ADSORPTIVE STUDIES OF AQUEOUS ZINC IONS BY FOAM FRACTIONATION

by

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ABSTRACT

A foam fractionating column equivalent to a single equilibrium stage, operating in simple mode, has been taken into consideration for the present investigations. The system chosen was zinc and sodium lauryl sulfate.

It was experimentally noticed that if the surface excess was measured at random operating conditions the column was producing inconsistent data violating the conditions of simple mode operation. It was therefore of utmost importance to investigate the variables affecting the operation of a foam fractionation column in the simple mode. It was concluded that the height of the foam/liquid interface, the air flow rate and the number of capillaries of the bubbler should be mutually adjusted to bring the column close to the simple mode operation so that the results obtained would be meaningful.

At the modified operating conditions, the effect of the metal ion and collector concentration on metal surface excess was investigated. The studies were extended to determine the effect of pH on metal surface excess at various bulk metal concentrations. Finally, the results were compared with those of the previous investigators.

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NOMENCLATURE

Cc	Concentration of the collector (g/l)
d	Diameter of the bubble (cm)
D*	Bulk phase diffusion coefficient (cm^2/sec)
G	Gas flow rate (cm^3/min)
$H_{f/l}$	Height of the foam/liquid interface (cm)
$dH_{f/l}$	Change in $H_{f/l}$ (cm)
n	No. of capillaries in the bubbler
N	Bubble generation rate per capillary (min^{-1})
r	Radius of the bubble (cm)
S	Surface generation rate (cm^2/min)
t	Time (min or sec)
V_f	Volumetric flow rate of the foam (cm^3/min)
x	Bulk concentration of the surfactant (g.mol/cm^3)
X_b	Bulk zinc concentration (g.mol/cm^3)
X_f	Feed concentration of zinc (g.mol/cm^3)
Y_f	Zinc ion concentration in the foamate (g.mol/cm^3)
Γ	Surface excess (g.mol/cm^2)

Abbreviations

PPM or ppm	Parts Per Million
Zn	Symbol for aqueous zinc ion
NaLS	Sodium lauryl sulfate $CH_3\ (CH_2)_{10}\ CH_2\ OSO_3\ Na$
DBS	Dodecyl Benzene Sulfonate
Na DBS	Sodium Dodecyl Benzene Sulfonate
THPED	N,N,N,N, Tetrakis - (2-Hydroxypropyl) - Ethylenediamine

1. INTRODUCTION

Foam fractionation is one of the important techniques of foam separation, which is dependent on the differences in surface activity. Foam fractionation is generally applied to remove traces of soluble ions present in aqueous solution. This method is based on the selective adsorption of solutes on the surface of bubbles as they rise through the pool liquid. The foam, which is the physical combination of bubbles, brings some solutes from the bulk of the liquid pool to the surface.

If the system contains surface active solutes, they can be directly adsorbed to the surface, and if the system contains surface inactive solutes like metal ions, it is general practice to use a surfactant which is able to attract the metal ions to the surface.

The most important parameter available to express the experimental results is surface excess. Surface excess is defined as the number of moles of the solute in a portion of the solution per unit interfacial area, in excess of the number of moles of solute in a portion of the interior which has exactly the same volume.

The present work is devoted to a study of the adsorption of aqueous zinc ions by anionic surfactant, sodium lauryl sulfate. The objective of this work is to critically study the operating variables of a simple mode apparatus developed by Dick (19) to measure surface excess. A better understanding of the sensitivity of the measured surface excess with these variables is required to maintain the apparatus in simple mode operation so that the results obtained are meaningful.

2. LITERATURE REVIEW

Actually, foam fractionation was brought into existence before 1928 by attempts to verify the Gibb's adsorption isotherm(1). Gradually, this technique was broadly employed to fractionate surface active agents like proteins, organic dyes, fatty acids, etc.,(2).

The very first article to appear in the literature on the separation of metal ions by foaming, was in 1957. Walling et al(3) studied the relative adsorption of calcium and sodium ions by N-palmitoyl methyl taurine foams. In the same article they presented some investigations regarding the preferential adsorption of a number of other cations by anionic foams.

In 1963, a standard separator for Aresket-300 in water was developed by Brunner and Lemlich(4) to yield reproducible results. Their experiments were carried out with enriching columns where a portion of the collapsed foam was returned to the top of the column to serve as a reflux. In 1965, Brunner and Stephan(5) presented an exploratory work about a pilot plant size foam fractionation unit operating at a feed of 500,000 g.p.d. They reported that they were able to reduce the concentration of alkylbenzene sulfonate in sewage to less than 1 ppm.

Grieves et al(6) have employed foam fractionation for inorganic and organic separations for the treatment of radioactive wastes. In their article, a fundamental analysis of foam separation as a mass transfer operation was presented utilizing both equilibrium and rate concepts of mass transfer.

Rubin(7) has presented an article on the removal of trace metals by foam separation processes. He has mainly discussed the flotation processes and has removed iron, copper and lead by making use of sodium lauryl sulfate as a collector. He has reported that valuable insights into the mechanism of metal removal could be obtained by an understanding of the hydrolytic reactions of the metals. The most important variables that affected the removal process were concentrations of metal and collector, pH and ionic strength of the solution.

Schonfeld and Kibbey(8) have developed a method for improving the efficiency of removing strontium from solution by foam separation. They reported that by using controlled reflux in a countercurrent continuous foam separation unit it was possible to improve the removal of strontium.

Sebba(9) introduced the low gas flow rate foam separation technique known as ion-flotation. He mentioned that the surfactant should be added in stoichiometric amounts so that it exists as simple ions and not as micelles. The surfactant must be able to react with the metal ion to form an insoluble soap which could be adsorbed to the surface by gentle bubbling. In 1962, Rubin and Gaden (10) presented various systems including eighteen metals that could be separated by foam fractionation.

Sodium lauryl sulfate, as an important surface active agent has been studied by many investigators. In 1971, Dick and Talbot(11) published an article on the use of an auxillary ligand, THPED, in the foam fractionation of copper with sodium lauryl sulfate.

Rubin and Lapp(12) have investigated the foam separation of lead with sodium lauryl sulfate. Their attempt was to relate the mechanism of the process to the hydrolytic behaviour of the metal, pH, ionic strength and collector concentration. Rubin and Johnson(13) in the same year have published an article on the effect of pH on ion and precipitate flotation systems. They worked with copper and iron and used sodium lauryl sulfate as the collector. They mentioned that sodium lauryl sulfate was an efficient strong-acid collector for removing the insoluble species.

An improved apparatus for the study of foams has been presented by Walling et al(14). Foam drainage measurements of five different systems were discussed, indicating that their apparatus gave useful results with rapidly draining films. Their apparatus consisted of a spherical vessel for foaming solution with a flat ground neck. The foam was allowed to rise through a cylindrical column. A similar type of apparatus was presented by Krieg et al(15) as a foam fractionator operating as a single stage. They measured surface concentration by the simple mass balance and for the determination of adsorption equilibria, they considered some important factors like batch operation, foam coalescence, mass transfer limitations and incomplete mixing. They mentioned that if the height-to-diameter ratio of the liquid pool is large, incomplete mixing in the liquid could make the concentration of the surfactant or counter-ions lower at the top of the liquid pool than at the point where the bulk liquid was sampled.

Wace and Banfield(16) have studied the foam separation of radioactive metals with surface excess as an important parameter. They have plotted surface excess of metals versus the bulk metal ion concentrations. The effect was found to be linear at the lower bulk concentrations of the metal and then leveling off at a saturation value.

Rubin and Jorne(17) have studied the separation of two surface active agents, sodium lauryl sulfate and sodium dodecyl sulfonate, and their relative separation.

They have determined the effect of the concentrations of each surfactant on the surface excess to verify the adsorption isotherm. They have also studied the relative distribution coefficient of the two surfactants.

Huang and Talbot(18) have published an article on the removal of copper, cadmium and lead ions from dilute aqueous solutions by foam fractionation. They have developed a mathematical model for solutions of pH less than 4. The model was combined with the modified Gouy-Chapman diffuse double layer theory to determine the relative separation of Cd^{2+}, Cu^{2+} and Pb^{2+} ions, which were foamed by NaDBS.

St. Eloi(20) has made equilibrium and batch removal studies on the foam fractionation of zinc with NaDBS as a collector along with excess NaCl. He reported that the distribution factor of zinc ions as a function of bulk zinc concentration increased with lower surfactant concentration. Ethanol showed evidence of surface activity because very fine and unstable foam was formed on the top of the liquid pool after the alcohol was injected. It was concluded that ethanol removed some additional zinc because it is surface active and polar.

Very recently Siy and Talbot(22) have published an article on foam fractionation of zinc, using the same apparatus that was designed by Dick and Talbot. They have reported that the order of increasing effectiveness in the removal of zinc ions by various forms of DBS^- is $KDBS < NaDBS < LiDBS < HDBS$.

In 1969, Dick(19) designed a foam fractionating column of decreasing diameter with a bubbler of 5 capillaries. He investigated the separation of copper by using a surfactant and an auxilliary ligand. The column was specially designed to carry out the foam fractionation in the simple mode. He did not report anything about the sensitivity of the operating conditions of the column and there was no evidence that the data were collected under simple mode operation. After that, St. Eloi(20) and Siy(21), who have used the same apparatus, followed the procedure suggested by Dick without any modification. It is therefore of the utmost interest to critically investigate the operating conditions of the apparatus in order that the data generated from such an experiment will come as close to the simple mode operation as possible. For this purpose, it was decided to measure the surface excess at various operating conditions and thereby define suitable operating conditions for the apparatus. Once these conditions have been defined, a critical evaluation of previous investigations will be made through the examination of their results and the generation of additional data for comparison.

3. THEORY AND DISCUSSION

3.1 Introduction

Foam fractionation is one of the foam separation techniques which is a sub-branch of adsorptive bubble separation methods. This generic name was first proposed by Lemlich in 1966(23).

Any separation process is based on the differences in properties. For example, distillation is based on the differences in volatility, while solvent extraction is based on the differences in solubility. On the other hand, foam fractionation is based on the differences in surface activity(23).

Foam fractionation is based on the selective adsorption of one or more solutes on the surface of the gas bubbles that rise through the solution. The separation is a direct function of the amount of the foam generated per unit interfacial area and the concentration of the foamate.

Foam fractionation takes place either in simple mode or in higher mode. Furthermore, foam fractionation in simple mode, which is directly related to the present research, can take place either in batchwise operation or in continuous flow operation as shown in FIG.NO.3.1. Each is one theoretical stage provided the pool is well mixed(23,24).

3.2 The Basic Principle of Foam Fractionation

Foam fractionation is based on the principle that the surface active material is carried up by the bubbles which are introduced into the liquid pool. The principle is explained step-by-step as follows, and is shown in FIG.NO.3.2.

As shown in FIG.NO.3.2(a), the liquid in the pool contains the surface active solutes. Gas is introduced into the system through a bubbler. Consider a single bubble introduced into the system, as shown in FIG.NO.3.2(b). The bubble contains gas inside, and it is surrounded by the liquid, containing surface active solutes.

All the surface active solutes, by nature, have great affinity to move to the bubble surface. The surface active solutes, present in the liquid medium will go to the surface of the bubble, and orient their hydrophobic (non-polar) end towards the gas phase, and their hydrophilic (polar) end towards the liquid phase, as shown in FIG.NO.3.2(c). The bubble is not stationary in the liquid, but travels to the surface carrying some solute particles with it, as shown in FIG.NO.3.2(d). The bubbles then combine together to form the foam which is collected from the foam/liquid interface, as shown in FIG.NO.3.2(a).

When the system contains metal ions which are non-surface active, the principle extends in the following manner. In this case the metal ions may be electrostatically attracted to the bubble surface by a negatively charged surface active agent. As explained above, the surface active solutes go to the surface of the bubble and orient with their negative charge (if the surfactant is anionic), as shown in FIG.NO.3.2(e). In order to neutralize the charge on the bubble surface, metal ions move to the surface and orient with their positive charge, as shown in FIG.NO.3.2(f). Thus an electrical double layer is formed at the surface of the bubble. Positive ions will be attracted towards the surface and the negative ions will be repelled from the surface, as shown in FIG.NO.3.2(g). Because of this attraction and repulsion, there is a diffuse layer developed around the bubble (in the present research, the volume of the diffuse layer is assumed to be negligible). The bubble thus carries up some metal ions to the surface, as shown in FIG.NO.3.2(h). The same principle prevails with all the bubbles introduced into the system.

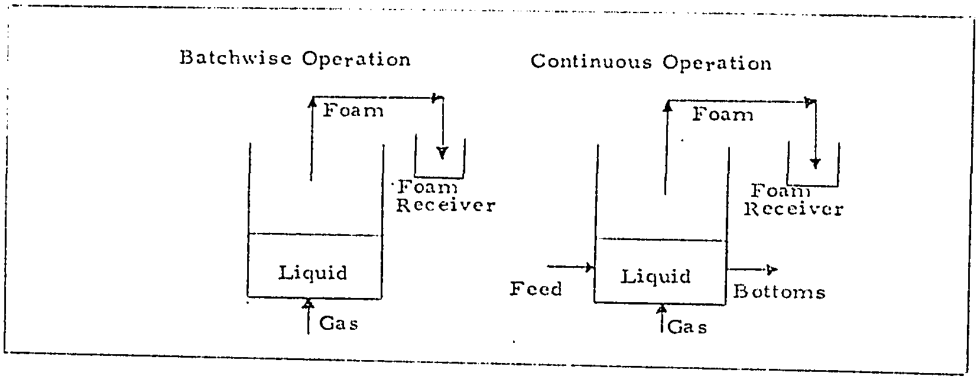


FIG. NO 3.1 FOAM FRACTIONATION IN SIMPLE MODE

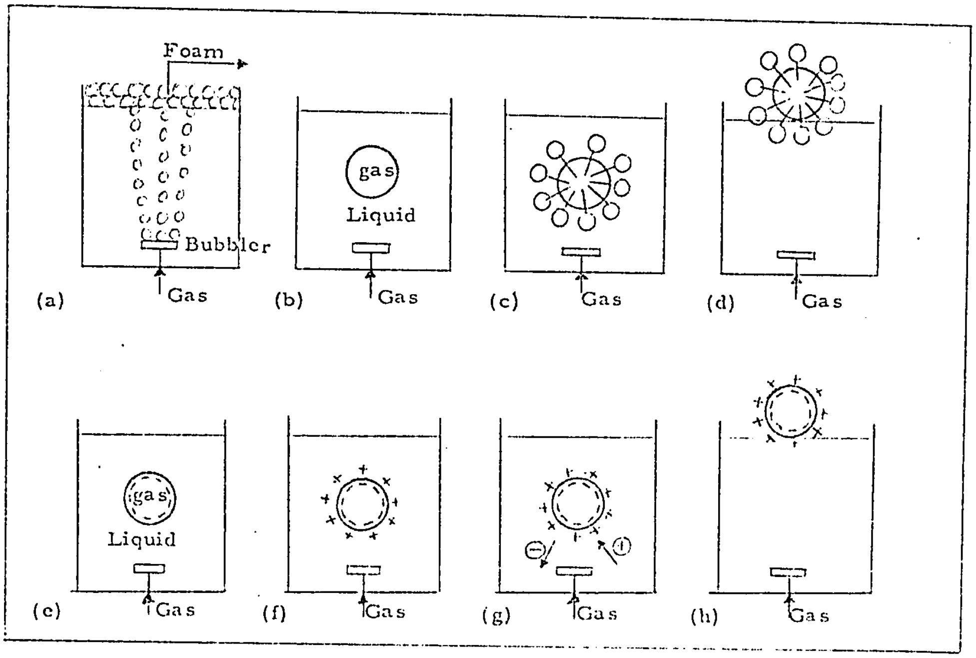


FIG. NO 3.2 THE BASIC PRINCIPLE OF FOAM FRACTIONATION

3.3 The Concept of Equilibrium

The equilibrium of concern in foam fractionation is not a thermal equilibrium, but an adsorptive equilibrium or surface equilibrium. That is, it is an equilibrium of solutes between the bubble surface and the bulk liquid. Sufficient contact time must be allowed to establish this surface equilibrium. If a surfactant is to be sufficiently concentrated under equilibrium conditions, a complete monolayer should be produced at the gas/liquid interface. At equilibrium conditions, the adsorbed surface molecules generally occupy an area of about $50A^2$/mol which corresponds to a surface excess of 3.0×10^{-10} mol/cm^2. For example, for an ionic surfactant like sodium dodecyl benzene sulfonate, the limiting surface excess is 3.0×10^{-10} mol/cm^2(16) which corresponds to a monolayer packed at $50A^2$/mol, as reported by Wace and Banfield(16).

