Chapter 3

EXPERIMENTAL: EQUIPMENT, SET-UP, AND PROCEDURE

3.0 Introduction

The experimental work was carried out in three stages.

First stage: a laboratory scale single nozzle horizontal jet ejector was employed (setup 1).

Second stage: a multi nozzle vertical jet ejector was used to study (setup 2) the effect of number of nozzles on the mass transfer characteristics.

Third stage: industrial scale multi nozzle jet ejector was investigated for mass transfer characteristics and scale-up (setup 3).

The detail of jet ejectors used to carry out experiments for three setups are summarized in Table 3.1.

3.1 Setup 1

3.1.1 Experimental set up

The experimental setup used in this work is shown schematically in Figure 3.2. The experimental set up is comprised of two systems: (i) liquid system and (ii) gas system.

1. **Liquid system**

   The liquid system comprises of

   (i) Tank (12) of 600 liters capacity with provisions of electrical heating.

   (ii) A circulating pump (5)

   (iii) Shell and tube heat exchanger (15) to control temperature.

   (iv) Pressure gauge (6) to measure the liquid phase pressure.

   (v) A separator (2) for gas liquid separation.

   The outlet steam from separator was either recycled or drained depending upon the requirement.

2. **Gas system**

   The system consist of

   (i) Chlorine / carbon dioxide gas cylinder (10).

   (ii) Soap film meter (9) to measure gas flow rate accurately.

   (iii) Soap film meter (8) to measure air flow rate.

Table 3.1 : Dimensions of ejectors

		Setup – I	Setup - II			Setup - III		
Nozzle diameter (mm)	D_N	3.28	3.28	2.0	1.50	8.2	4.7	3.7
Number of Nozzle (orifice)	n	1	1	3	5	1	3	5
Nozzle No.		1	2	3	4	5	6	7
pitch *		--	$2D_N$			$2D_N$		
Area ratio (appx) **	A_R	9.3	9.3			9.3		
Diameter of Throat/ mixing tube (mm)	D_T	10	10			25		
Length of Throat/ mixing tube *** (mm)	L_T	60	60			150		
Projection ratio #	P_R	2	4.5			4.5		
Angle of convergent	θ_{con}	well rounded	well rounded			well rounded		
Angle of divergence of conical diffuser ##	θ_{div}	7^0	7^0			7^0		
Length of the conical diffuser (mm)	L_d	120	120			425		
Diameter of the diffuser exit (mm)	D_C	25	25			77		
Diameter of extended contactor (mm)	D_C	25	25			(–)		
Length of extended contactor (mm)	L_C	1000	1000			(–)		
Diameter of the suction chamber (mm)	D_S	25	25			77		
Length of the suction chamber (mm)	L_S	40	45			122		
Distance between nozzle & commencement of throat (mm)	L_{TN}	20	45			112		
Diameter of secondary gas inlet (mm)	$D_{G,in}$	10	10			25		
Volume of free jet (m^3)	V_C	0.75×10^{-6}	1.689×10^{-6}			26.32×10^{-6}		
Volume of throat (m^3)	V_T	4.71×10^{-6}	4.710×10^{-6}			73.6×10^{-6}		
Volume of divergence (m^3)	V_D	30.6×10^{-6}	30.600×10^{-6}			1156.78×10^{-6}		
Total ejector volume (m^3)	V_J/V_R	36.061×10^{-6}	37.000×10^{-6}			1256.7×10^{-6}		

Reference :
* Panchal (1991), ** Acharjee et al (1975), *** Biswas et al. (1975),
# Yadav et a., (2008) ## Mukherjee et al. (1988)

