A STUDY OF ABSORPTION COLUMN WITH SINGLE BUBBLE CAP TRAY IN THE PRODUCTION OF SODIUM BICARBONATE

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ABSTRACT

In this investigation, experiments were conducted to study the hydrodynamics of a single bubble-cap column of standard design and it's use in the production of sodium bicarbonate from the absorption of carbon dioxide in sodium carbonate solution.

A 5-stage column, 15 cm in diameter was employed for this purpose. The results showed that the dry and wet pressure drop data obtained coincided with those given in the literature and a plot of stationary operating region was also constructed.

The column was found to operate satisfactory for the production of sodium bicarbonate up to a suspension concentration of 20 wt.%.

Other results showed that the operating pressure (range 0.5-1.25 bar gauge) has no effect on the conversion to sodium bicarbonate. While the conversion increased with operating time where at 2 hrs, the conversion is 77% and at 6 hrs it is 94%.

INTRODUCTION

The chemical industry afford numerous examples of process in which a gas is dissolved by a liquid and then undergoes a chemical reaction in the liquid phase. For example, in the contact process for the manufacture of sodium bicarbonate, in which carbon dioxide is absorbed by sodium carbonate solution. Equipment of packed and plate towers are generally used for large illustrations. The plate columns may be fitted either with perforated and or with bubble-cap trays. One of these is the absorption column with single bubble-cap. The sodium bicarbonate formed tends to plug the packing or perforation. Thus, the bubble-cap column is more appropriate for such systems. However, many manufacturers employ a single bubble-cap column of proprietary design. In the present study, the use of single bubble-cap columns of standard design was studied to assess it's capability to handle such systems of three phase nature.

Bubble-cap is the oldest and most widely used device for contacting vapor and liquid in absorption towers[1]. In the bubble-cap plate, the vapor passes through the plate by way of short vertical pipes (risers) surmounted by caps which force the vapor to bubble through the liquid and at the same time acts as seal to prevent liquid flowing out through the risers. The edges of the caps are serrated with slots to break up the vapor steam into bubbles. The liquid flows across the plate and then through one or several down pipes to the next lower plate. Weirs are fitted at the entry to the down pipes to maintain a constant level of liquid on the plate, and the lower ends of the pipes are sealed by the liquid on the plate below to prevent the ingress of vapor.

The pressure drop of a bubble-cap is important because it plays a large part in determining the range of vapor and liquid rates that can be used on any particular size and type of plate. It is usual to adjust the dimensions of the vapor riser and cap such that the area for vapor flow in the riser, the reversal zone in the dome of the caps and annular section surrounding the riser are constants. The pressure drop in the riser and cap can be determined experimentally with no liquid on the plate (dry pressure drop). According to Atkins[2], the pressure drop is equivalent to three or four times the velocity head in the cap. The pressure drop is given by[4]:

$$\Delta P_c = 0.05 k F_s^2 \qquad (1)$$

where:

$$F_s = V_g \sqrt{\rho_G} \qquad (2)$$

ΔP_c is the pressure drop (mmH_2O), ρ_G is the vapor density (kg/m^3), V_g is the vapor velocity in cap or slot (m/sec), and k is a constant between 3 and 6.

The pressure drop of a plate carrying liquid (wet pressure drop) is rather a complicated function of the gas velocity and the depth of liquid. Figure (1) shows the experimental results of Kemp and Pyle[3] for air and water with pressure drop plotted against F_s for several values of static seal (height of clear liquid level above the top of the slots) on plates fitted with 3 in and 4 in. diameter caps. It will be seen from this figure that each increase of the static seal (height of clear liquid level above the top of the slots) on plates fitted with 3 in. and 4 in. diameter caps. It will be seen from this figure that each increase of the static seal by 1 in. rises the pressure drop by about ¾ in. water which was considered to be a measure of the aeration of the liquid. The cap spacing was found to have a slight effect on the pressure drop at any given value of F_s.