If surface equilibrium is attained in a system of ionic surfactant and counter-ions, then the adsorption is called "multilayer adsorption". In foam fractionation research, there has been no confirmation of the exact mechanism of multilayer adsorption. One concept is that the surfactant monolayer forms initially and then the counter-ions are attracted to the interface, and the other concept is that the adsorption takes place by the surfactant ions with the accompanying counter-ions at the same time(17). If multiple adsorption takes place in a dynamic flow process, appreciable bonding energies are essential, and such energies exist with the mildly surface active micellar structures below the critical micelle concentration. However, it is necessary to remember that a number of assumptions have to be made in predicting the dynamic surface equilibria . It is very important in a practical application to measure surface excess dynamically(17).

As the pH is an affecting parameter in foam fractionation, hydronium ions, sodium ions, nitrate or sulfate ions and hydroxyl ions will take part in the multilayer adsorption, at interfacial surface between the bubble and the bulk liquid. This equilibrium can be treated as the ratio between the surface concentration and the concentration in the equilibrated solution. By producing and collapsing the foam under controlled conditions, the collapsed foam, is richer in surfactant and metal ions than the parent bulk liquid. The equilibrium between the surfactant and the counter-ions at the interface governs the necessary fractionation(25).

Foam fractionation also resembles distillation (vapor/liquid equilibrium). The rising bubble surface corresponds to the vapor, and the interstitial liquid flowing down through the foam corresponds to the liquid down flow(23).

The number of theoretical stages in the foam is considered to be an important parameter by foam fractionation researchers, and there are theoretical expressions, available in literature to calculate it(24). The equilibrium curve can be obtained by plotting the effective concentration of "solute in up flow" in equilibrium with the pool concentration versus pool concentration, and the operating line can be obtained by plotting the effective concentration of "solute in up flow" at any level in the foam column versus the pool concentration. From these plots, the number of theoretical stages are usually calculated by graphical procedures. The liquid pool is generally considered to be one theoretical stage (it resembles the reboiler in distillation column). In the present research problem, the column is treated as "a single equilibrium stage" with an assumption that there are no stages to measure in the foam column. That means the foam is not enriched due to the bubble coalescence or drainage. In other words, the column is operated strictly in simple mode.

3.4 Equilibrium Condition for the Adsorption of NaLS

The necessary and sufficient conditions for the equilibrium of a foam fractionating column are that, (i) the residence time of the bubbles rising through the liquid pool should be large enough for mass transfer to take place, and (ii) the liquid should be well mixed(26). It has already been mentioned by Bikerman(27) that a submergence of 30 cm should be more than ample in most cases. In connection with the present experimental set-up, Dick(19) fixed a height of 33 cm for the liquid above the bubbler.

The rate of diffusion of the surfactant without back diffusion is given by(28)

$$\frac{d\Gamma}{dt} = \left[\sqrt{\frac{D^*}{\pi}}\right]\left[\frac{x}{\sqrt{t}}\right] \qquad \text{———} \qquad (3.1)$$

where Γ is surface excess (g.mol/cm^2),

D^* is the diffusion coefficient (cm^2/sec),

x is the bulk concentration (g.mol/cm^3),

t is the time (sec).

Dick(19) determined the diffusivity of the lauryl sulfate anion by Wilke's method using a molal volume of 318.5 $cm^3/g.mol$ at the normal boiling point. The method is available in Treybal(29). He has reported that $D^* = 4.6 \times 10^{-6}$ cm^2/sec, for $x = 0.5$ g /litre or 1.73×10^{-6} $g.mol/cm^3$. The value of surface excess has already been reported as $\Gamma = 4.8 \times 10^{-10}$ $g.mol/cm^2$(17). By using the above equation 3.1, it was concluded by Dick(19) that the time required to form a complete monolayer of surfactant is 0.013 sec. It was observed experimentally that the residence time of bubbles within the bulk was around 0.5 sec, which obviously meant that there was ample time to complete the monolayer of NaLS. Thus the bubble surface was at the necessary condition of equilibrium, before reaching the foam/liquid interface(19).

3.5 Mass Balance Over The Single Equilibrium Stage

As mentioned previously, the present experimental set-up was proposed to operate strictly in simple mode. Recycle of the foam is mostly unfavourable because the collector micelles that are formed in the foamate may not be dissociated when returned to the pool liquid. Therefore, a batch operation is preferable. The foamate is made up of a surface region and a bulk region. The interstitial liquid between the bubbles is regarded as the bulk region. The volume of the surface region is very small when compared to that of the bulk region which is assumed to have the same composition as the pool liquid. The operating conditions or equations for a batch column are derived by the mass balance on the collapsed foam assuming that the surface concentration is dependent on the equilibrium between the surface and the bulk(30).

The mass balance thus can be written as

$$V_f Y_f = S\Gamma + V_f X_b \qquad (3.2)$$

where Γ = Surface excess (g.mol/cm^2),
V_f = Volumetric flow rate of the foam (cm^3/min),
Y_f = Concentration of foamate (g.mol/cm^3),
X_b = Concentration of bulk liquid (g.mol/cm^3),
S = Surface generation rate (cm^2/min).

For a properly designed bubbler of n capillaries, generating bubbles at a frequency of N bubbles per minute per capillary, the surface generation rate is given by

$$S = nN\,(4\pi r^2)$$ where 'r' is the radius of single bubble and 'd' is the diameter.

$$= nN\,(\pi d^2)$$

The above equation has been written under the assumption that the bubble surface in the pool liquid is always spherical. In foam fractionation research, this assumption has been supported repeatedly due to the fact that as a result of the positive surface tension existing at any gas/liquid interface, small gas bubbles introduced into the liquid will spontaneously tend to adopt a spherical shape.

The bubble diameter is obtained as follows-

If 'G' is the gas flow rate (cm^3/min)

$$G = (nN)\left(\frac{4}{3}\pi r^3\right)$$

$$= (nN)\left(\frac{\pi d^3}{6}\right)$$

$$d = \left(\frac{6G}{nN\pi}\right)^{1/3}$$

Knowing the air flow rate, G, the diameter of the bubble, d can be calculated, and thereby 'S' can be determined. Hence, the mass balance equation becomes,

$$\Gamma = \frac{V_f}{S}\,(Y_f - X_b) \qquad (3.3)$$

The above formula holds good equally to metal ions and to surfactant ions, since the mass balance is valid for all components of the system.

Equation 3.3 is based on the following assumptions - (i) the surface excess is considered at the surface of the bubbles only, (ii) the adsorption occurs within the liquid phase of the column with sufficient contact time to reach the equilibrium, and (iii) the bubbles are all spherical and uniform, and the breakage of the bubbles is negligible.

These assumptions have already appeared in literature in one way or other, as published in the article of Rubin and Gaden(10).

4. EXPERIMENTAL SET-UP

4.1 General Comments

The entire credit for designing the experimental set-up has already been given to Dick (19). The specially designed column which operates in simple mode has been considered as "an equilibrium stage". Although the geometrical design of the apparatus looks very simple, it is of great importance for the foam fractionation in simple mode. The apparatus is briefly described in the following paragraphs.

4.2 Description

The schematic diagram of the experimental set-up is shown in FIG. NO. 4.1.

The present experimental set-up mainly consisted of a conically shaped COLUMN which was constructed of an inverted three litre pyrex separatory funnel with the stopcock portion replaced by a foam delivery tube.

The major component of the column is THE BUBBLER which was inserted into the bottom of the column through the central hole of the RUBBER STOPPER at the bottom of the column. The purpose of the bubbler is to produce bubbles of uniform size. In order to meet this requirement, the bubbler was made of five glass capillaries of 0.24 inch long and 0.007 inch internal diameter, imbedded in a teflon chamber.

A STROBOSCOPE was used to measure the bubble generation rate.

A 300 ml LEVEL CONTROL BULB located beside the column was connected to the column through the rubber stopper. The main purpose of this bulb was to control the height of the foam/liquid interface. An ADJUSTING SCREW in the hose from the level control bulb was used to maintain the liquid level at any desired value. The third hole of the rubber stopper was used for drainage.

The foam delivery tube at the top of the column was connected to a FOAM RECEIVER. The delivery tube was bent slightly into the receiver so that if any coalescence or drainage occurs it is not recycled back to the column. There was also an AIR VENT at the top of the foam receiver. A CYLINDER containing oil-free compressed air, was used to supply the air and a regulator was used to control the air-pressure. The air was first reduced to 6 psig, and then humidified in a series of two FILTERING FLASKS by passing through FRITTED SPARGERS, which were immersed in distilled water.

The humidified air was then passed into the calibrated ROTAMETER. The up-stream pressure of air passing to the column, was maintained at 3 inches of mercury as indicated by the MERCURY MANOMETER. The measured air was then passed directly into the column.

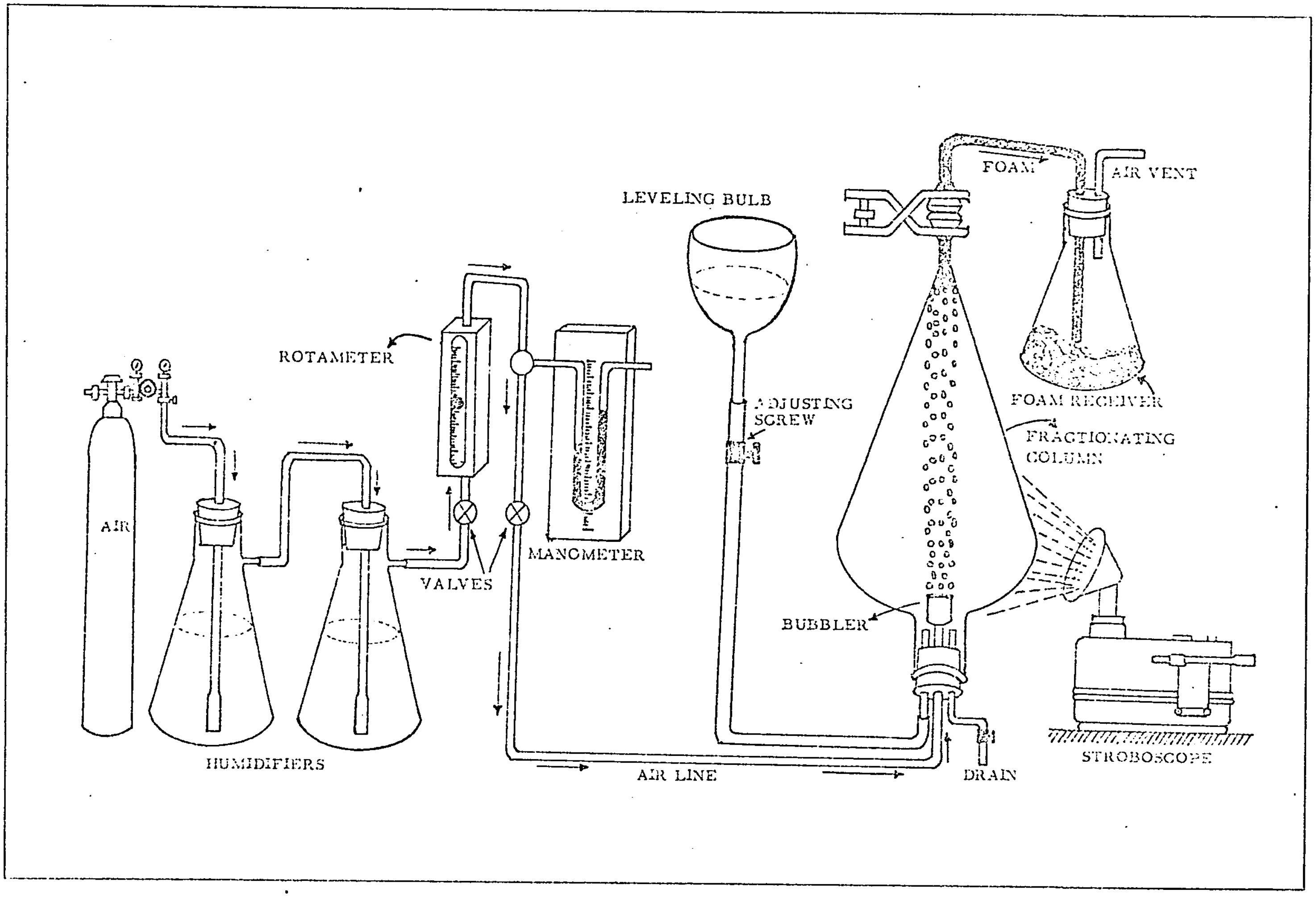


FIG. NO:4.1 SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SET-UP (SINGLE STAGE FOAM FRACTIONATION IN SIMPLE MODE)

4.3 Procedure

The following procedure was adopted through out the experimental runs to collect the necessary data for the present investigations.

Distilled water was always deionized by passing through a mixed bed ion exchanger. Deionized distilled water, zinc standard solution, and sodium lauryl sulfate were mainly used to prepare the feed solution. Four litres of feed solution was prepared for a given metal concentration and collector concentration. The pH of the feed solution was adjusted to the desired value by using either HNO_3 or NaOH, or both.

Before charging the feed solution to the column,the foam collection flask was weighed accurately. The air flow rate was then adjusted to the desired value by simultaneously adjusting the two needle valves of the rotameter and manometer. The liquid level was then adjusted to the required mark. When the column was operating at steady state i.e., when the level of the foam/liquid interface is perfectly constant, the foam collection flask was placed in position and the timer was started at the same time. Then the bubble generation rate was determined using a Strobotac electronic stroboscope. Foam was collected over a measured time interval (approximately 10 minutes). Then the receiver was weighed and stoppered. A foamate density of 1 g/cm^3 was assumed for the solution so that the volume of the foam could be numerically equal to the weight of the foam collected.

4.3a Foam Breakage

Approximately one week is needed for the foam to break naturally. In the present investigation, foam was broken rapidly by freezing it for a period of 15 minutes and then by allowing the foam to thaw forming a clear solution. This procedure saved considerable time in experimentation.

After the breakage of the foam, the solution was analysed for the concentration of the metal ion by using a Unicam model SP90, Atomic Absorption Spectrophotometer. The operating conditions of this instrument are listed in Appendix A, part I.

4.4 Precautions

(i) In order to make sure that the column is operating in the simple mode, the foam/liquid interface must be held constant by adjusting the level control bulb as well as the adjusting screw of the hose.

(ii) Necessary care should be taken so that the capillaries of the bubbler are not blocked, and the bubbler always produces the same number of uniform bubbles at constant air flow rate.

(iii) Air should be passed through the bubbler at all times so that the capillaries of the bubbler will not be wetted by the pool liquid.

(iv) After completion of each run, the column should be drained and cleaned by rinsing with deionized distilled water.

(v) Deionized distilled water should be used for all solutions.

4.5 List of the Instruments and Chemicals

The following instruments and chemicals were used for the present investigations.

Instruments

1. Atomic Absorption Spectrophotometer, UNICAM SP90, Unicam Instruments Ltd., England.
2. Model 220 pH meter, FISHER (ACCUMET).
3. Strobotac electronic stroboscope, type 1538-A, General Radio Company.
4. Mixed bed ion exchanger, Barnstead Hose Nipple Cartridge, Barnstead Company, Lot NO.9.034-3.