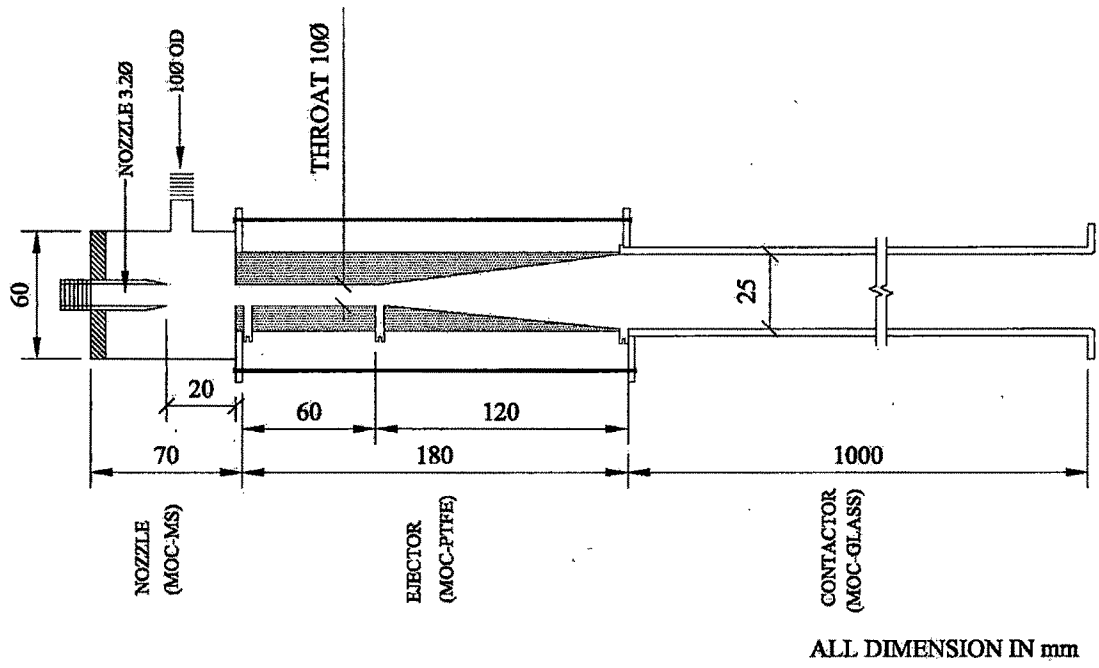


Figure 3.1 : Detail of jet ejector used in experimental setup 1

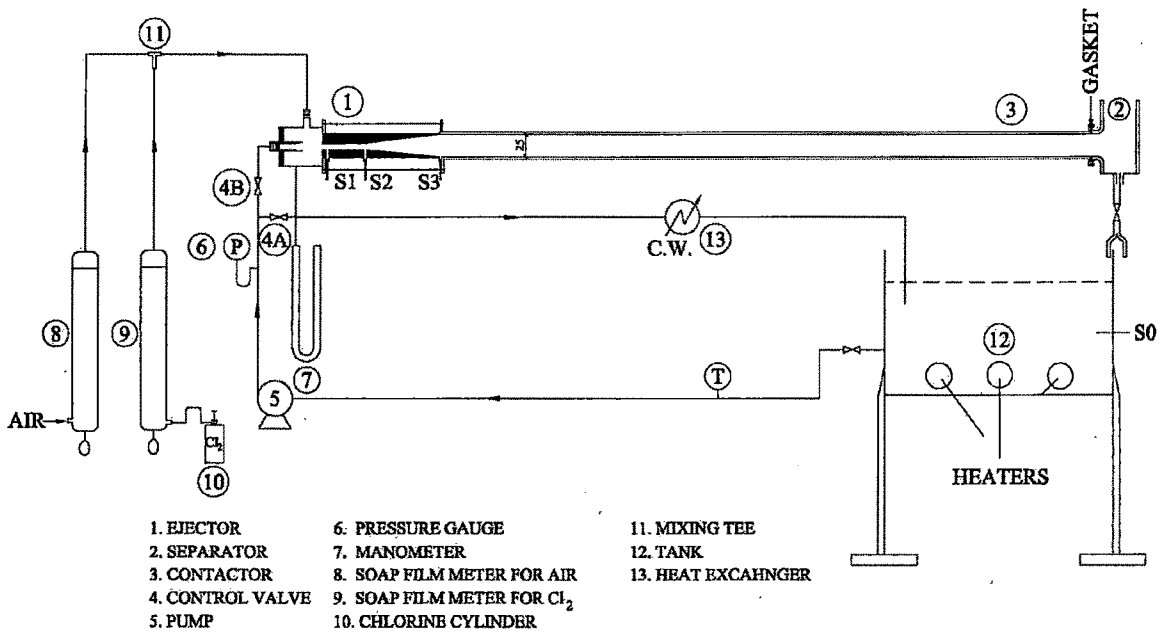


Figure 3.2 : Schematic diagram of experimental setup 1

(iv) Tee (11) to mix air and chlorine/CO_2. The tee is connected by 2 meter long tube (for thorough mixing of air and chlorine /CO_2) to the secondary fluid inlet of the jet ejector.

(v) Manometer (7) to measure suction pressure of gas stream.

(vi) Jet ejector (1) having detail as described in Table 3.1. The primary fluid inlet of the ejector is connected to outlet of pump (5) through control valve (4B). Bypass line is connected to reservoir (12) thorough valve (4A) and heat exchanger (13). Secondary fluid inlet is connected to a gas mixture line coming from Tee (11).

(vii) Contactor (3) : Ejector outlet is connected to contactor. At the outlet of the contactor is a gas liquid separator (2). Separator is vented to atmosphere and hence outlet pressure measuring device is not installed.

(viii) Sample points S1, S2, S3 are provided to withdraw the sample of reaction product. S1, S2 and S3 sample points are provided along the length of the ejector and sample S0 is drawn from the tank (12).

3.1.2 Experimental procedure

1. Preparation of caustic solution

First circulation of water through bypass line was started. Then required quantity of caustic lye was added slowly in tank (12). The strength of caustic was estimated by titrating against $N/10\ HCl$ solution using phenolphthalein as indicator. When the required strength was attained the addition of caustic lye was stopped. The solution was cooled to required temperature by heat exchanger (13). The temperature was kept at 30^0C through out the experiment.

2. Adjusting flow rate of Air

After the desired strength of caustic soda was achieved the flow of caustic soda solution through the ejector was started. The velocity of air was measured by using soap film meter (8). The flow rate of air was adjusted by setting the operating pressure. The liquid flow rate as well as air flow rate was kept constant for all experiments.