It may be interesting to note the qualitative effect of liquid and vapor loads on bubble cap tray performance as limited by tray dynamics. This is illustrated by Fig. (2)[5], where an area of satisfactory operation is shown surrounded by excessive entrainment, flooding and vapor pulsation. With our present knowledge of bubble tray dynamics, it is not possible to predict the exact boundaries of the area of satisfactory operation[6,7]. The region of satisfactory operation is bounded by areas where undesirable phenomena occur. Coning occurs at low liquid flow rates, where the vapor forces the liquid back from the slots and passes out as a continuous stream, with consequent loss in efficiency[8,9]. Low vapor pressure rates result in pulsation vapor flow or dumping. With low liquid rates, vapor passes through the slots intermediately, but with higher liquid rates some slots dump liquid rather than passing vapor. Both pulsation vapor flow and dumping, which can be referred to joining as weeping, results in poor efficiency. At very high vapor rates, the vapor bubbles carry liquid as spray or droplets to the plate above, giving excessive entrainment. With high liquid rates, a point is reached where the drop in pressure across the plate equals the liquid head in the down comer. Beyond this point, the liquid build up and floods the tray.

EXPERIMENTAL WORK

Experimental Apparatus

Absorption Column with single bubble-cap (5-stages)

A schematic diagram of the equipment is presented in Fig. (3) which consists of: (1) cylindrical parts made of Q.V.F. glass, 10 in. length, 6 in. diameter. (2) five-stage single bubble-caps, 6 in. diameter. (3) Two tanks made of Q.V.F. glass, 0.1 m^3 in volume. (4) a centrifugal pump used for pumping the liquid feed to the column. (5) a cooler used for cooling the product. (6) rotameters to measure the volumetric flow rate of air, carbon dioxide, water, and sodium carbonate solution. (7) a pressure difference indicator to measure the pressure drop across the column. (8) a pressure reducing valve to produce the pressure of air from (four bar to one bar gauge or less), with pressure indicator its range from zero to six bar gauge. (9) pressure reducing valve to reduce the pressure of carbon dioxide from (hundred bar gauge to around one bar gauge), with pressure indicator its range from zero to six bar gauge. (10) carbon dioxide cylinder.

Spray type absorption column

A schematic diagram of the equipment is presented in Fig. (4), which consists of the following parts: (1) cylindrical column made of Q.V.F. glass, 3 in. diameter, 12 in. length. (2) a rotameter to measure volumetric flow rate of carbon dioxide with the range of 1 to 10 liter/min. (3) a pressure reducing valve to reduce the pressure of carbon dioxide from one hundred bar gauge to around on bar, with pressure indicator. (4) carbon dioxide cylinder. (5) a pressure indicator to measure the pressure inside the column.

Experimental Procedure

Dry and wet pressure drop

The dry pressure drop was measured across the five stage column at various flow rate of air from 2 to 14 m^3/hr. The pressure of air was about 0.5 bar gauge. Water manometers was used for this purpose.

The wet pressure drop was also measured across the column while changing the flow rate of air from 2 to 14 m^3/hr, at each liquid flow rate ranging from 50 to 350 liter/min.

The data obtained are plotted in curves of the gas flow rate (m^3/hr), G versus the dry wet pressure drop across the column (mmH_2O), ΔP at constant liquid flow rates.

Operating region

To determine the satisfactory operating pressure region of such columns, the column was operated at different air and liquid flow rates and recording the conditions where pulsation, ordinary condition, entrainment, or flooding occurred. A curve of liquid flow rate L, (m^3/hr) versus the vapor flow rate of gas G, (m^3/hr) on normal scale is plotted and the area of satisfactory region was obtained.

Three Phase Study

5-stage absorption column with single bubble-cap

In order to asses the capability of the present column to handle three phases, the column was operated at optimum conditions obtained previously viz liquid flow rate of 0.1 m^3/hr and gas flow rate of 10 m^3/hr. The liquid feed was 16 wt% sodium carbonate solution and the feed was air (60 vol%) and carbon dioxide (40 vol.%). The liquid and gas composition was obtained from published data[10]. Excess gas was vented to the atmosphere and the product bicarbonate suspension was removed from an outlet at the bottom of column.

Spray absorption column

In order to determine the effect of operating pressure on the production of sodium bicarbonate, the following experiments were carried out using a spray type column. Two liter of sodium carbonate was prepared (about 16 wt.%) and fed to the absorption column. Carbon dioxide was then fed at the button of the column through a sparger at certain flow rate at different pressure ranging from 0.5 to 1.5 bar gauge for constant time duration (two hours). Another set of experiments were done at constant pressure (about 1.25 bar gauge)[10] but changing the time of operation from 2 to 6 hrs to calculate the rate of conversion. A curve of the conversion (%) versus time t (hr) on normal scale was plotted.

