flow. The data for the 3/4-inch tubing (Figure 4) indicate that trouble would be encountered in using this size tubing for low flows. Under many conditions no liquid flow would be obtained because of air backup into the feed line. It might be possible to circumvent this condition with a properly designed air inlet.

The air inlet was raised to ten inches above the liquid inlet for additional tests with 1/4-inch diameter tubing (air flow through Valve 4 in Figure 1), and the results of tests with this arrangement are also shown in Figure 2. The results indicate that the air lift is somewhat more efficient when operating

Figure 3
Effect of Air Rate and Water Rate
on Submergence Ratio for
1/2-inch I.D. Tubing

Figure 4
Effect of Air Rate and Water Rate
on Submergence Ratio for
3/4-inch I.D. Tubing

with the higher air inlet position; i.e., it allowed the lift to function at lower submergence ratios.

b. Constant Submergence Tests

Study 2 was made by feeding from the bottom of the feed tank, thereby maintaining a constant submergence ratio. This method of operation would tend to give smoother operation than would flow out the side of the vessel, because possible small changes in the submergence ratio (due to variable input rates) would not seriously affect the air lift rate. This study was originally set up to obtain data in a statistically-designed fractional replication pattern of tests, but preliminary work showed that the range of air rates for initiating liquid flow was too large to permit setting up a meaningful program (<0.05 and 0.4 scfm for $1/4$ - and $3/4$ -inch tubing, respectively); therefore, this statistical program was not completed.

The results show that maximum liquid flows were obtained with approximately 0.05 and 0.6 scfm of air for the $1/4$ - and $1/2$ -inch diameter tubing, respectively, and with at least 0.8 scfm of air for the $3/4$ -inch diameter tubing. These data are shown in Figures 5, 6, and 7. Data were again obtained with the air inlet both at 0 and 10 inches above the liquid inlet.

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Figure 5

Effect of Submergence Ratio and Air Inlet Position on Lift Capacity for 1/4-inch I.D. Tubing

Figure 6

Effect of Submergence Ratio and Air Inlet Position on Lift Capacity for 1/2-inch I.D. Tubing

The higher air inlet position gave higher liquid flows beyond the normal point of maximum liquid flow for the 1/4- and 3/4-inch diameter tubing but gave less liquid flow for the 1/2-inch diameter tubing; the reason for this discrepancy is not known. Previous work⁽⁵⁾, which utilized an air inlet position of two to six inches above the liquid inlet, had shown that the position of the air inlet had no effect on lift capacity. Based on results of both the present study and the previous work, the air inlet position should probably be located at least two inches above the liquid inlet to insure consistent operation.

The data for 3/4-inch Tygon tubing from the present study are plotted in Figure 8 together with data for 1/2-inch stainless pipe from previous work⁽⁵⁾. The 3/4-inch diameter Tygon tubing has approximately the same inside diameter as 1/2-inch schedule 40 pipe (0.75 inch vs. 0.622 inch). Good correlation was obtained at the higher air inlet position.

2. Lateral Displacement Studies

The purpose of the last study was the determination of the effect of a lateral displacement on lift capacity. The first part of this study utilized an initial lift of 10 feet, a lateral dis-

Figure 7
Effect of Submergence Ratio and Air
Inlet Position on Lift Capacity for
3/4-inch I.D. Tubing

I.D. PIPE-0.622 INCH ~ TUBING- 0.750 INCH
TOTAL LIFT-30 FEET ~ SUBMERGENCE RATIO 30%

Figure 8
Comparison of Lift Capacity
for Pipe and Tubing

placement of 25 feet, and a final lift of 20 feet. A few runs were then made with the initial lift raised to 17 feet. The final phase of this work utilized a lateral displacement of 75 feet with an initial lift of 17 feet. Because of space limitations, the 75-foot lateral displacement was actually obtained in a horizontal distance of 25 feet with two turn-arounds to obtain a total of 75 feet of horizontal run. The line used for the lateral displacement had three slopes--horizontal, up five degrees, and down five degrees. An air inlet ten inches above the liquid inlet was used throughout these tests.

a. Effect of Lateral Run on Lift Capacity

The liquid flows obtained with a lateral displacement included in the lift piping were 10 to 90 per cent (over the range of air rates studied) of those obtained with no lateral displacement. Use of a lateral displacement of 25 feet with the 1/4-inch diameter tubing produced an average of 75 per cent of the liquid flows obtained with no lateral displacement. These data are shown in Figure 9. Use of lateral displacements of 25 and 75 feet with the 1/2-inch diameter tubing produced an average of 50 and 10 per cent, respectively, of the liquid flows obtained with no lateral displacement. These data are shown in Figure 10. Increasing the lateral displacement from 0 to 25

SUBMERGENCE RATIO-30%
SLOPE OF LATERAL RUN-0 DEGREES
HIGH AIR INLET POSITION
INITIAL LIFT-10 FEET ~ TOTAL LIFT-30 FEET

Figure 9
Effect of Lateral Displacement
on Lift Capacity of
1/4-inch I.D. Tubing

SUBMERGENCE RATIO-30%
SLOPE OF LATERAL RUN-0 DEGREES
HIGH AIR INLET POSITION
INITIAL LIFT-10 FEET TOTAL LIFT-30 FEET

Figure 10
Effect of Lateral Displacement
on Lift Capacity of
1/2-inch I.D. Tubing

feet with both the 1/4- and 1/2-inch diameter tubing produced essentially the same effect as would be obtained by reducing the submergence ratio from 30 to 20 per cent. Increasing the lateral displacement from 0 to 75 feet with the 1/2-inch diameter tubing produced essentially the same effect as would be obtained by reducing the submergence ratio from 30 to 15 per cent. Runs made with the initial lift of 17 feet gave liquid flows that were approximately 95 per cent of those obtained with an initial lift of 10 feet.