Chemicals

1. Certified Atomic Absorption Standard, Zinc Reference solution, 1000 ppm, Fisher Scientific Company, Lot NO. SO-Z-13.
2. Sodium Lauryl Sulfate, Fisher Certified Reagent, Fisher Scientific Company, Lot NO. S-329.
3. HNO_3 and NaOH, Analytical Grade.
4. Medical Compressed air, Liquid Carbonic Canada Ltd.

5. RESULTS AND INTERPRETATION

5.1 Preliminary Comments

A total of 135 runs were carried out for the present investigations. All the calculations were performed by suitable computer programs (APL/360). The data and the results are tabulated in Appendix C. The computer programs are presented in Appendix B.

The system chosen for the present studies, was zinc and sodium lauryl sulfate (NaLS). The feed concentrations of the zinc metal ion and the NaLS were kept constant in most of the experimental runs except where the concentrations were the affecting parameters. These concentrations were fixed from the information given by previous investigators. It was decided by Dick(19) that 0.5 g/l of NaLS would be satisfactory because no further increase in foam stability was apparent when the NaLS concentration was increased. St. Eloi(20) and Siy(21) already reported for the zinc and NaDBS system that beyond 10 ppm of bulk zinc concentration there was no considerable increase in zinc surface excess. Rubin and Jorne(17) reported that the critical micelle concentration for NaLS and NaDBS was the same, i.e.. 2.2×10^{-3}M, and that the limiting surface excess for both surfactants was 2.7×10^{-10} and 3.0×10^{-10} g.mol/cm^2.

respectively. From this information, it was assumed that the limiting surface excess for Zn and NaLS system and for Zn and NaDBS system should not be changed much, and that at 10 ppm bulk zinc concentration the surface excess should be at the optimum value.

All the collected data were utilized to plot the parameters. The results were interpreted using theoretical concepts.

5.2 Range of the Parameters

Various parameters that have been used in the present investigations and their corresponding range are listed in the following table. Most of the present investigations are valid within this range, but the general trend of the results is extended beyond this range.

S.NO.	PARAMETER	RANGE
1	Surface excess (g.mol/cm^2)	0.318 to 1.460
2	Air flow rate (cm^3/min)	0 to 200
3	Height of the foam/liquid interface above the bubbler (cm)	15 to 36
4	Change in $H_{f/l}$ (cm)	+0.5 to -1.25
5	Number of capillaries	2 to 5
6	Bubble diameter (cm)	0.256 to 0.376
7	Bubble generation rate for 5 capillaries (min^{-1})	3570 to 11020
8	Surface generation rate (cm^2/min)	1484.35 to 3277.16
9	Foam generation rate (g/min)	0.366 to 4.259
10	Feed conc. of the metal (ppm)	0.5 to 113.5
11	Feed conc. of the collector (g/l)	0.05 to 0.5
12	Metal conc. in the foamate (ppm)	2.863 to 116.045
13	Collector ratio	1 to 113.5
14	Enrichment ratio	1.002 to 4.4
15	(V_f/S) ratio	6.44 to 12.99
16	pH	1.75 to 7.55

5.3 Effect of $H_{f/1}$ on Foamate Concentration

In order to make sure that the column was operated as a single equilibrium stage in simple mode, the effect of the height of the foam/liquid interface above the bubbler ($H_{f/1}$) on the foamate concentration was determined. It should be understood that the height of the foam/liquid interface essentially determines the height of the foam column. The data are shown in TABLE.NO.5.1. and are plotted in FIG.NO.5.1. and FIG.NO.5.2.

It was noted from the FIG.NO.5.1. that the concentration of the zinc present in the foamate was found to increase exponentially as the height of the foam/liquid interface was decreased from the top of the column. In other words, the foam was enriched more amd more as the foam height above the liquid was increased. As the $H_{f/1}$ was decreased from 32 cm to 15 cm, the metal concentration increased at least 15 times.

The column was designed especially to carry out batchwise foam fractionation in the simple mode. The necessary and sufficient conditions for the column to be operating in simple mode are, (i) there should not be any concentration gradient in the liquid pool, and (ii) there should not be bubble coalescence in the rising foam(23). Bubble coalescence releases adsorbed solute that runs down through the rising foam as an internal reflux enriching the foam beyond that of a single stage separation. When the foam rises, the liquid drains due to gravity. As the solute molecules migrate to the air/liquid interfaces associated with the bubbles the liquid flows downward between the bubbles thereby causing the foam to be continuously enriched in solute. The most obvious reasons for the foam enrichment are due to drainage and bubble coalescence. Bubble coalescence, due to the standing of the foam, may be caused by inter-bubble gas diffusion and the rupture of the film between the bubbles, which may be responsible for an erroneously high enrichment(31). Even though such enrichment is very useful under certain circumstances, it is undesirable in simple mode operation.

At each point of the plot shown in FIG.NO.5.1., the concentration was tested for uniformity as follows. It was obvious that if the foam was being enriched with drainage and coalescence, the concentration would not be uniform with time. This fact was experimentally verified by plotting concentration versus time. The concentration was measured at equal intervals of time and plotted as shown in FIG.NO.5.2. It was noticed from the plot that the concentration increased with time at higher foam heights, i.e., below the $H_{f/1}$ of 32 cm in the column. Above, the concentration was found to be either constant or non-uniform. At the heights between 33 and 36 cm, the foam was very wet and the concentration was found to be very diluted. At these heights, more liquid was entrained in the foam which erroneously increased the amount of the foam per unit interfacial area. Moreover at these foam heights, the diameter of the column at the entrance of the bubbles into the foam was very small which caused the bubbles to coalesce together allowing the re-entry of the solute particles back to the solution. Therefore, the heights between 33 and 36 cm in the column were regarded as undesirable. The present attempt was to choose the proper level which would give maximum concentration without any drainage and coalescence. This was possible only at a height of 32 cm. So, a height of 32 cm was chosen as the optimum $H_{f/l}$ for this particular column.

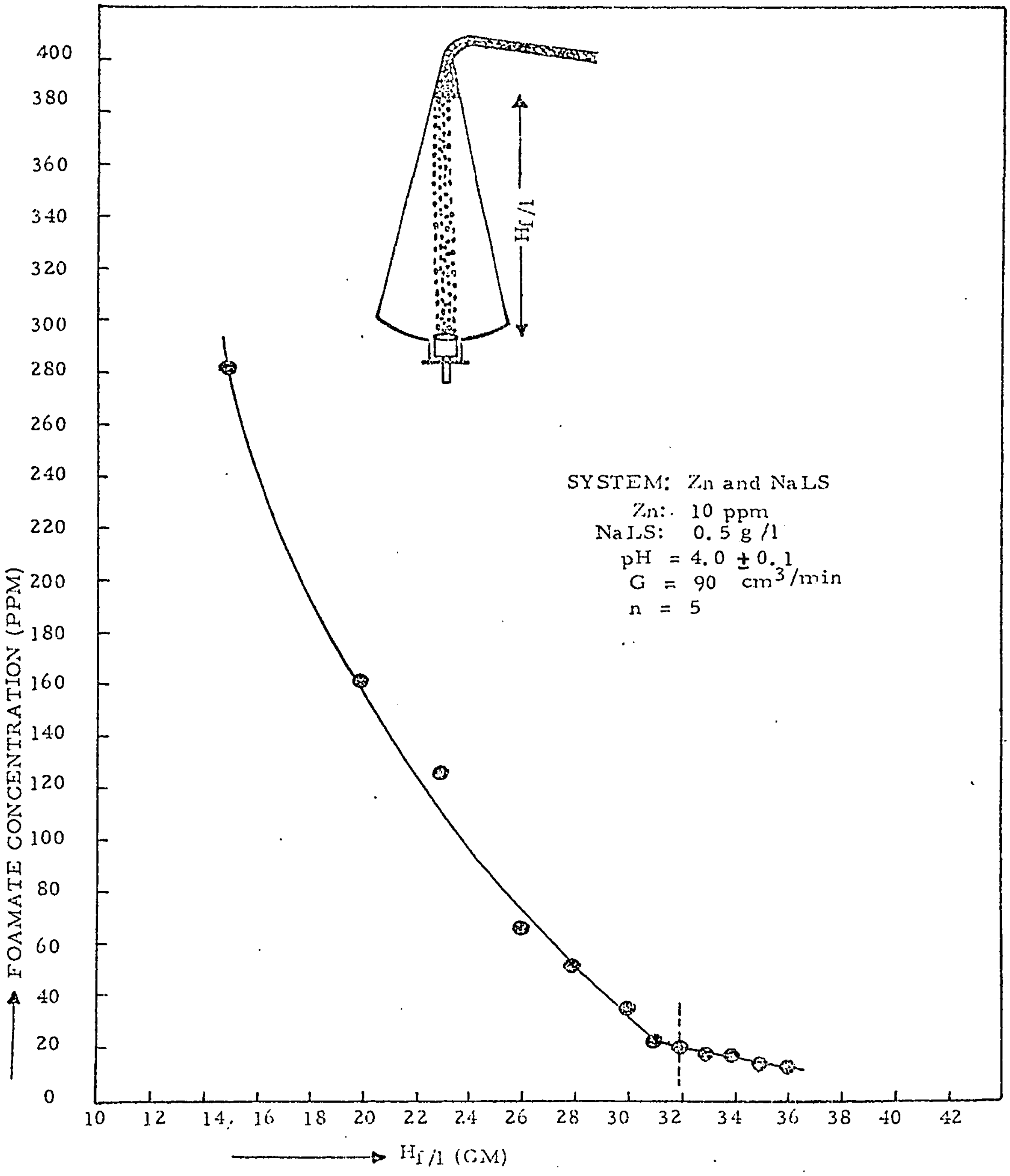


FIG. NO: 5.1 EFFECT OF $H_{f/l}$ ON FOAMATE CONCENTRATION

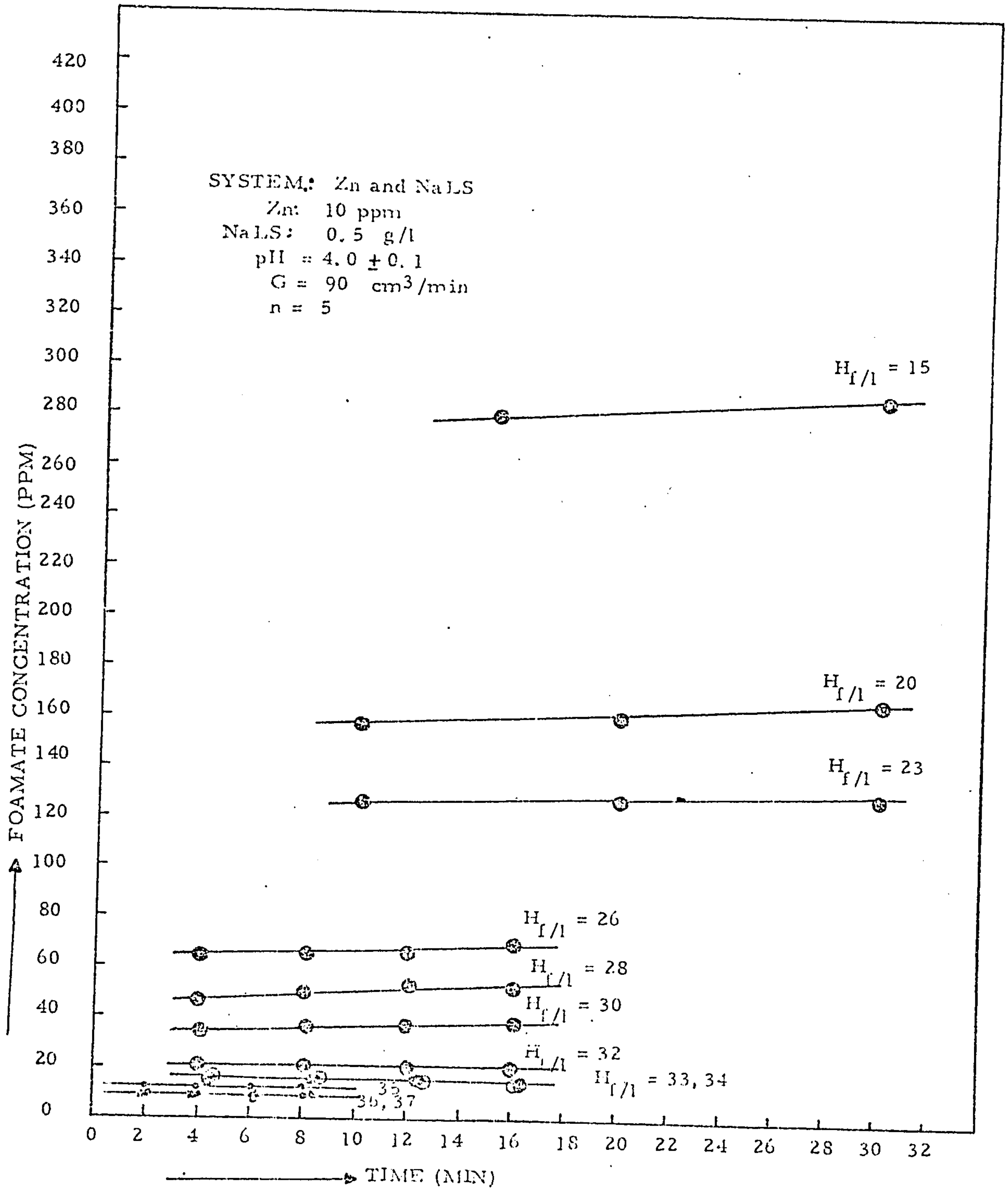


FIG. NO: 5.2 EFFECT OF TIME ON FOAMATE CONCENTRATION

5.4 Effect of Air Flow Rate on Surface Excess

After fixing the optimum height of the foam/liquid interface, the next series of runs was carried out to determine the effect of air flow rate on the measured zinc surface excess. The data and the results are shown in TABLE.NO.5.2. and the results are plotted in FIG.NO.5.3.

It was observed from the plot that the measured zinc surface excess had a maximum at a flow rate of 90 cm^3/min. This flow rate was regarded as optimum because the same flow rate was used to determine the optimum $H_{f/1}$ in the previous section. Beyond this optimum point (i.e., at the flow rates lower than 90 cm^3/min and higher than 90 cm^3/min), the measured surface excess was found to decrease gradually. It was also observed that the zinc concentration of the foam at lower flow rates increased more than that at the optimum flow rate, and at higher flow rates it decreased (Refer TABLE.NO.5.2.).

For a perfect single equilibrium stage, the measured surface excess calculated from the surface concentration which is in equilibrium with bulk liquid concentration should not be affected just by the change in the physical entrainment of the bubbles.

As given in equation 3.3, measured surface excess is the function of three main parameters namely (V_f/S) ratio, Y_f and X_b. In the present study, (V_f/S) ratio was found to increase with the air flow rate. The plot of (V_f/S) ratio versus G is shown in FIG.NO.5.4. From TABLE.NO.5.2., note that the bulk concentration, X_b was not changed much. Y_f was found to increase at lower flow rates (Refer TABLE. NO.5.2.) because of the high residence time of the foam. It decreased at the high flow rates because of the very high liquid content of the collected foam and the interfacial turbulence which caused re-entry of the adsorbed ions into the solution(32). Thus at lower flow rates, there was internal reflux taking place which caused enrichment of the foam. At higher flow rates, too much liquid was collected and thereby the foamate concentration was found to be diluted. Similar observations were made when the $H_{f/l}$ was increased above 32 cm. At the low flow rates, the foam was enriched due to coalescence and drainage, and at high flow rates the amount of the foam collected per unit interfacial area was increased erroneously. Thus it became evident that the data collected at lower air flow rates were not produced under the existence of the simple mode operation and that at the higher flow rates were not desirable. Therefore the measured surface excess obtained beyond the optimum air flow rate was considered as a false surface excess, and the one that was obtained at the optimum air flow rate was treated as the actual or true surface excess. It was then attempted to modify the false surface excess by adjusting the operating conditions.