RESULTS AND DISCUSSION

Hydraulic of 5-stage absorption column

Experiments were performed for measuring the pressure drop across the column, at different flow rates of air ranging from 2 to 16 m^3/hr at constant pressure (0.5 bar gauge). Sample of data sheet for the experiments is listed in Table (1). Fig. (5) shows the experimental results, the data shows good agreement with the previous work by Attridg[4].

A set of experiments were performed to determine the wet pressure drop across the column by changing the flow rate of air from 2 to 16 m^3/hr at constant pressure (0.5 bar gauge), with different flow rate of water ranging from 50 to 350 liter/min. Sample of data sheet for experimental is listed in Table (2). Fig. (6) shows the experimental results, the data shows good agreement with the previous work by Kemp and Pyle[3].

Experiments were performed to determine the occurrence of pulsation, normal operation, entrainment and flooding at different flow rate of liquid ranging from 50 to 350 liter/hr while the flow rate of gas ranging from 1.5 to 16 m^3/hr. Samples of data sheet of experiment are listed in Table (3). Fig. (7) shows the experimental results.

Three Phase Study

In these experiments, the effect of operating pressure and operating time on the conversion of $NaCO_3$ to $NaHCO_3$ was studied.

Effect of operating pressure

The preparation of $NaHCO_3$ was carried out using column operated at different pressures viz. 0.5, 0.75, 1.00, and 1.25 bar gauge. The results as shown in Table (4) indicated that changing the pressure has little effect on conversion which was on average about 62.35%.

Effect of operating time

Saturation of a constant volume of Na_2CO_3 solution (2 liter of 16 wt.%) with CO_2 was carried out at a constant pressure of 1.5 bar gauge. The operating time was varied from 2 to 6 hrs. The results given in Table (5) show that the conversion increases with time sharply at first then nearly levels out. Fig. (8) shows the experimental results.

Suspension concentration in the 5-stage column

Experiments were performed at different concentrations of sodium bicarbonate in the solution. A 25 liter of solution was prepared with the percentage of: Na_2CO_3 = 6 wt.%, and $NaHCO_3$ = 10 to 20 wt.% (the concentration was changed by a step of 2 wt.%)

The column was prepared with the satisfactory region, i.e., with the values: air flow rate, 10 m^3/hr at 0.5 bar gauge, and liquid flow rate of 0.1 m^3/hr.

These experiments showed the state of the three phase system through the column especially across the single bubble-cap in each stage, and how the suspended solution transferred from one stage to other without plugging the slots or down comer. The column operated satisfactory up to 20 wt.% suspension concentration.

CONCLUSIONS

1. The satisfactory region of operation of the single bubble-cap column was within liquid flow rate of 5.5 to 13.7 $m^3/hr.m^2$ (per unit x-section of column), and the gas flow rate of 388 to 603 $m^3/hr.m^2$ (per unit x-section of column).
2. The operating pressure has no significant effect on conversion of Na_2CO_3 to $NaHCO_3$ from 0.5 to 1.25 bar gauge.
3. The conversion increased with increasing operating time in the range used viz. 2 to 6 hrs.
4. The single bubble cap column operated satisfactory for the production of $NaHCO_3$ up to a suspension concentration of 20 wt.%.
5. The dry plate pressure drop data were correlated using Eq. (1) but the value of the constant k is equal to 6.0.

REFERENCES

1. Norman, W. S., "Absorption, *Distillation, and Cooling Tower*", London, Longmans, Green and co.. Ltd., 1962.
2. Atkins, G. T., "*Chem. Eng. Progress*", 50, 116, 1954.
3. Kemp, H. S. and Pyle, C., "*Chem. Eng. Progress*", 45, 455, 1949.
4. Atteridge, P. T., Lemieux and Schreiner, W. C., *A.I.Ch.E. journal*, 2, 3, 1956.
5. Smith, B. D., "*Design of Equilibrium Stage Processes* Tray Hydrodynamic", McGraw-Hill book comp., 1963.
6. Coulson, J. M. and Richardson J. F., "*Chemical Engineering*", volume 2, Pergamon Press Comp., 1978.
7. Coulson, J. M. and Richardson J. F., "*Chemical Engineering*", volume 6, Pergamon Press Comp., 1983.
8. Fair, J. R. and Mathew R. L., "*Petrol Refiner*", April, p.153, 1958.
9. Perry, R. H. and Green, D., "*Chemical Engineer's Handbook*", sixth ed., McGraw-Hill International Editions, 1984.
10. Peteu, I. and Dimit, N., "*Manufacture of Soda*", Didactional and pedagogical publishing house, Charset, 1967.