3. Adjusting Cl_2/CO_2 flow rate

Chlorine/Carbon dioxide rate was adjusted by the pressure regulator attached with the chlorine/carbon dioxide cylinder (10). The circulation of caustic solution was stopped while chlorine flow rate was being set. The chlorine flow rate was kept very low compared to the air. The chlorine/ carbon dioxide flow rate were measured by using soap film meter (9).

4. Operation and sampling

First all the flow rates were adjusted and then the pump (5) was started. The caustic solution and air-chlorine mixture were circulated through the ejector. Sufficient time was given to flush the system before taking the samples. The sample was withdrawn using syringe form sample point no. S1. The samples were drawn one by one from sample point no. S2 and S3 after closing sample point S1. The above samples were analyzed.

The procedure was repeated for different set of liquid concentration and gas concentration.

The results are tabulated in Table A1.1.

3.2 Setup 2

3.2.1 Experimental set up

The experimental setup for Stage 2 is shown schematically in Figure 3.4. In this setup the ejector having detail as Figure 3.3 and Table 3.1 is installed vertically. (photograph A.5.1)

The schematic flow diagram is self indicative and self explanatory.

There are two rotameters, RT1 and RT2, to measure flow rates of operating liquid and air respectively. The Cl_2/CO_2 flow rate is measured with the help of soap film meter (GM2). There are four sample points S0, S1, S2 and S3 to collect liquid samples to measure concentration of caustic at inlet of ejector, immediate after free jet, at the end of the throat and at the end of diffuser respectively. There are two liquid tanks (1) separation vessel (SV) (2) solution reservoir (ST).The system contains V-1, V-2, V-3,V-4 and V-5 control valves to control the flow of fluids.