It is already known from the previous section that the height of the foam/liquid interface has great influence on the (V_f/S) ratio and the concentration of the solute in the foam. If the foam/liquid interface is raised at the lower air flow rates, the (V_f/S) ratio is increased and the concentration of the foamate is decreased. Similarly at the higher flow rates if the foam/liquid interface is lowered the (V_f/S) ratio is decreased and the concentration of the foamate is increased.

At the flow rate of 90 cm^3/min, the (V_f/S) ratio was 9.386×10^{-4} cm. The study resulting in FIG.NO.5.3. was repeated to bring the value of (V_f/S) ratio close to 9.386×10^{-4} cm by adjusting the height of the foam/liquid interface. It was observed that if the (V_f/S) ratio was maintained constant, the concentration was found to be constant. The corrected plot for the effect of the air flow rate on surface excess is shown in FIG.NO.5.5. and the results are tabulated in TABLE.NO.5.3.

At each point, at least two trials were taken. This procedure was found to be successful between the flow rates 60 and 200 cm^3/min. At flow rates of less than 40 cm^3/min, no correction could be achieved.

The change required in $H_{f/1}$ to achieve constant (V_f/S) ratio is plotted in FIG.NO.5.6., and these values are shown in TABLE.NO.5.4. An empirical linear relationship to represent this relationship is presented as follows:

$$dH_{f/1} = 1.206-0.013G$$

The above approximate equation can be used to predict the change in $H_{f/1}$ by knowing the operating air flow rate. This equation is valid for any other column of the same type when the initial optimum $H_{f/1}$ is estimated at an air flow rate of 90 cm^3/min.

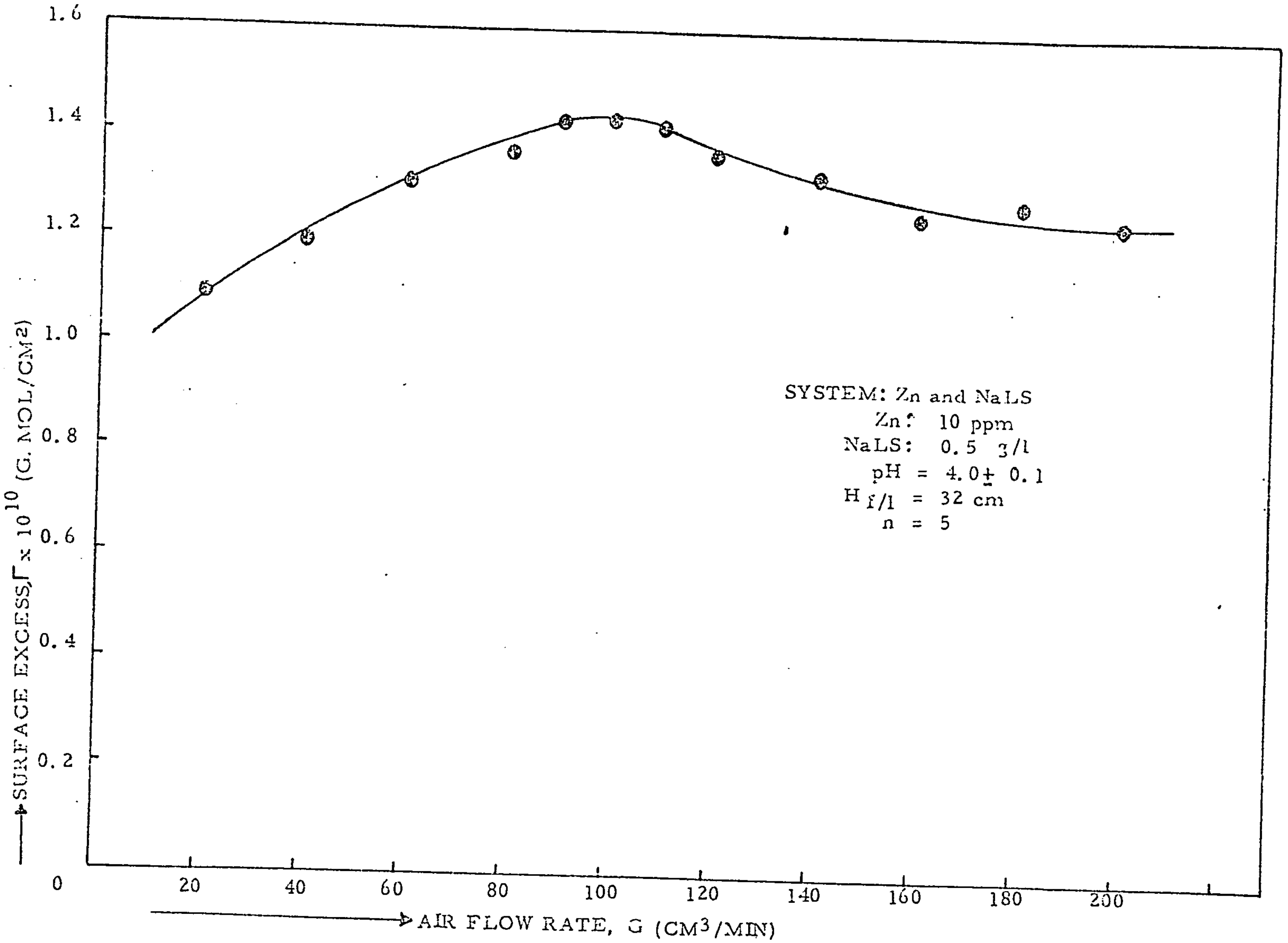


FIG. NO: 5.3 EFFECT OF AIR FLOW RATE ON SURFACE EXCESS

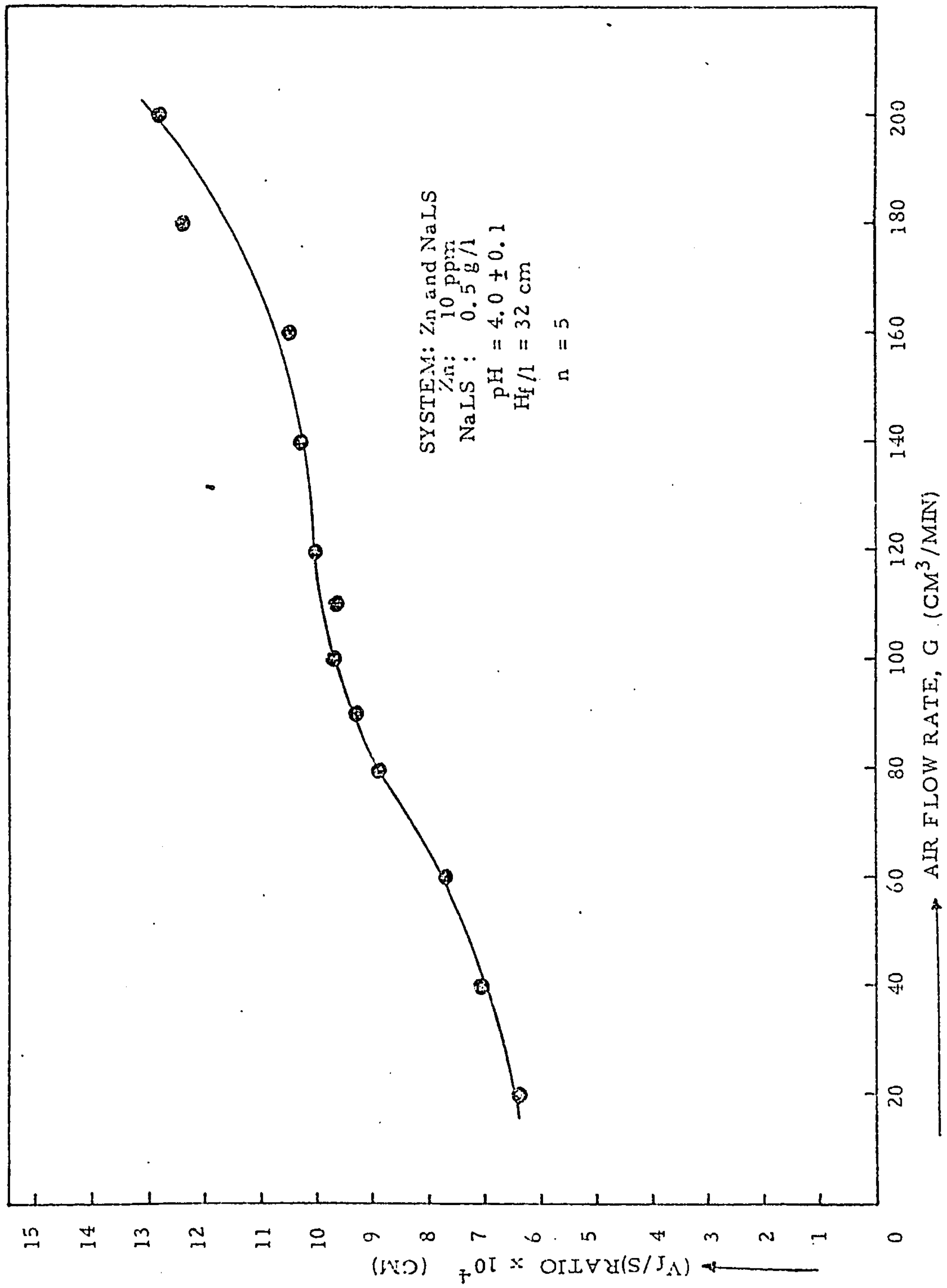


FIG. NO:5.4 EFFECT OF AIR FLOW RATE ON (V_f/S)RATIO

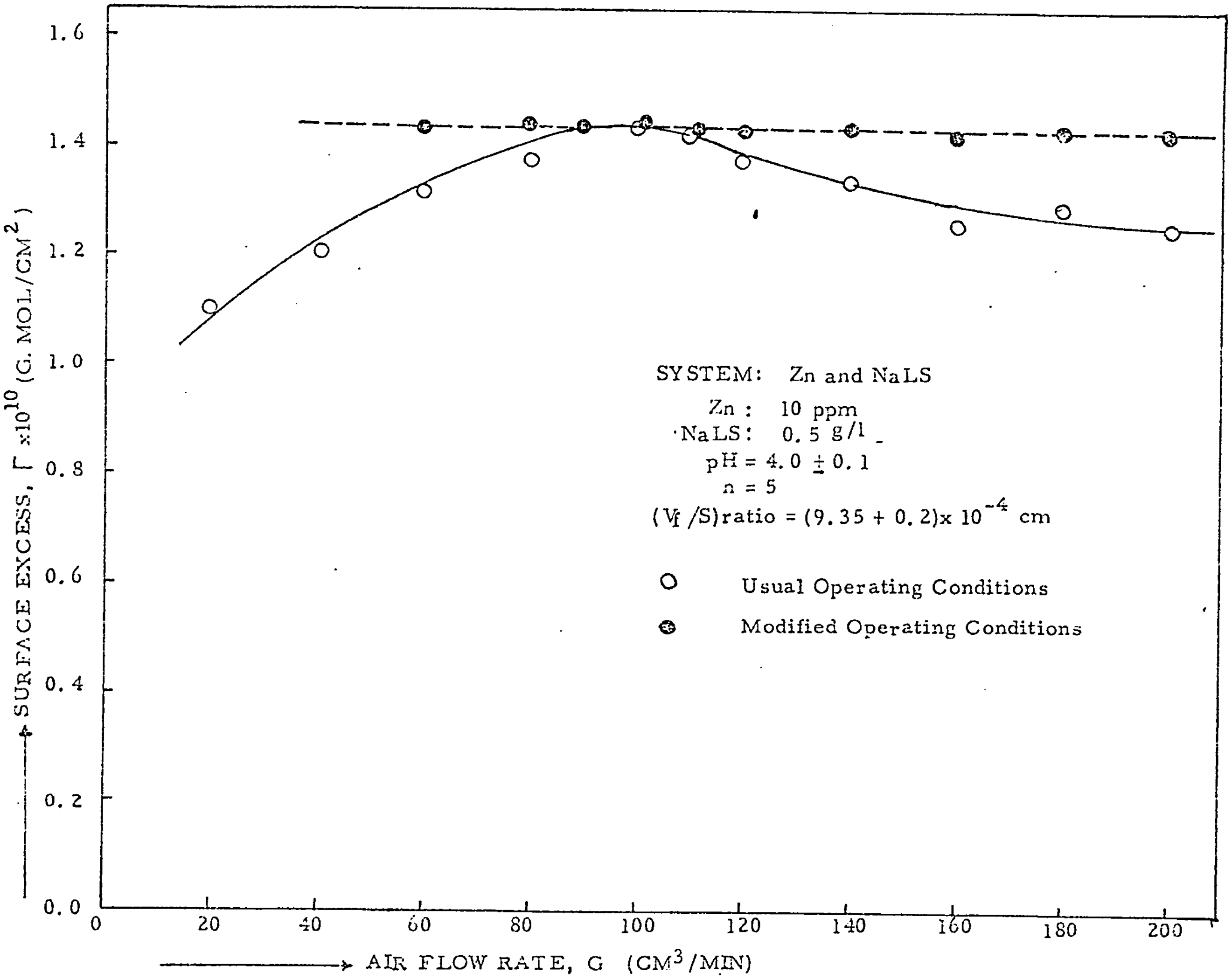


FIG. NO: 5.5 EFFECT OF AIR FLOW RATE ON SURFACE EXCESS (CORRECTED PLOT)

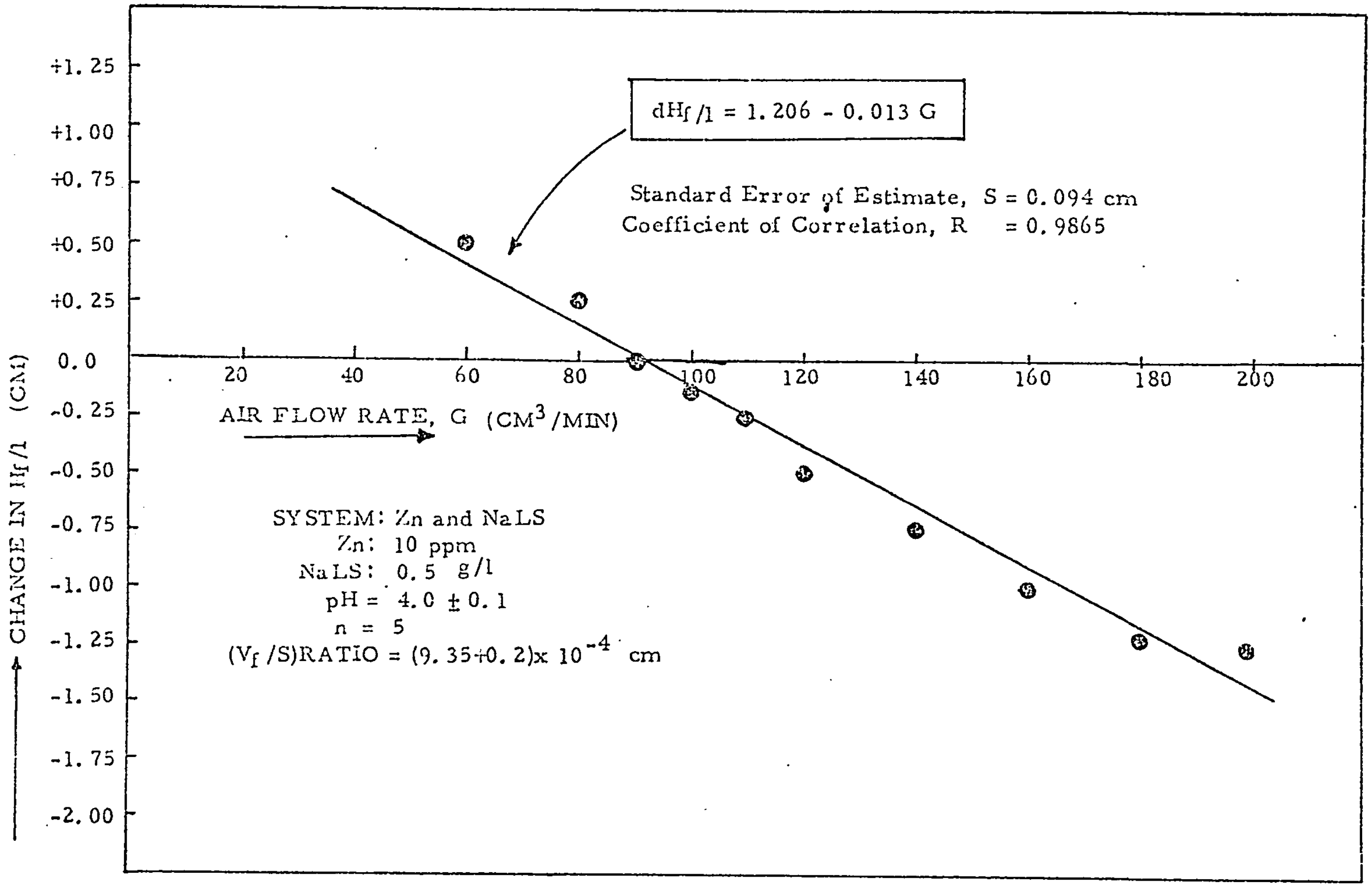


FIG. NO:5.6 CHANGE IN $H_f/1$ Vs AIR FLOW RATE

5.5 Effect of No. of Capillaries (Bubbles) on Surface Excess (Effect of Bubble Diameter)

This section is specially devoted to the examination of the bubbler by determining the effect of bubble diameter at constant air flow rate. The collected data and the results are given in TABLES 5.5, 5.6, 5.7 and 5.8, and the results are plotted in FIG.NO.5.7.