Table (1) Dry pressure for single bubble-cap (one stage)

Air flow rate (m^3/hr) at 0.5 bar	Pressure drop (mmHg) Experimental	Pressure drop (mmHg)*	
		k=5.0	k=5.5
2	0.2	0.14	0.15
4	0.7	0.53	0.59
6	1.5	1.20	1.32
8	2.7	2.12	2.34
10	4.0	3.34	3.66
12	6.0	4.80	5.28
14	7.50	6.53	7.18
16	10.5	9.10	10.01

**The pressure drop calculated by Eq. (1) using the k constant 5.0 and 5.5.*

Table (2) wet pressure across the absorption column with single bubble-cap (5-stage)

Flow rate of air (m^3/hr) at 0.5 bar gauge	Pressure drop (mm H_2O) at various water flow rates					
	100 l/hr	150 l/hr	200 l/hr	250 l/hr	300 l/hr	350 l/hr
2	24.00	26.40	27.20	29.20	32.80	37.60
3	26.00	28.10	30.00	32.00	32.50	57.45
4	27.50	29.80	32.00	36.20	52.20	83.9
5	30.50	32.24	37.04	41.04	74.62	108.1
6	31.48	35.48	40.28	51.48	92.28	
7	33.64	39.24	49.64	71.48		
8	35.80	43.80	59.00	89.40		
9	43.36	50.19	72.59			
10	45.36	54.96	100.36			
11	49.68	65.68				
12	54.00	74.00				
13	55.52	83.52				
14	65.04	89.04				
15	67.04					
16	73.40					

Table (3) Satisfactory region using air-water system

Liquid flow rate (l/hr)	Air flow rate (m^3/hr) at 0.5 bar gauge	State
60	1.5 to 6	Pulsation
	6 to 11	Normal operation
	11 to 15	Entrainment
	15 to 16	Excessive entrainment
100	1.5 to 6	Pulsation
	6 to 11.5	Normal operation
	11.5 to 15	Entrainment
	15 to 16	Excessive entrainment
150	1.5 to 6	Pulsation
	6 to 10.5	Normal operation
	10.5 to 12	Entrainment
	12 to 16	flooding entrainment
200	1.5 to 6	Pulsation
	6 to 9	Normal operation
	9 to 9.5	Entrainment
	9.5 to 16	flooding
250	1.5 to 6	Pulsation
	6to 8.5	Normal operation
	8.5 to 9	Entrainment
	9 to 16	Flooding
300	1.5 to 6	Pulsation
	6 to 7	Normal operation
	7 to 16	Entrainment and flooding

Table (4) Effect of pressure on sodium bicarbonate production

Operating pressure (bar gauge)	Mass of $NaHCO_3$ formed (gm)	Mass of Na_2CO_3 reacted* (gm)	Conversion (%)
0.50	2351.5	234.6	63.2
0.75	333.0	210.3	56.5
1.00	376.4	237.7	64.0
1.25	386.0	243.7	65.5

* Sodium bicarbonate produced at constant batch operation in a spray absorption column. Mass of Na_2CO_3 = 371.2 gm, volume of batch = 2 L, wt.% = 16%, concentration = 136 gm/L

Table (5) Effect of time on sodium bicarbonate production

Batch operation (hr)	Mass of $NaHCO_3$ formed (gm)	Mass of Na_2CO_3 reacted (gm)	Conversion
2	450	285.8	77.1
3	514	324.8	87.5
4	557	351.7	94.7
6	571	360.4	97.1