3.2.2 Experimental procedure

The procedure is described stepwise as follows:

1. The nozzle plate to be studied was fixed on the jet ejector. Then empty runs were conducted by using water and air to check the leakage.

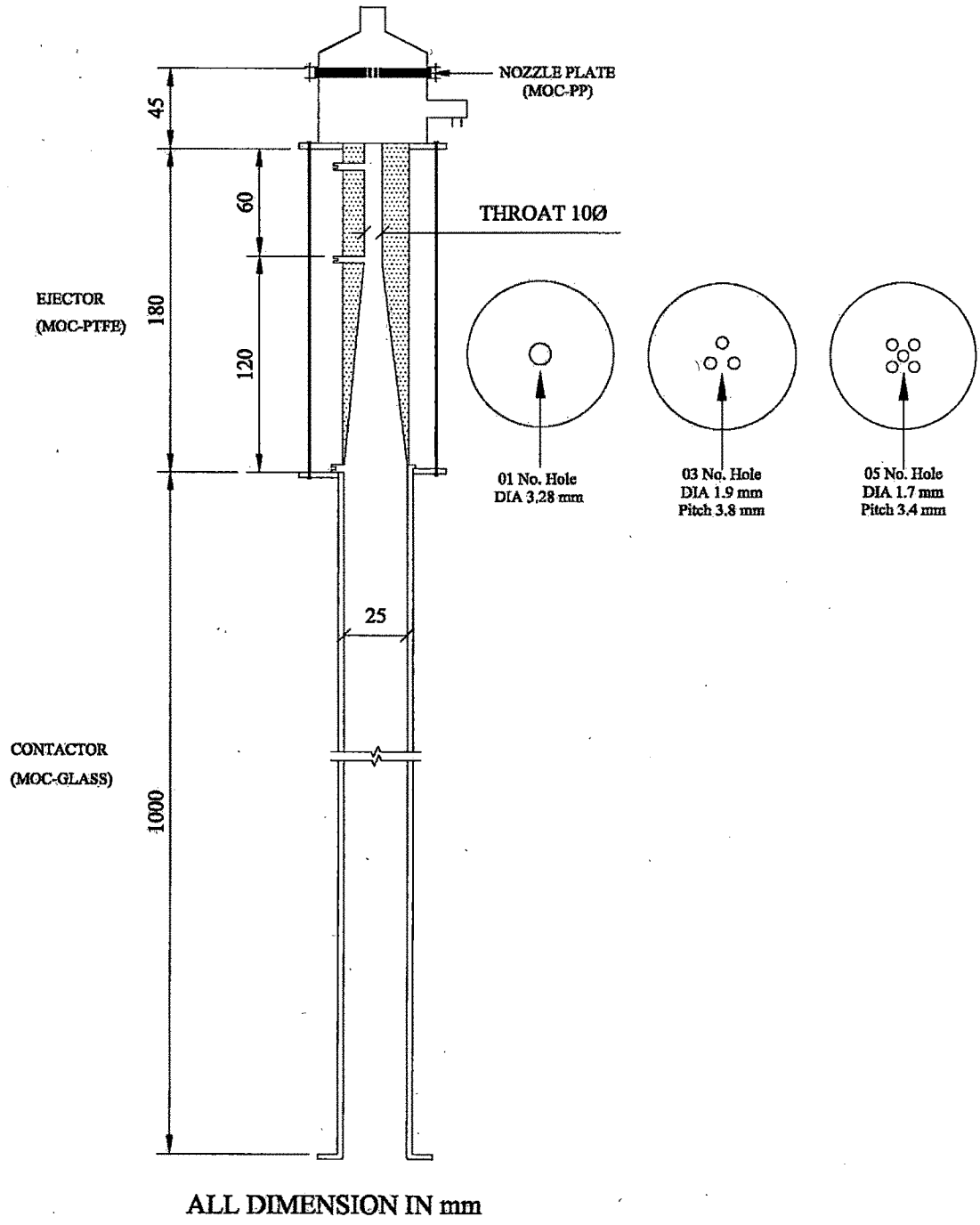
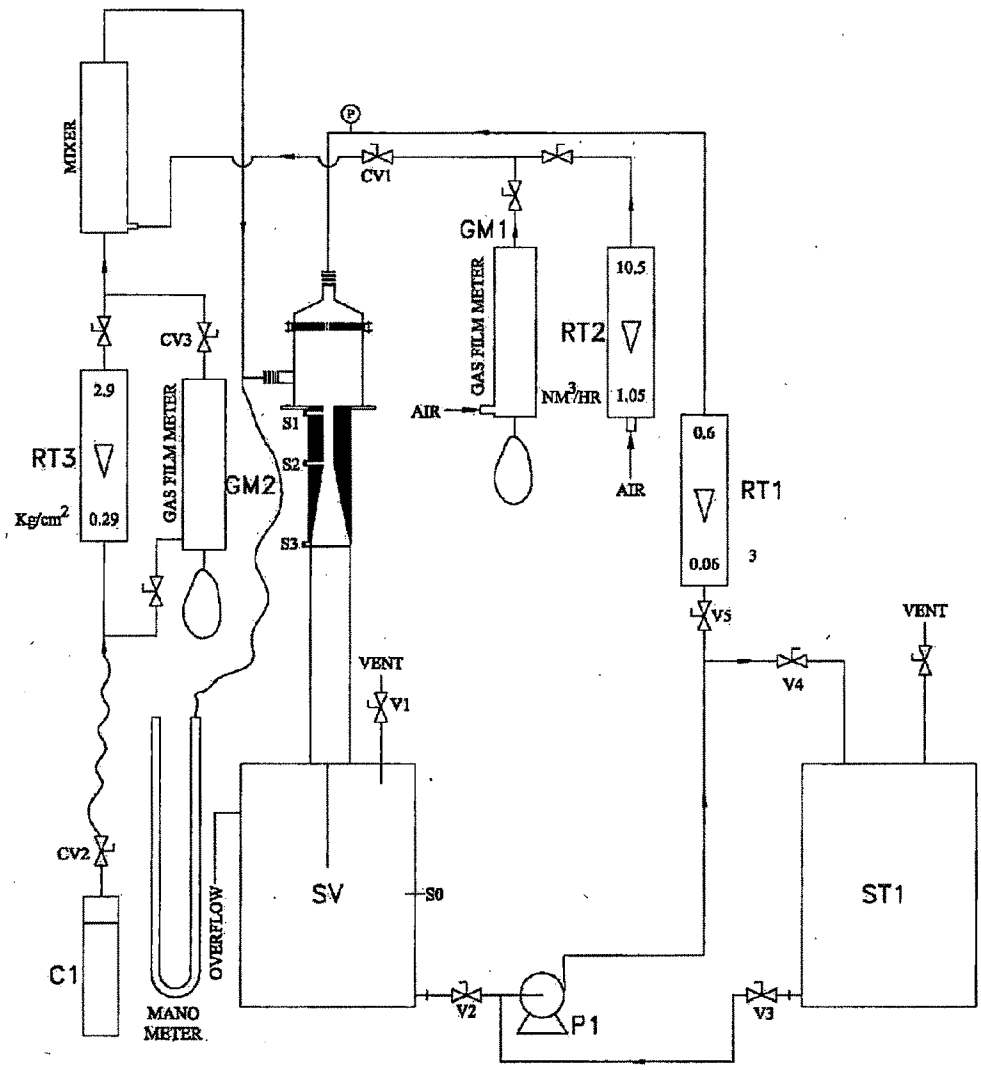


Figure 3.3 : Details of jet ejector used in experimental setup 2

2. Required strength of sodium hydroxide solution was prepared by circulating liquid through by pass line by adjusting valve V-3, V-4 and V-5.
3. Air flow rate and gas concentration were adjusted by circulating liquid from the tank (SV). During this process solution tank was kept isolated by keeping valve V-3 and V-4 closed.