The requirement to operate the bubbler at constant air flow rate to produce bubbles of different sizes was met by sealing the capillaries one by one as shown in FIG.NO.5.7. As can be seen from the figure, when n= 5, there are 5 arrays of bubbles coming out with the smallest diameter. When n = 4 (one capillary is sealed), 4 arrays of bubbles are coming out with an increased bubble diameter, and so on. Finally when n = 2, the maximum bubble diameter occurs at the same air flow rate. When n = 1, it became impossible to maintain the steady state due to excessive back pressure development. This case was therefore not examined.

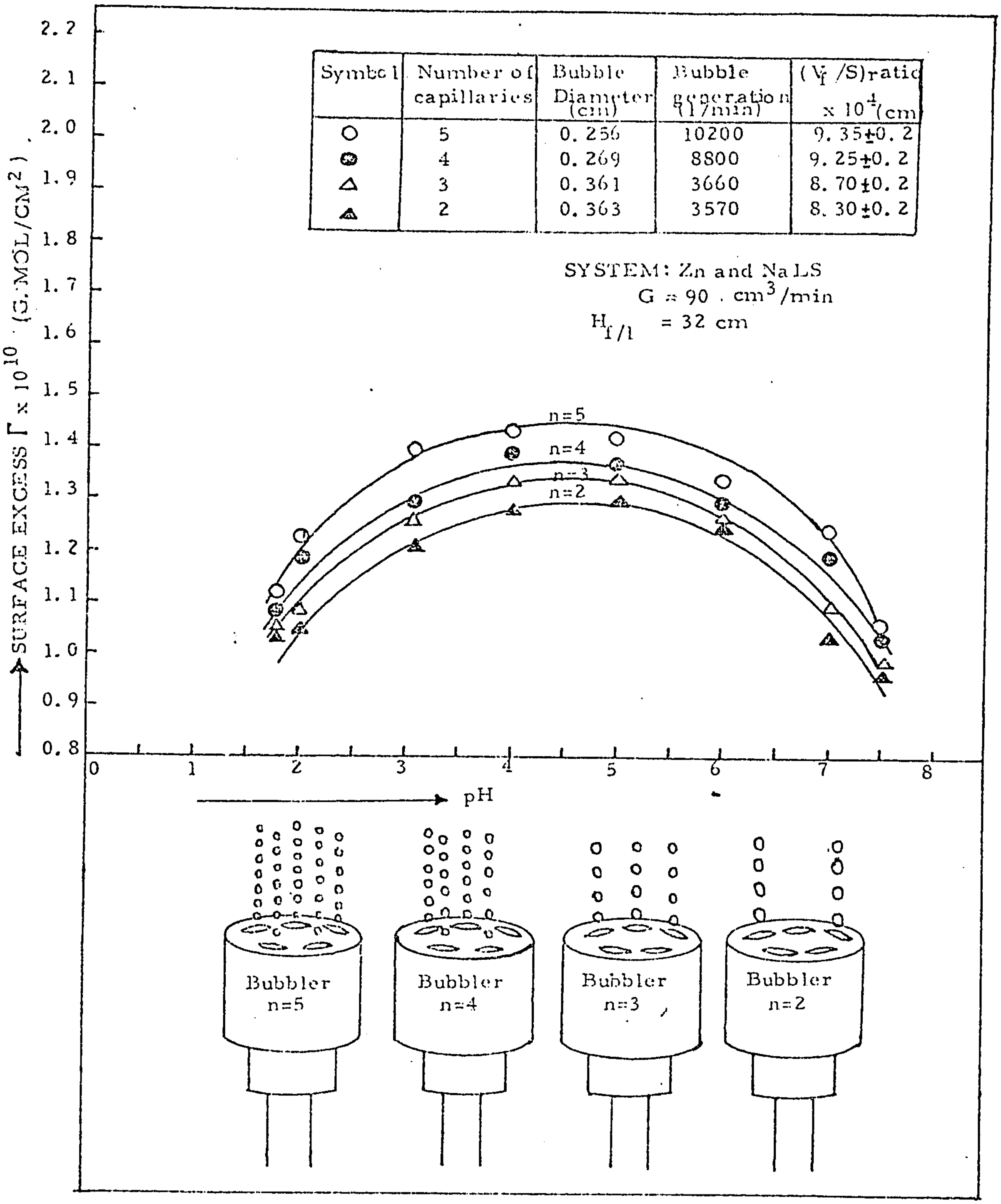
Data under these four different situations were collected and are plotted in FIG.NO.5.7. to find the effect of pH on surface excess. Here the main intention was not to find the effect of pH or the effect of number of capillaries, but to find the effect of the number of bubbles as generated by those capillaries, and thereby to find the effect of bubble diameter.

It was noticed from the plot that when n = 5, the bubble size was the smallest and the bubble generation rate was the highest. Consequently the interfacial area was the highest and the measured surface excess was found to be maximum. When n = 4, 3, 2, the measured surface excess was found to decrease gradually at any particular pH value. It was also observed from the results (Refer TABLES 5.5, 5.6, 5.7, and 5.8) that this change in the measured surface excess was mainly due to the change in (V_f/S) ratio in equation 3.3. The values of (V_f/S) ratio for each case are listed on the plot as well as on the tables.

The effect of (V_f/S) ratio is basically correct as far as the soap bubbles are concerned (Refer Appendix A, part II). For a given soap bubble, as its diameter is decreased, the (V_f/S) ratio must be increased. However, the measured surface excess for any particular system should not be affected by the physical entrainment of the bubbles. In this study, the measured surface excess was found to be affected by the size of the bubbles, whereas the foamate concentration was not affected at all. It was concluded that the curves obtained for n = 4, 3, 2, represented a false surface excess. Again the necessary efforts were made to bring the values of false surface excess to the true values.

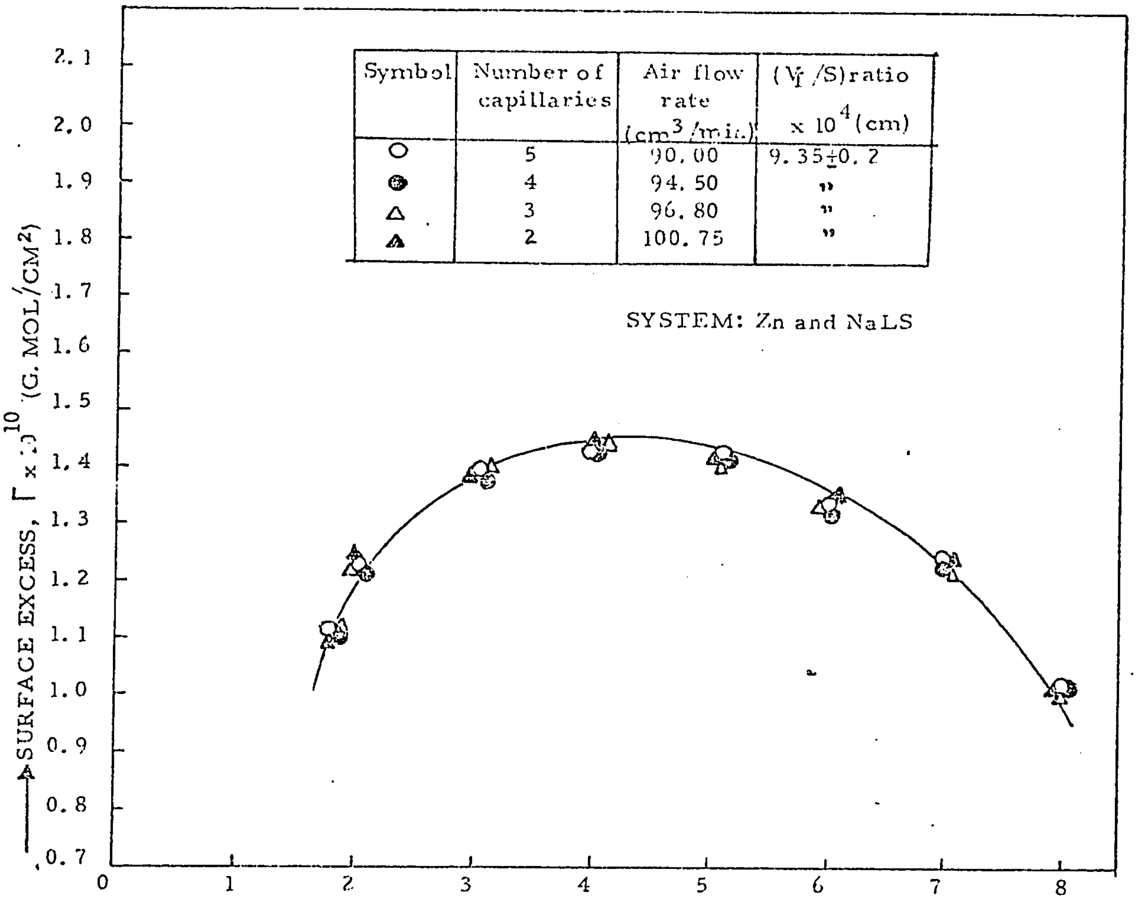
The requirement to bring the false surface excess to the true surface excess was met by increasing the air flow rate when n = 4, 3, 2, and by adjusting the $H_{f/1}$ to obtain constant a (V_f/S) ratio. At each point in this work, at least 2 or 3 trials were made to bring the (V_f/S) ratio to the constant value. The new data and the results are shown in TABLES 5.9, 5.10 and 5.11. The results are plotted in FIG.NO.5.8.

It is therefore concluded from the preceding sections (5.3, 5.4 and 5.5) that the apparatus can be operated in the modified way so that it exists in the simple mode operation at all times. For a given number of capillaries, proper air flow rate and the corresponding proper $H_{f/1}$ should be maintained so that there will not be any coalescence or drainage. Any such coalescence or drainage will result in the measurement of a false surface excess. The results should be compared at constant (V_f/S) ratio to ensure that true values of the surface excess are measured.



Symbol	Number of capillaries	Bubble Diameter (cm)	Bubble generation (1/min)	(V_f/S)ratio $\times 10^4$ (cm
○	5	0.256	10200	9.35±0.2
⊛	4	0.269	8800	9.25±0.2
△	3	0.361	3660	8.70±0.2
▲	2	0.363	3570	8.30±0.2

FIG. NO: 5.7 EFFECT OF NO' OF CAPILLARIES ON SURFACE EXCESS
(EFFECT OF BUBBLE DIAMETER)



Symbol	Number of capillaries	Air flow rate (cm^3/min)	(V_f/S)ratio x 10^4(cm)
○	5	90.00	9.35±0.2
●	4	94.50	"
△	3	96.80	"
▲	2	100.75	"

SYSTEM: Zn and NaLS

FIG. NO: 5.8 EFFECT OF NO. OF CAPILLARIES ON SURFACE EXCESS (CORRECTED PLOT)

5.6 Effect of The Concentrations of Metal-Ion and Collector on Surface Excess

At the modified operating conditions, the investigations were extended as follows.

Two different concentrations of the collector, 0.05 g/l and 0.5 g/l, were chosen to determine the effect of bulk zinc concentration on surface excess. The data and the results are shown in TABLES 5.12 and 5.13.

In foam fractionation, collector ions which are surface active by nature, initially orient around the bubble surface. The adsorption of collector-ions causes co-adsorption of equivalent counter-ions so that both collector and counter-ions can be extracted from the bulk to the surface.

It was noticed from FIG.NO.5.9 that when the collector concentration was very small (i.e., 0.05 g/l), the zinc surface excess gradually increased for a certain range and then slowly decreased as the bulk zinc concentration increased. In the other case when the collector concentration was very high (i.e., 0.5 g/l), the surface excess gradually increased and then became constant.

The plot indicated that even a smaller amount of collector was almost sufficient to saturate the bubble surface. This was concluded from the fact that if the bubble surface was not saturated with the collector ions, the zinc surface excess would never reach the maximum indicated value for any bulk zinc concentration. When the bubble surface was saturated with the collector and metal ions, a further increase in bulk zinc concentration may not increase the surface excess at all.

It was also observed from the plot that at very low bulk zinc concentrations, surface excess was found to be greater with lower collector concentration, where as at higher bulk zinc concentrations, surface excess was found to be greater with higher collector concentration. Siy(21) reported a similar trend for the zinc and NaDBS system. At the lower bulk zinc concentration, his results had the same trend, but the curve for lower collector concentration in his studies did not decrease at higher bulk zinc concentration.

It is worthwhile to note here the surface excess for higher collector concentration also decreased if the bulk zinc concentration increased further. This fact was experimentally checked by working at a stoichiometric bulk zinc concentration of 113.5 ppm (Refer TABLE.NO.5.19, RUN.133). The surface excess was found to decrease to an extremely low value, i.e., 0.039×10^{-10} g.mol/cm^2. The reason for the very low surface excess in this case was that a very large quantity of sodium hydroxide was required for the pH adjustment and thus large amount of sodium ions competed with the zinc ions for adsorption.

In order to explore the above mentioned effect from a different point of view, the same data were used to plot distribution factor versus bulk zinc concentration. These results are shown in TABLES 5.14 and 5.15, and are plotted in FIG.NO.5.10. The trend of the curves was found to be similar to that of Siy(21). He has already interpreted that the distribution factor, i.e., Γ / X_b increased as X_b decreased because the denominator, X_b decreased more rapidly than the numerator, Γ . At low bulk zinc concentration, the distribution factor was increased with decrease in collector concentration, but at higher bulk zinc concentration, the two curves were almost coincided.