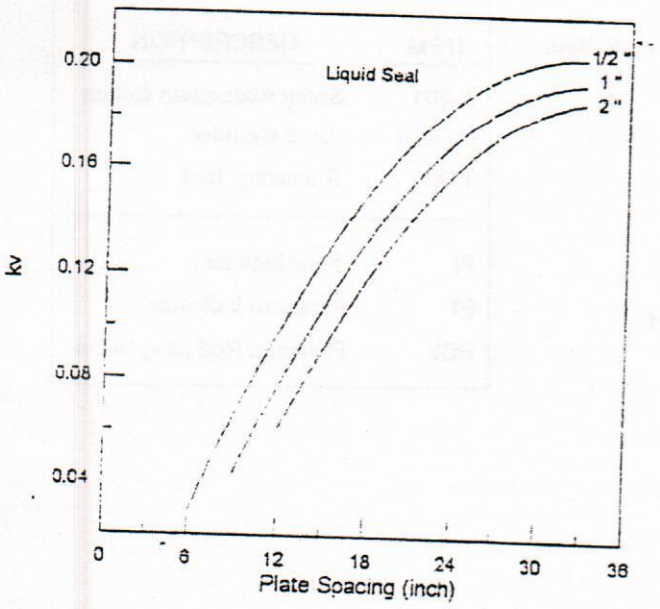

Fig. (1) The allowable vapour velocity for bubble-cap plates

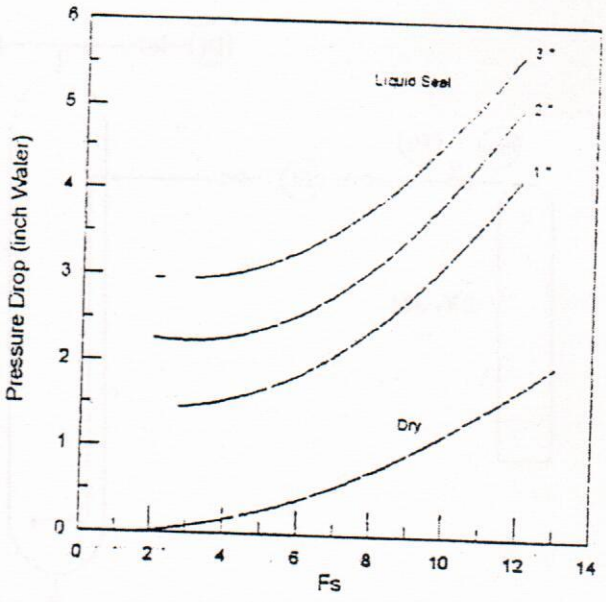

Fig. (2) Pressure drop at bubble-cap plate[5]