SV = Separation Vessel
ST = Solution Reservoir
RT1 = Rotameter for Measuring Liquid flow rate
RT 2 = Rotameter for Measuring Air flow rate
RT3 = Rotameter for Measuring Solute gas
GM1 & GM2 = Gas Film Meter
P1 = Pumps
S1, S2 & S3 = Sample points
V1, V2, V3, V4, CV1, CV2, CV3 = Control Valves

Figure 3.4 : Schematic diagram of experimental setup 2

4. After adjusting gas flow rate and gas concentration, valve V-2 was closed and required flow rate of caustic solution was adjusted by operating valve V-3, V-4 and V-5.

5. Once liquid flow rate, gas flow rate and gas concentration were set, the required samples were drawn and analyzed.

6. The procedure is repeated for another set of nozzle plate, liquid concentration and gas concentration.

7. The results are tabulated in Table A1.2.

3.3 Setup 3

3.3.1 Experimental set up

1. The experimental Setup 3 is shown schematically in Figure 3.6. This experiments were conducted on industrial stage ejector. The details of ejector are shown in Figure 3.5 and Table 3.1. (photograph A.5.2 and A.5.3 in appendix)

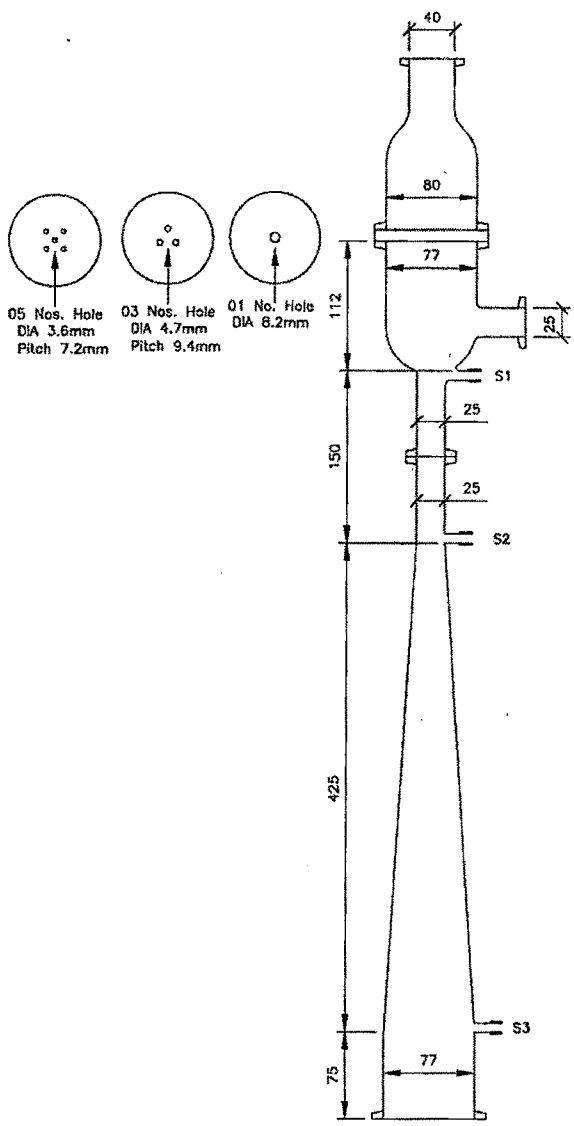


Figure 3.5 : Detail of the jet ejector used in experimental setup 3

2. The schematic flow diagram is self indicative.

3. The ejector is having 3 sample point S1, S2 and S3. Sample S0 is drawn from tank T1 directly. The air flow rate is measured by using electronic anemometer. There is a rotameter for measuring Cl_2 flow rate and a soap film meter to calibrate the rotameter. There are two tanks T1 and T2. Tank T1 is used to prepare sodium hydroxide solution and tank T2 is ejector outlet tank. V1, V2, V3 and V4 are control valves. The pump P1 is provided to circulate sodium hydroxide solution through the ejector. Pressure gauge P1 is provided to measure the primary fluid pressure (water).