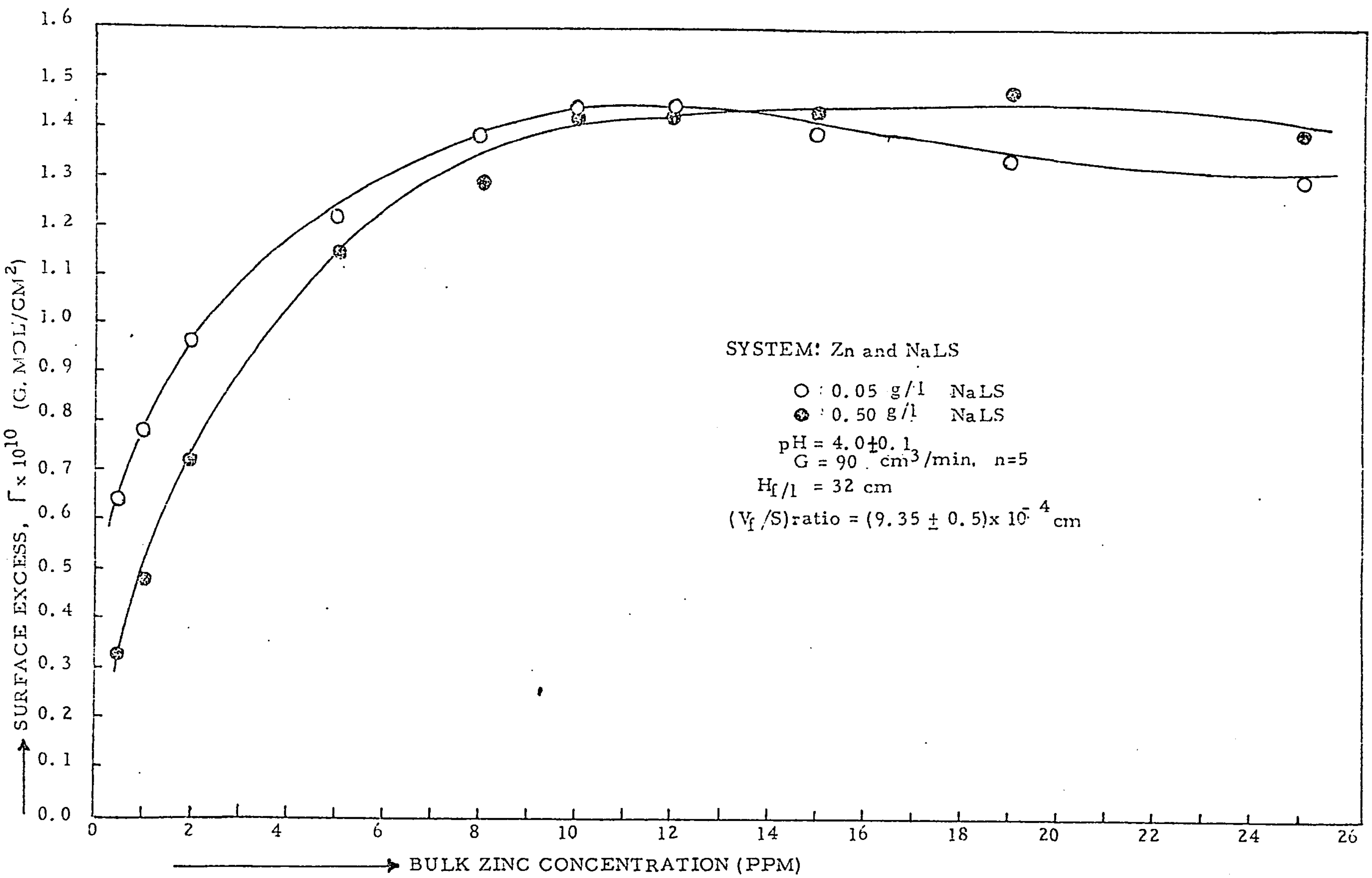


FIG. NO: 5.9 EFFECT OF THE CONCENTRATIONS OF THE METAL ION AND COLLECTOR ON SURFACE EXCESS

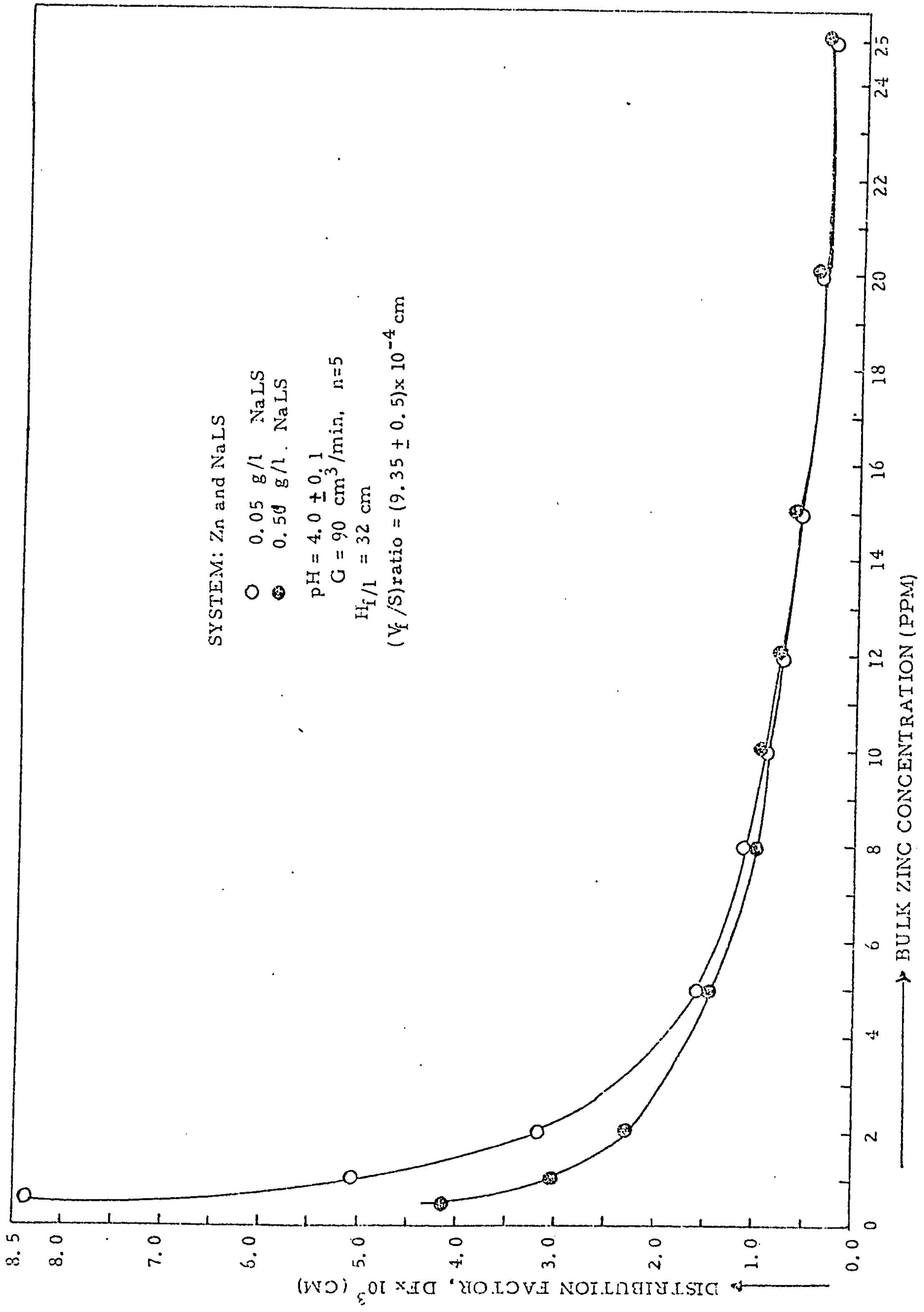


FIG. NO: 5.10 EFFECT OF THE CONCENTRATIONS OF THE METAL ION AND COLLECTOR ON DISTRIBUTION FACTOR

5.7 Effect of pH on Surface Excess at Various Bulk Zinc Concentrations

The present section is devoted to determine the effect of pH on zinc surface excess at various bulk zinc concentrations by keeping the collector concentration constant. This series of runs was carried out at constant (V_f/S) ratio, i.e., (9.35 ± 0.2) x 10^{-4} cm. The data and the results are shown in TABLES 5.5, 5.16, 5.17, 5.18 and 5.19, and the results are plotted in FIG.NO.5.11.

It was noticed from the plot that at any particular pH, the surface excess was found to be a maximum for a bulk zinc concentration of 10 ppm. When the bulk zinc concentration was very high, i.e., 113.5 ppm, the surface excess was found to be almost zero indicating that there was no possible separation. As stated previously, very large quantities of NaOH were required for the pH adjustment and so unusually large amounts of sodium ions were introduced into the system.

The trend of the curves for 1 ppm and 2 ppm was exactly the same, and the curve for 25 ppm was obtained just below the curve of 10 ppm. It was concluded that, in the case of 25 ppm, the bubble surface was not saturated completely and so the surface excess did not reach the maximum possible value.

The mechanism for the effect of pH on the surface excess can be explained as follows: at the lower pH the concentration of the hydronium ions, H_3O^+, is higher, and the hydronium ions preferentially move to the double layer to neutralize the charge of the collector ions, thereby reducing the zinc surface excess. As the pH is increased, hydronium ion concentration decreases and the zinc surface excess increases. At a pH of 4.0, there is little competition from the hydronium ions, and hence the zinc surface excess reaches a maximum in all the cases. The maximum on each curve could also be explained as the optimum pH region for the formation of the co-ordination compound consisting of zinc ions and free lauryl sulfate ions. This fact was originally presented by Sebba(34). When pH increases further, sodium ions which are introduced into the system by the addition of NaOH for pH adjustment will compete with zinc ions in the double layer region and thereby reduce the zinc surface excess. Alternatively the reason for the reduction of the surface excess in the alkaline region is that a part of the zinc must be precipitated by combining with OH^- ions of NaOH to form $Zn(OH)_2$. It was noticed experimentally that at higher pH-values, $Zn(OH)_2$ precipitate was found in the foamate as an insoluble scum. This precipitate is not collected by the foam fractionation technique but by precipitate flotation. In order to determine the actual concentration of the foamate, this precipitate should be analysed separately. But this was not taken into account in this study.

The solubility product of $Zn(OH)_2$ is available in the literature and is given in Appendix A, part III. From the definition of the solubility product, the value of pH for complete precipitation was calculated at various bulk zinc concentrations. At these pH values, it was experimentally noticed that the zinc was precipitated.

The same results were used to plot enrichment ratio versus pH as shown in FIG.NO.5.12. This plot was made to illustrate the efficiency of adsorption separately. Moreover, when the data are accurately collected at constant (V_f/S) ratio, there should not be much difference whether surface excess or enrichment ratio is investigated. It was noticed from the plot that for any bulk zinc concentration the trend for the effect of pH on surface excess or enrichment ratio was almost the same. The interpretation for these curves is exactly the same as explained before. It is important to note here that the adsorption efficiency was found to be increased with decrease in bulk zinc concentration. Siy(21) has already reported that the degree of separation for Zn and NaDBS system increased with a decrease in bulk zinc concentration. Rubin(33) has also reported in his ion flotation studies for copper and NaLS system that the removal should increase by decreasing the metal ion concentration.