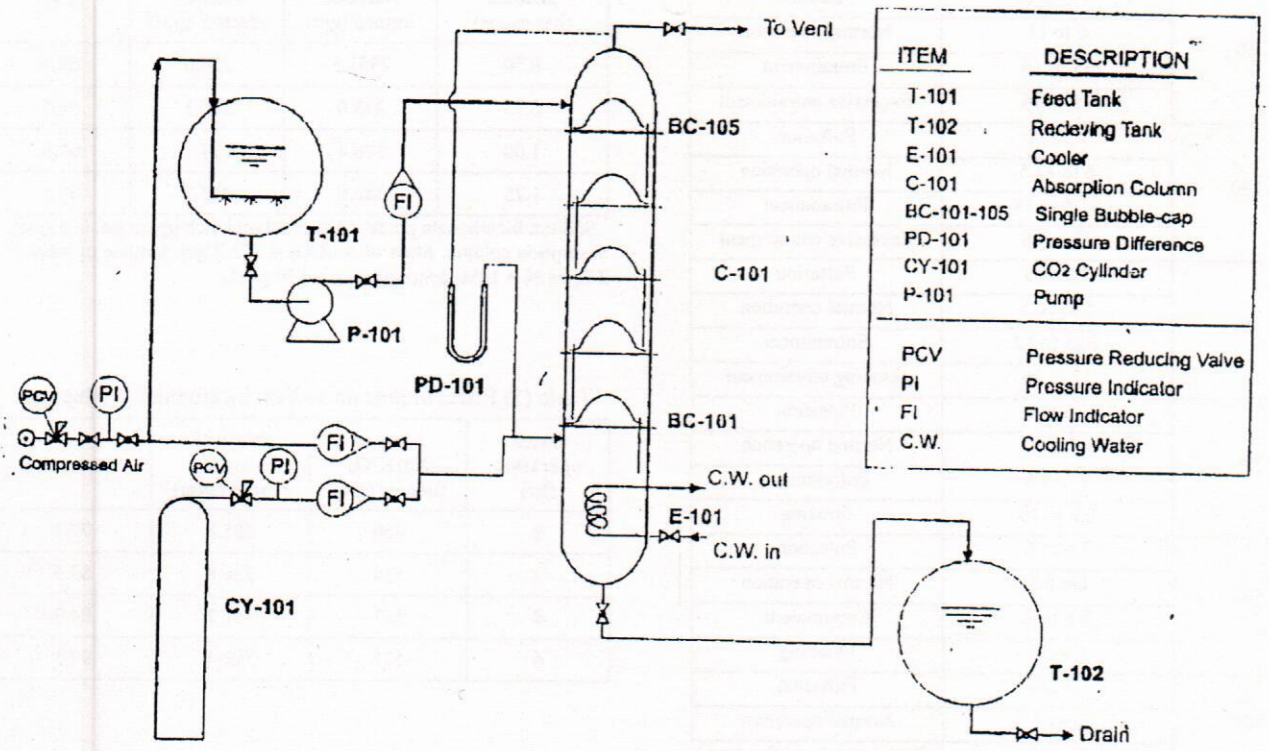

Fig. (3) Process flow diagram of absorption column unit with single bubble-cap (five-stage)