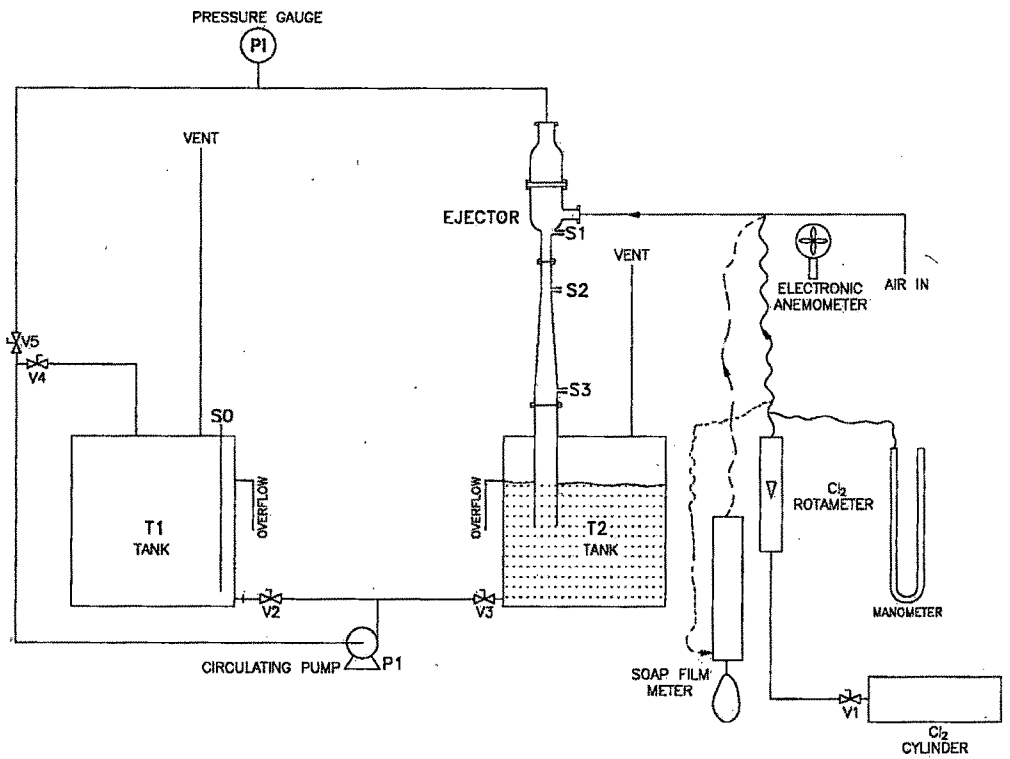


Figure 3.6 : Schamatic diagram of experimental setup 3

3.3.2 Experimental procedure

1. The experimental procedure is almost same as in setup 1and setup 2. Before starting the experiment the rotameter for chlorine was calibrated by soap film meter.

2. The required nozzle plate was fitted.

3. The required sodium hydroxide concentration was prepared by circulating the solution and operating valve V5, V4, V2 and V3.

4. The primary fluid (aqueous $NaOH$ solutions) flow rate was adjusted to the required value by operating valve V5 and V4. The secondary air flow rate was measured by electronic anemometer. The flow rate is kept constant throughout the experiment.

5. The required chlorine rate was adjusted by operating valve V1. After the system reaches steady state the liquid sample S0, S1, S2 and S3 were drawn and analyzed.

6. The experiment was repeated for different concentrations of sodium hydroxide and chlorine and nozzle plates.

7. The results are tabulated in Table A1.3.