b. Effect of Slope of Lateral Run on Lift Capacity

The last phase of the study was the determination of the effect the slope of the lateral run would have on lift capacity. Figure 11 presents the data for the 1/2-inch diameter tubing. With lateral runs of both 25 and 75 feet a negative slope of the lateral run, i.e., a slope in the direction of flow, gave higher liquid flow rates than either a zero or a positive slope. Visual observations showed that the majority of the flow regimes obtained in this investigation were of the slug type (alternate slugs of air and liquid), with some flows being of the semi-annular type (liquid flowing near the walls with gas passing up the center). The slugs of liquid diminished in

Figure 11
Effect of Slope of the Lateral
Line on Lift Capacity of
1/2-inch I.D. Tubing

quantity of liquid holdup in the system. Up to a six-fold increase in liquid holdup occurred as the air rate or the submergence ratio was increased over the ranges studied. The data obtained in the lateral displacement study (Study 3) indicated that the runs with the downward slope had the lowest liquid holdups while the run with the upward slope had the highest holdup. The spread in the data precluded developing a useable correlation. Table 2 summarizes the liquid holdup data.

Table 2

LIQUID HOLDUPS

Tubing Size (inch)	Length of Tubing (feet)	Range of Liquid Holdup Volume (cc)	Volume of Tubing Occupied by Liquid (%)
0.25	30	110 to 235	38 to 81
0.50	55	95 to 680	4 to 32
0.75	30	236 to 1370	9 to 52

size (partially because of friction between the flowing fluid and the wall of the pipe) as they passed up through the tube. With a downward slope in the lateral section, the liquid would collect at the low point before it entered the second vertical section, and large slugs of liquid were again formed in the final lift section. This phenomenon would explain the increase in liquid rate. This same phenomenon probably resulted in slightly increased flows in the 75-foot lateral displacement tests, because of the presence of the two turn-arounds, compared to those that would have been obtained with a straight run installation of the same length.

3. Liquid Holdups

Liquid holdups in the air lift lines (EFHJ or EFGJ) were determined by simultaneously closing Valves 2 and 5 (shown in Figure 1), and drawing off the retained liquid through the drain valve. An increase in air rate, liquid rate, or submergence ratio generally caused an increase in the

4. Discharge Behavior of Air Lifts

The discharge of liquid at the outlet of an air lift can be very sporadic under certain conditions (e.g., with low submergence ratios and/or relatively high air rates). This sporadic behavior could have a detrimental effect on the smooth operation of subsequent equipment. Although this irregular behavior does exist, the variations obtained in the liquid flows over time intervals of 5 minutes or longer were only ± 5 per cent of the average rates; thus, consistent operation is obtained if the output is averaged over a sufficiently long period of time. Visual observation of this sporadic behavior showed that there were alternating periods of high liquid flow and no liquid flow. The duration of a period when liquid was flowing and the volume of liquid that flowed during this period were determined at various operating conditions. It was found that these periods of discharge (and volume of each discharge) were very irregular. The periods of discharge varied from 5 to 120 seconds, with the majority of the periods being under 40 seconds. The durations of periods of no liquid flow were not measured. Measured liquid flow rates during discharge periods varied from 25 to 200 per cent of the constant input rates for both the 1/2-inch and 3/4-inch diameter tubing at low flows. The variation in discharge rate at high liquid rates for the 1/2-inch tubing was small, but for the 3/4-inch diameter tubing the variation was large (± 50 per cent). Previous work with air lifts had also revealed this irregular behavior of air lifts; the use of rotameters on the outlet line of an overhead receiver had been unsuccessful because of the irregular behavior, even with rates as high as 25 liters per minute.

V. CONCLUSIONS

The data obtained in these studies have shown that oversized piping can be used for transferring liquids at low rates. However, the results indicate that the discharge is very sporadic under the conditions studied--a behavior which could possibly have a detrimental effect on the operation of subsequent equipment.

The data also show that the presence of a lateral run in air lifts, such as those necessary for intercell transfer of solutions, should be feasible.

VI. RECOMMENDED FUTURE WORK

The transient behavior of extraction column operation is currently being studied by analog simulation. Since air lifts are used on several column feed streams in the ICPP, it is necessary to know the characteristics of the discharge to permit determination of a computer signal correctly representing the feed stream flow. Insufficient information was obtained in this study to define clearly the sporadic discharge behavior of air lifts. A more refined experimental setup is required for accurate measurement of this sporadic behavior under a wide variety of conditions. An experimental air lift system, soon to be completed, will be used to determine this irregular discharge behavior.

Additional work to determine the operating characteristics of various air inlet devices could also be done in the present air lift setup. However, sufficient information is probably already available for designing suitable air inlet devices for most of the conditions that would be encountered in ICPP operations in the foreseeable future.

Processing of many future fuels could produce solutions containing considerable quantities of solids. A major problem to be considered is the effect of these solids on extraction column performance; a secondary problem is the effect of these solids on air lift performance. An experimental program would be necessary to determine the operating characteristics of an air lift used to transport slurries.

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