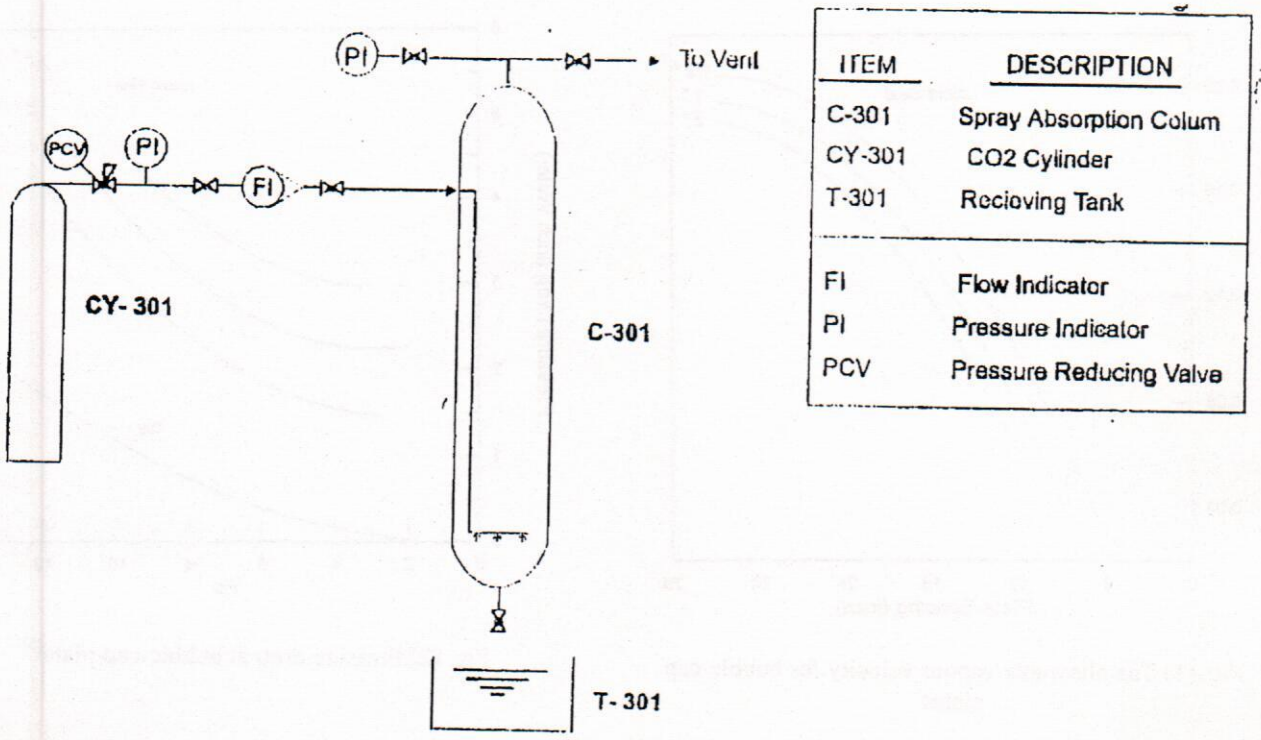

Fig. (4) Process flow diagram of spray absorption column unit

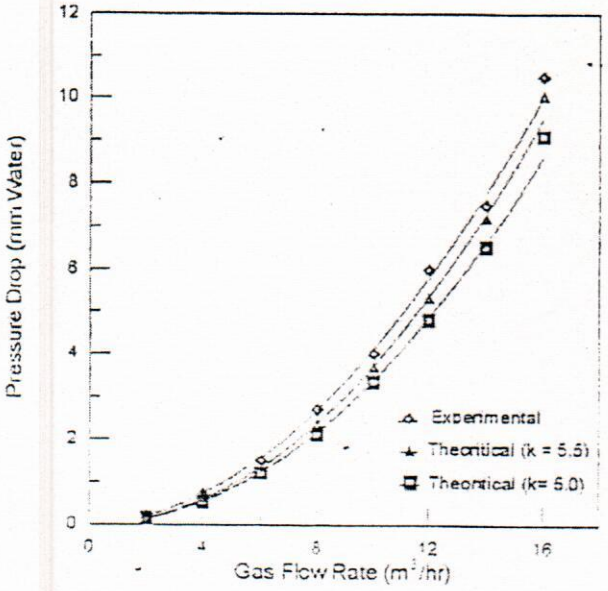

Fig. (5) Dry pressure drop across absorption column with single bubble-cap (one plate)

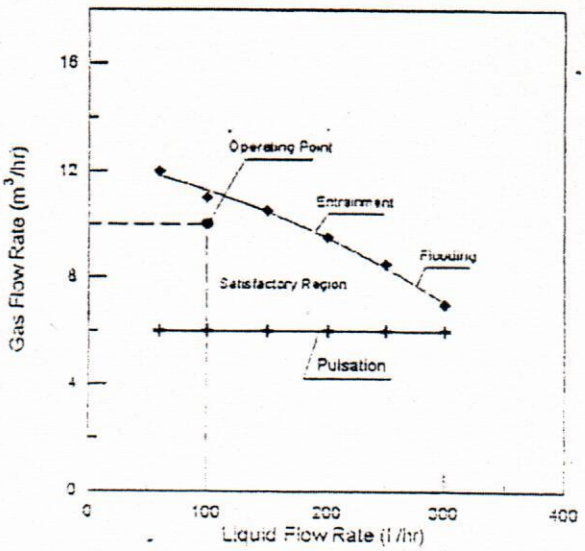

Fig. (7) Single bubble-cap tray performance chart

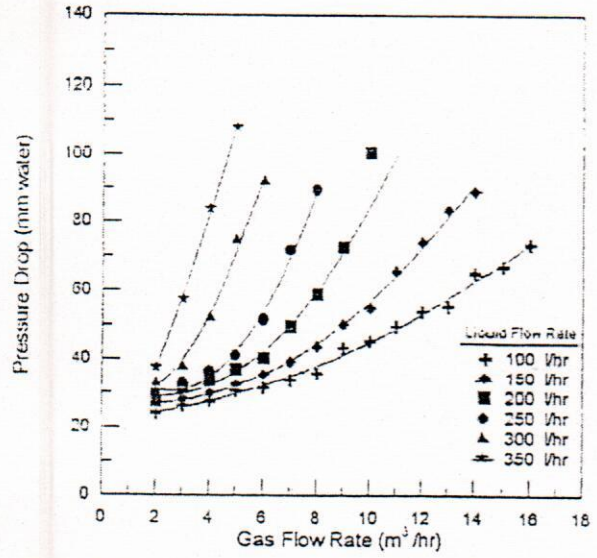

Fig. (6) Wet pressure drop across absorption column with single bubble cap (one plate)

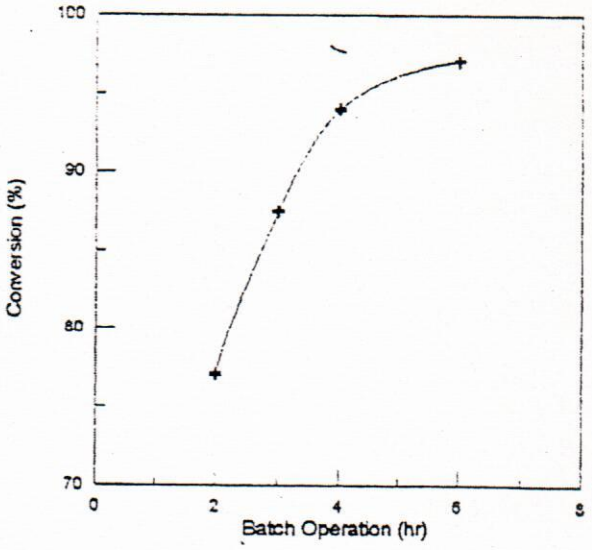

Fig. (8) Conversion of sodium bicarbonate in absorption column various batch operations