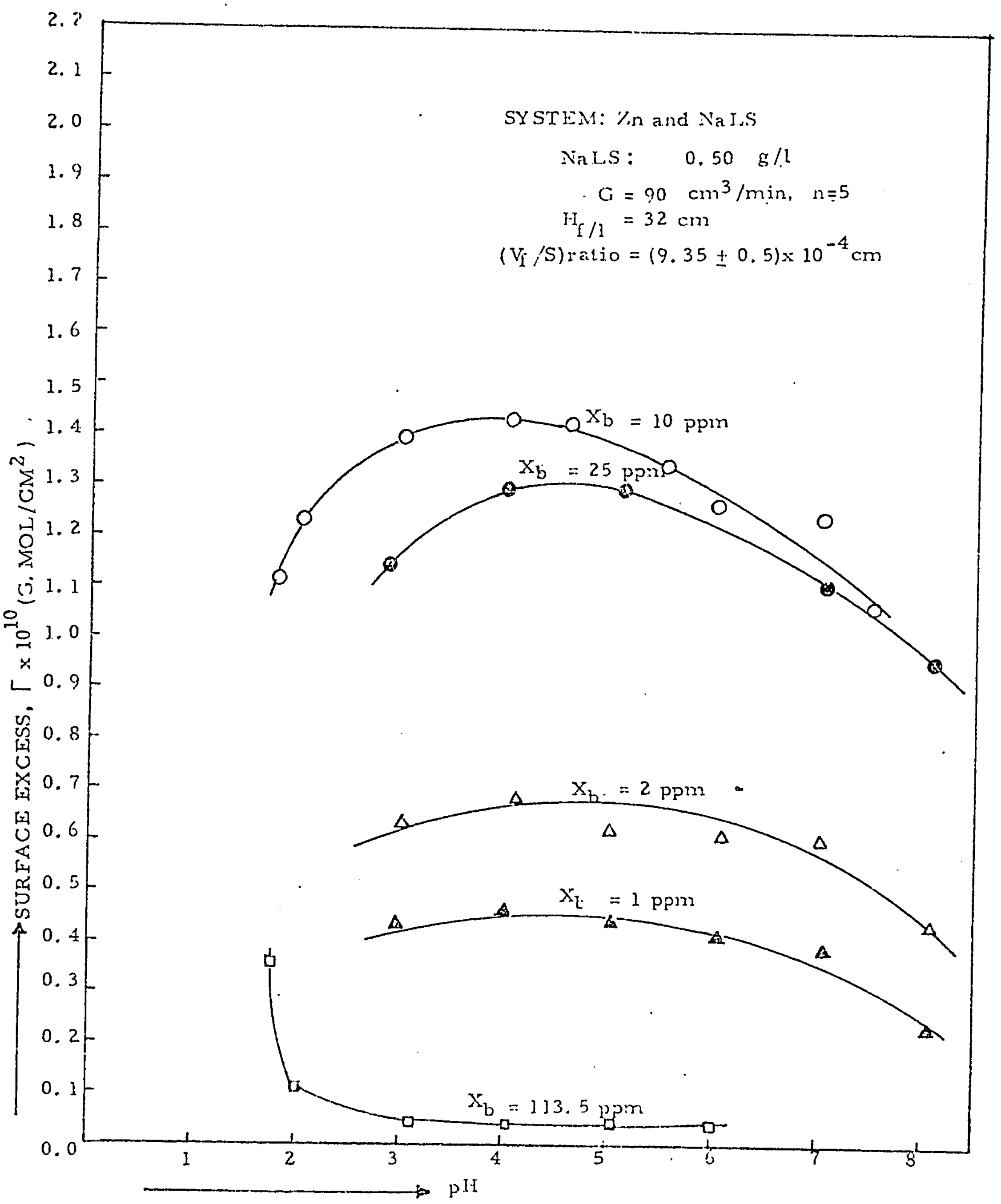


FIG. NO: 5.11 EFFECT OF pH ON SURFACE EXCESS AT VARIOUS BULK ZINC CONCENTRATIONS

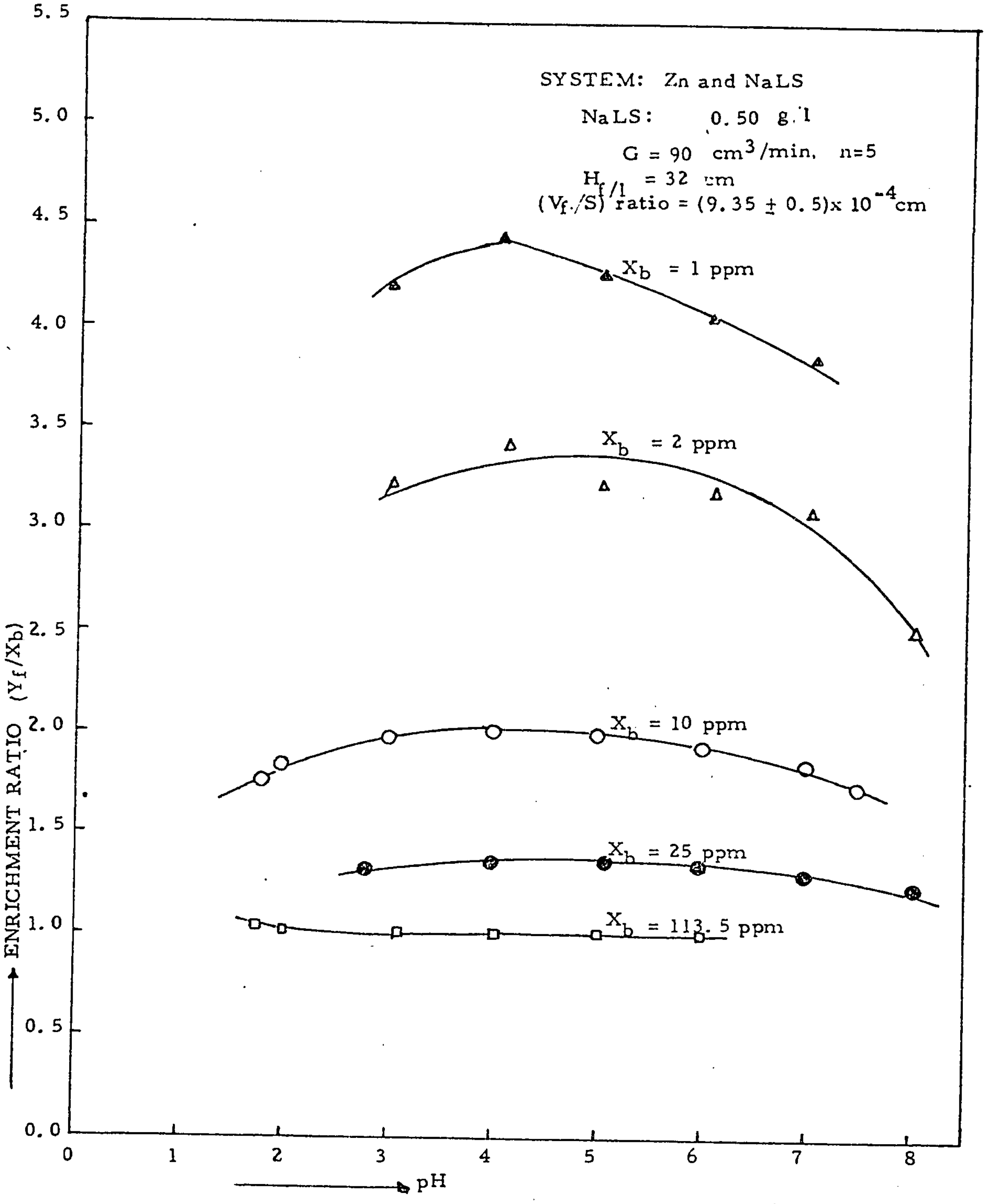


FIG. NO: 5.12 EFFECT OF pH ON ENRICHMENT RATIO AT VARIOUS BULK ZINC CONCENTRATIONS

5.8 Importance of The (V_f/S) Ratio

The (V_f/S) ratio is the amount of the foam collected per unit interfacial area. For a particular system, the amount of the foam can be changed according to the entrainment of the bubbles or due to the geometry of the bubbles. It was found that this ratio was very sensitive to the air flow rate and the height of the foam/liquid interface. It was concluded that more meaningful data can be collected if the (V_f/S) ratio is kept constant. No conscious effort was made by previous investigators to keep this ratio constant.

One would expect that the most important variables that may affect the (V_f/S) ratio are the air flow rate, the height of the foam/liquid interface, the concentrations of the collector and metal ion and the pH of the solution. In the present investigations, it was observed that the (V_f/S) ratio was not affected by the concentrations of the collector and metal ion and the pH of the solution. The (V_f/S) ratios obtained by other investigators using the same equipment are tabulated in TABLE.NO.5.21. From these results, it was observed that pH had some effect on the (V_f/S) ratio, but there was no definite trend. It was also noticed that the foam generation rate at constant air flow rate did fluctuate significantly. In Dick's results(19) for Cu/NaLS system, the (V_f/S) ratio varied from 6.22×10^{-4} cm to 7.60×10^{-4}cm at the same air flow rate. In St. Eloi's (20) results, for Zn/NaDBS/NaCl system, the (V_f/S) ratio varied from 3.14×10^{-4} cm to 5.64×10^{-4} cm. St. Eloi used very high flow rates, but the ratio was found to be very low. In Siy's results, for Zn/NaDBS system, the (V_f/S) ratio varied from 8.99×10^{-4} cm to 15.35×10^{-4} cm. This was due to the fact that the surface generation rate and the foam generation rate were fluctuating for the same air flow rate.

It can be concluded that these investigators never attempted to rectify the wide variation of the (V_f/S) ratio. However, they appear to have obtained reproducible results. According to their interpretation, the trend of their results was acceptable, but there was no evidence presented that their column was operated exactly under the conditions of simple mode.

6. SUMMARY AND CONCLUSIONS

The present studies, based on the surface adsorption of aqueous zinc ions by foam fractionation, are summarized and concluded as follows.

(i) The given experimental set-up was thoroughly examined and the operating conditions were fixed to collect the data accurately in the simple mode. It was decided that the column should possess only one optimum level of foam/liquid interface, for foam fractionation in simple mode. For the particular unit employed, a height of 32 cm above the bubbler was reported as the optimum $H_{f/l}$ at an air flow rate of 90 cm^3/min. The optimum height was found to be very sensitive to a change in the air flow rate. The change in $H_{f/l}$ was correlated as a direct function of the air flow rate. The following approximate equation

$$dH_{f/l} = 1.206 - 0.013G$$

can be used to find out the optimum $H_{f/l}$ at any air flow rate. This operating condition was fixed on the basis of surface excess calculations with constant (V_f/S) ratio.

(ii) The bubbler was examined thoroughly to gain some information regarding the number of capillaries possessed by the bubbler. If the bubbler was operated with 5,4,3,2, number of capillaries respectively at the same air flow rate, the measured surface excess was found to be in the decreasing order. It was observed experimentally that if the number of capillaries were changed, the column was disturbed from simple mode due to the effect of the geometry of the bubbles. This difficulty was overcome by adjusting the air flow rate and the height of the foam/liquid interface until a constant (V_f/S) ratio was obtained. The (V_f/S) ratio in the present context was treated as the optimum ratio.

(iii) At the modified operating conditions, the effect of the metal ion and collector concentrations on zinc surface excess was investigated. All the data were collected at constant (V_f/S) ratio. At the lower bulk zinc concentration, the surface excess was found to increase with a decrease in collector concentration, and this effect was reversed at higher bulk zinc concentration. It was concluded that the large amount of sodium ions introduced into the system for pH adjustment competed with zinc ions for adsorption and thereby the surface excess was reduced at higher bulk zinc concentration. For the same experimental results, the distribution factor or degree of separation was studied in place of surface excess.

(iv) The studies were extended to determine the effect of pH on surface excess at different bulk zinc concentrations. At a bulk zinc concentration of 10 ppm, the surface excess was found to be maximum for any particular pH. A pH of 4.0 was reported as the optimum for any bulk zinc concentration. The same data were used to plot enrichment ratio versus pH. The enrichment ratio was found to increase with decrease in bulk zinc concentration.

(v) The present investigations were carried out at constant (V_f/S) ratio i.e., $(9.35 \pm 0.5) \times 10^{-4}$ cm in an effort to produce meaningful results. An attempt was made to compare this ratio with the results of the other investigators. It was noted from the results of others that pH affected (V_f/S) ratio, but there was no definite trend. It was observed that the other investigators never tried to rectify the wide variation of the (V_f/S) ratio. Moreover it was noticed that even though the other investigators have obtained reproducible results, there was no evidence that the column was operated exactly under the conditions of simple mode.

7. RECOMMENDATIONS

(i) The optimum height of the foam/liquid interface should be determined initially for any given column operating in simple mode.

(ii) The effects of pH, concentrations of collector, and metal ion on (V_f/S) ratio should be investigated.

(iii) At the constant (V_f/S) ratio, the effect of the metal ion concentration on the collector surface excess should be investigated.

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APPENDIX-A

1. ATOMIC ABSORPTION SPECTROPHOTOMETER (OPERATING CONDITIONS)

The following are the operating conditions used for the data given in tables 5.22 to 5.29 -

Wave Length = 213.9 mμ

Slit Width = 0.4 mm

Fuel Pressure = 6.0 psig

Air Pressure = 40.0 psig

Fuel Flow Rate = 400 cc/min

Air Flow Rate = 5.0 l/min

Burner Height = 1.2 cm

Sensitivity = 0.04 ppm

Propane is used as Fuel.

II. EFFECT OF BUBBLE DIAMETER ON (V_f/S) RATIO OF A SPHERICAL SOAP BUBBLE

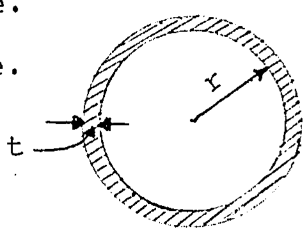
Consider a spherical soap bubble of radius, r and the film thickness, t as shown in the figure.

Let "V_f" be the volume of the film around the bubble surface.

Let "S" be the surface area of the bubble.

Let "V1" be the volume of outer sphere.

Let "V2" be the volume of inner sphere.



By visual observation, the volume of the soap film, V_f is obtained as -

$$V_f = V1 - V2$$

$$= (4\pi/3)(r+t)^3 - (4\pi/3)(r)^3$$

$$= (4\pi/3)(t^3 + 3rt(r+t)) \quad .... \text{A1}$$

Surface Area of the bubble, s is given by -

$$S = 4\pi r^2 \quad .... \text{A2}$$

$$(V_f/S) = (1/3r^2)(t^3 + 3rt(r+t))$$

$$(V_f/S) = (t^3/3r^2) + (t^2/r) + (t) \quad .... \text{A3}$$

From the equation (A3), it can be seen that for a constant film thickness(t), (V_f/S) ratio increases as the bubble size decreases. If the bubble size increases, the thickness of the film generally decreases, and thereby (V_f/S) ratio decreases further.

III. SOLUBILITY PRODUCT OR PRECIPITATION VALUE

The solubility product is the product of the concentrations of the ions of a substance in a saturated solution of the substance.

$$K_{sp} = (Zn^{++})\ (OH^{-})^{2}$$

Where K_{sp} = Solubility Product,

Zn^{++}= Concentration of Zinc in solution,

and OH^{-} = Concentration of Hydroxyl in solution.

From the Hand Book(35),

$$K_{sp} \text{ for } Zn(OH)_2 = 1.8 \times 10^{-14}$$

By using the above equation of solubility product, the concentration of the hydroxyl ion, (OH^{-}) was calculated and thereby the pH of the solution for complete precipitation was obtained. At various bulk zinc concentrations, the values of pH obtained are tabulated as follows.

Conc. of Zn in ppm	Conc. of Zn in mol/litre	p^{OH}	p^{H}
1	$0.1525\times10^{-4}M$	4.46	9.54
2	$0.3049\times10^{-4}M$	4.61	9.39
10	$1.5297\times10^{-4}M$	4.96	9.04
25	$3.8240\times10^{-4}M$	5.16	8.84
113.5	$17.3627\times10^{-4}M$	5.49	8.51

APPENDIX B

The following computer programs (APL/360) are used for the presentation of the data and the results:

FILE.NO.	USAGE
FILE 1	To compute and tabulate surface excess and distribution factor at constant metal ion and collector concentrations.
FILE 2	To compute and tabulate surface excess and distribution factor at varying metal ion and collector concentrations.
FILE 3	To compute the enrichment ratio and to tabulate the corresponding data.
FILE 4	To compute the concentrations of the foamate samples by knowing the calibrated transmittance from the atomic absorption spectrophotometer.
FILE 5	To curve-fit a linear regression line by least squares method.

```
)FNS FILE1
∇ FILE1
 [1] ⍝   THIS IS APL/360 PROGRAM
 [2] ⍝   TO COMPUTE SURFACE EXECESS AND DISTRIBUTION FACTOR
 [3] 'ENTER THE DATA ONE BY ONE'
 [4] 'AIR FLOW RATE,G IN(ML/MIN) IS:'
 [5] G←⎕
 [6] 'BUBBLE RATE,NN,IN(1/MIN) IS:'
 [7] NN←⎕
 [8] 'WEIGHT OF FOAMATE,W IN(G.) IS:'
 [9] W←⎕
 [10] 'FOAM GENERATING TIME,T IN (MIN) IS:'
 [11] T←⎕
 [12] 'FOAMATE CONCENTRATION,YF,IN(PPM) IS:'
 [13] YF←⎕
 [14] 'FEED CONCENTRATION,XF,IN (PPM) IS:'
 [15] XF←⎕
 [16] 'MOLECULAR WEIGHT OF METAL,M, IS:'
 [17] M←⎕
 [18] 'PH OF THE SOLUTION,PH, IS:'
 [19] PH←⎕
 [20] '     '
 [21] N←⍴(NN)
 [22] I←1
 [23] '      '
 [24] '      '
 [25] '      '
 [26] '    NOMENCLATURE:'
 [27] '    '
 [28] '    VF = FOAM GENERATION RATE(G./MIN)'
 [29] '    YF = FOAMATE CONCENTRATION(PPM)'
 [30] '    XB = BULK CONCENTRATION(PPM)'
 [31] '     G = AIR FLOW RATE(ML/MIN)'
 [32] '     D = DIAMETER OF SINGLE BUBBLE(CM)'
 [33] '    NN = BUBBLE GENERATION RATE(1/MIN)'
 [34] '     S = SURFACE GENERATION RATE(SQ.CM/MIN)'
 [35] '    GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)'
 [36] '    DF = DISTRIBUTION FACTOR(CM)'
 [37] '      '
```

```
     )FNS FILE1,38
[38] '  RUN     VF      YF     XB       G       D      NN         S         GAMMAx(1E10)  FH   (VF/S)'
[39] '       (G./MIN)  (PPM)  (PPM)  (ML/MIN)  (CM)  (1/MIN)  (SQ.CM/MIN)  (G.MOL/Q.CM)         x(1E4)'
[40] '      '
[41] REP:→(N<I)/0
[42] VF←W[I]÷T[I]
[43] C1←(6×G[I])*(1÷3)
[44] C2←(NN[I]×3.1415927)*(1÷3)
[45] D←C1÷C2
[46] SS←3.1415927×D*2
[47] S←NN[I]×(3.1415927)×D*2
[48] RATIO←(VF÷S)×(1E4)
[49] XB←XF
[50] C3←S×M×1E6
[51] REP1:C4←VF×(YF[I]-XB)
[52] GAMMA←(C4÷C3)×(1E10)
[53] ⍝   NOW TO COMPUTE THE ACTUAL XB, ACTUAL GAMMA
[54] ⍝   BY USING ABOVE APPROXIMATE GAMMA,BASED ON XF
[55] ⍝   AMOUNT OF EXCESS METAL IN GRAMS IS:
[56] AMOUNT1←GAMMA×S×T[I]×M×(1E¯10)
[57] ⍝   AMOUNT OF METAL,PRESENT IN FEED SOLUTION,IN GRAMS IS:
[58] AMOUNT2←4×(1E¯2)
[59] ⍝   HENCE THE REMAINING AMOUNT IN BULK IS:
[60] C5←AMOUNT2-AMOUNT1
[61] ⍝   HENCE THE BULK CONCENTRATION IN(G./L) IS:
[62] C6←C5÷4
[63] ⍝   THUS BULK CONCENTRATION AT THE END OF THE RUN IS (PPM)
[64] ENDXB←C6÷(1E¯3)
[65] AVGXB←(XF+ENDXB)÷2.0
[66] DIFFXB←(XB-AVGXB)
[67] REP2:→(DIFFXB≤0.001)/REP3
[68] XB←AVGXB
[69] →REP1
[70] REP3:DF←(GAMMA÷(XB÷M))×(1E¯10)×(1E6)×(1E3)
[71] ANS1←(4 0 FMT I);(9 3 FMT VF);(9 3 FMT YF[I]);(7 3 FMT XB);(8 3 FMT G[I])
[72] ANS2←(8 3 FMT D);(8 0 FMT NN[I]);(12 3 FMT S);(12 3 FMT GAMMA);(10  3 FMT PH[I])
[73] ANS←ANS1,ANS2,(8 3 FMT RATIO)
[74] ANS
[75] '        '
[76] I←I+1
[77] →REP
    ∇
```

```
)FNS FILE2
∇ FILE2
 [1] ⍝   THIS IS APL/360 PROGRAM
 [2] ⍝   TO COMPUTE SURFACE EXECESS AND DISTRIBUTION FACTOR
 [3] '  WHEN BULK ZINC CONCENTRATION IS VARYING '
 [4] 'ENTER THE DATA ONE BY ONE'
 [5] 'AIR FLOW RATE,G IN(ML/MIN) IS:'
 [6] G←⎕
 [7] 'BUBBLE RATE,NN,IN(1/MIN) IS:'
 [8] NN←⎕
 [9] 'WEIGHT OF FOAMATE,W IN(G.) IS:'
 [10] W←⎕
 [11] 'FOAM GENERATING TIME,T IN (MIN) IS:'
 [12] T←⎕
 [13] 'FOAMATE CONCENTRATION,YF,IN(PPM) IS:'
 [14] YF←⎕
 [15] 'FEED CONCENTRATION,XF,IN (PPM) IS:'
 [16] XF←⎕
 [17] 'MOLECULAR WEIGHT OF METAL,M, IS:'
 [18] M←⎕
 [19] 'PH OF THE SOLUTION,PH, IS:'
 [20] PH←⎕
 [21] '    '
 [22] N←⍴(NN)
 [23] I←1
 [24] '      '
 [25] '     '
 [26] '      '
 [27] '    NOMENCLATURE:'
 [28] '    '
 [29] '    VF = FOAM GENERATION RATE(G./MIN)'
 [30] '    YF = FOAMATE CONCENTRATION(PPM)'
 [31] '    XB = BULK CONCENTRATION(PPM)'
 [32] '     G = AIR FLOW RATE(ML/MIN)'
 [33] '     D = DIAMETER OF SINGLE BUBBLE(CM)'
 [34] '    NN = BUBBLE GENERATION RATE(1/MIN)'
 [35] '     S = SURFACE GENERATION RATE(SQ.CM/MIN)'
 [36] '    GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)'
 [37] '    DF = DISTRIBUTION FACTOR(CM)'
 [38] '     '
```

```
      )FNS FILE2,39
[39]  '  RUN      VF        YF      XB        G         D       NN            S              GAMMAx(1E10)  PH    (VF/S)'
[40]  '          (G./MIN)  (PPM)   (PPM)   (ML/MIN)   (CM)   (1/MIN)   (SQ.CM/MIN)    (G.MOL/Q.CM)              x(1E4)'
[41]  '       '
[42]  REP:→(N<I)/0
[43]  VF←W[I]÷T[I]
[44]  C1←(6×G[I])*(1÷3)
[45]  C2←(NN[I]×3.1415927)*(1÷3)
[46]  D←C1÷C2
[47]  SS←3.1415927×D*2
[48]  S←NN[I]×(3.1415927)×D*2
[49]  RATIO←(VF÷S)×(1E4)
[50]  XB←XF[I]
[51]  C3←S×M×1E6
[52]  REP1:C4←VF×(YF[I]-XB)
[53]  GAMMA←(C4÷C3)×(1E10)
[54]  ⍝   NOW TO COMPUTE THE ACTUAL XB, ACTUAL GAMMA
[55]  ⍝   BY USING ABOVE APPROXIMATE GAMMA,BASED ON XF
[56]  ⍝   AMOUNT OF EXCESS METAL IN GRAMS IS:
[57]  AMOUNT1←GAMMA×S×T[I]×M×(1E¯10)
[58]  ⍝   AMOUNT OF METAL,PRESENT IN FEED SOLUTION,IN GRAMS IS:
[59]  AMOUNT2←4×(1E¯3)×XF[I]
[60]  ⍝   HENCE THE REMAINING AMOUNT IN BULK IS:
[61]  C5←AMOUNT2-AMOUNT1
[62]  ⍝   HENCE THE BULK CONCENTRATION IN(G./L) IS:
[63]  C6←C5÷4
[64]  ⍝   THUS BULK CONCENTRATION AT THE END OF THE RUN IS (PPM)
[65]  ENDXB←C6÷(1E¯3)
[66]  AVGXB←(XF[I]+ENDXB)÷2.0
[67]  DIFFXB←(XB-AVGXB)
[68]  REP2:→(DIFFXB≤0.001)/REP3
[69]  XB←AVGXB
[70]  →REP1
[71]  REP3:DF←(GAMMA÷(XB÷M))×(1E¯10)×(1E6)×(1E3)
[72]  ANS1←(4 0 FMT I);(9 3 FMT VF);(9 3 FMT YF[I]);(7 3 FMT XB);(8 3 FMT G[I])
[73]  ANS2←(8 3 FMT D);(8 0 FMT NN[I]);(12 3 FMT S);(12 3 FMT GAMMA);(10  3 FMT PH[I])
[74]  ANS←ANS1,ANS2,(8 3 FMT RATIO)
[75]  ANS
[76]  '       '
[77]  I←I+1
[78]  →REP
    ∇
```

```
     )FNS FILE3
∇ FILE3
 [1] ⍝  THIS IS APL/360 PROGRAM
 [2] ⍝  TO COMPUTE ENRICHMENT RATIO
 [3] ⍝  AND TO TABULATE THE CORRESPONDING DATA
 [4] VF1←1.883 1.852 1.893 1.898 1.920 1.897 1.961 1.957 1.938 1.938 1.972 1.983
 [5] VF2←1.979 1.983 1.991 1.974 1.963 2.002 2.001 1.976 1.968 2.007 1.979 1.952
 [6] VF3←1.967 1.996 1.958 1.971 1.952 1.984 2.007 1.975
 [7] VF←VF1,VF2,VF3
 [8] YF1←4.202 4.444 4.253 4.033 3.848 2.699 6.429 6.820 6.462 6.398 6.247 5.055
 [9] YF2←17.783 18.591 19.660 20.020 20.000 19.211 18.544 17.384 33.00 33.88
 [10] YF3←34.021 33.891 32.759 31.567 116.045 114.269 113.824 113.771 113.808 113.730
 [11] YF←YF1,YF2,YF3
 [12] XB1←0.999 0.999 0.999 0.999 0.999 0.999 1.999 1.999 1.999 1.999 1.999 1.999
 [13] XB2←9.998 9.998 9.998 9.998 9.998 9.998 9.998 9.998 24.99 24.99 24.99 24.99
 [14] XB3←24.99 24.99 113.499 113.499 113.499 113.499 113.499 113.499
 [15] XB←XB1,XB2,XB3
 [16] G1←90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90 90
 [17] G2←90 90 90 90 90 90 90 90 90 90 90 90
 [18] G←G1,G2
 [19] NN1←10200 10220 10220 10210 10220 10220 10200 10210 10210 10210 10220 10210
 [20] NN2←10200 10190 10200 10200 10200 10190 10200 10200 10210 10220 10220 10220
 [21] NN3←10220 10210 10200 10210 10200 10200 10210 10200
 [22] NN←NN1,NN2,NN3
 [23] CR1←113.50 113.50 113.50 113.50 113.50 113.50 56.70 56.70 56.70 56.70 56.70
 [24] CR2←56.70 11.34 11.34 11.34 11.34 11.34 11.34 11.34 11.34 4.5 4.5 4.5 4.5
 [25] CR3←4.5 4.5 1.0 1.0 1.0 1.0 1.0 1.0
 [26] CR←CR1,CR2,CR3
 [27] PH1←2.950 4.020 5.050 6.110 7.100 8.120 3.000 4.100 5.000 6.150 7.010 8.110
 [28] PH2←1.800 2.025 3.050 4.025 5.100 6.000 7.050 7.510 2.850 4.050 5.100 6.000
 [29] PH3←7.050 8.100 1.750 2.000 3.100 4.050 5.100 6.000
 [30] PH←PH1,PH2,PH3
```

```
      )FNS FILE3,31

[31] ⍝  LET ER = ENRICHMENT RATIO
[32] ER←YF÷XB
[33] N←ρ(VF)
[34] I←1
[35] '     '
[36] '    NOMENCLATURE:'
[37] '    '
[38] '    VF = FOAM GENERATION RATE(G./MIN)  '
[39] '    YF = FOAMATE CONCENTRATION(PPM) '
[40] '    XB = BULK CONCENTRATION(PPM) '
[41] '     G = AIR FLOW RATE(ML/MIN)  '
[42] '    NN = BUBBLE GENERATION RATE(1/MIN) '
[43] '    CR = COLLECTOR RATIO '
[44] '    ER = ENRICHMENT RATIO '
[45] '     '
[46] '  RUN    VF       YF       XB       G      NN       CR       ER       PH '
[47] '       (G/MIN)   (PPM)    (PPM)  (ML/MIN)
[48] '   '
[49] REP:→(N<I)/0
[50] ANS1←(4 0 FMT I);(9 3 FMT VF[I]);(9 3 FMT YF[I]);(9 3 FMT XB[I]);(8 2 FMT G[I])
[51] ANS2←(7 0 FMT NN[I]);(9 3 FMT CR[I]);(7 3 FMT ER[I]);(8 3 FMT PH[I])
[52] ANS←ANS1,ANS2
[53] ANS
[54] I←I+1
[55] →REP
∇
```

```
      )FNS FILE4
    ∇ FILE4
[1]  ⍝  THIS IS APL/360 PROGRAM
[2]  ⍝  TO COMPUTE THE CONCENTRATIONS OF FOAMATE SAMPLES
[3]  ⍝  BY KNOWING THE CALIBRATED TRANSMITTANCE FROM
[4]  ⍝  THE ATOMIC ABSORPTION SPECTRO PHOTOMETER
[5]  '  ENTER THE DATA ONE BY ONE'
[6]  '  READ THE VALUES OF TRANSMITTANCE'
[7]  Y1←⎕
[8]  '  READ THE CORRESPONDING CONCENTRATIONS,X'
[9]  X←⎕
[10]  '  READ THE TRANSMITTANCE OF SAMPLES(2 VECTORS),XX'
[11]  X1←⎕
[12]  X2←⎕
[13]  XX←X1,X2
[14]  ⍝  COMPUTE ABSORBANCE FROM TRANSMITTANCE
[15]  Y2←(100.0÷Y1)
[16]  Y3←⍟Y2
[17]  Y4←Y3÷2.3025851
[18]  ⍝  NOW Y4 IS CALLED ABSORBANCE
[19]  ⍝  THEN CURVE-FIT(ABSORBANCE VS CONC.)
[20]  ⍝  COMPUTE SUMMATIONS
[21]  S1←+/(Y4)
[22]  S2←+/X
[23]  S3←+/(Y4×X)
[24]  S4←+/(X*2.0)
[25]  ⍝  SOLVE THE NORMAL EQUATIONS
[26]  N←⍴(X)
[27]  P←N,S2,S2,S4
[28]  M←2 2 ⍴ P
[29]  V←S1,S3
[30]  AB←V⌹M
[31]  A←AB[1]
[32]  B←AB[2]
[33]  ⍝  FIND THE STANDARD ERROR OF ESTIMATE
[34]  PY4←A+(B×X)
[35]  SUM←+/((Y4-PY4)*2.0)
[36]  AVERAGE←SUM÷N
[37]  S←AVERAGE*0.5
```

```
     )FNS FILE4,38

[38] ⍝  FIND THE COEFFICIENT OF CORRELATION
[39] YMEAN←(+/Y4)÷N
[40] N1←+/((PY4-YMEAN)*2.0)
[41] N2←+/((Y4-YMEAN)*2.0)
[42] N3←N1÷N2
[43] R←N3*0.5
[44] '    '
[45] '     '
[46] '  THE CALIBRATED TRANSMITTANCE:'
[47] (9 3 FMT Y1)
[48] '  THE CALIBRATED CONCENTRATIONS(PPM):'
[49] (9 3 FMT X)
[50] '    '
[51] '  THE LINEAR REGRESSION LINE IS:'
[52] '     Y ='; (8 3 FMT A);' +'; (8 3 FMT B);' xX'
[53] '    S  ='; (8 4 FMT S);';  R ='; (8 4 FMT R)
[54] ⍝  NOW CALCULATE CONCENTRATIONS OF SAMPLES
[55] XX1←(100.0÷XX)
[56] XX2←⍟(XX1)
[57] XX3←XX2÷2.3025851
[58] ⍝∘  NOW XX3 IS CALLED ABSORBANCE OF SAMPLES
[59] ⍝  COMPUTE CONCENTRATIONS FROM CURVE-FIT
[60] C←((XX3-A)÷B)×4.0
[61] '     '
[62] NN←⍴(XX)
[63] I←1
[64] '  S.NO.  TRANSMITTANCE   ABSORBANCE   CONCENTRATION OF'
[65] '                                       SAMPLES(PPM)    '
[66] '    '
[67] REP:→(NN<I)/0
[68] (5 0 FMT I);(13 2 FMT XX[I]);(14 2 FMT XX3[I]);(16 2 FMT C[I])
[69] I←I+1
[70] →REP
∇
```

```
      )FNS FILE5
    ∇ FILE5
     [1] ⍝  THIS IS APL/360 PROGRAM
     [2] ⍝  LEAST SQUARES METHOD
     [3] 'ENTER THE DATA ONE BY ONE'
     [4] Y←⎕
     [5] X←⎕
     [6] N←⍴(Y)
     [7] ⍝  COMPUTE SUMMATIONS
     [8] S1←+/X
     [9] S2←+/(X⋆2)
     [10] S3←+/Y
     [11] S4←+/(X×Y)
     [12] S5←(S1×S3)-(N×S4)
     [13] S6←(S1⋆2)-(N×S2)
     [14] S7←(S1×S4)-(S2×S3)
     [15] B←S5÷S6
     [16] A←S7÷S6
     [17] '     '
     [18] '     '
     [19] '  THE LINEAR REGRESSION LINE OF Y ON X IS:'
     [20] '    '
     [21] 'Y =';(7 3 FMT A);' + ';(7 3 FMT B);'X '
     [22] '    '
     [23] ⍝  NEXT PART OF PROGRAM IS
     [24] ⍝  TO FIND STANDARD ERROR OF ESTIMATE OF Y ONX,SYX
     [25] YEST←A+(B×X)
     [26] SUM←+/((Y-YEST)⋆2)
     [27] AVERAGE←SUM÷N
     [28] SYX←AVERAGE⋆0.5
     [29] '     '
     [30] 'THE STANDARD ERROR OF ESTIMATE IS:'
     [31] '  S =';(7 3 FMT SYX)
     [32] ⍝  NEXT PART PROGRAM IS:
     [33] ⍝  TO FIND COE]FFICIENT OF CORRELATION
     [34] YMEAN←S3÷N
     [35] P1←+/((YEST-YMEAN)⋆2)
     [36] P2←+/((Y-YMEAN)⋆2)
     [37] P3←P1÷P2
     [38] R←P3⋆0.5
     [39] '    '
     [40] 'THE COEFFICIENT OF CORRELATION IS:'
     [41] '    '
     [42] '  R =';(6 4 FMT R)
    ∇
```

APPENDIX-C

COMPUTER PRINT-OUTS

TABLE.NO: 5.1

EFFECT OF HFL ON FOAMATE CONCENTRATION

HFL = HEIGHT OF THE FOAM/LIQUID INTERFACE ABOVE THE BUBBLER (CM)
YF = CONCENTRATION OF THE METAL ION IN THE COLLAPSED FOAM AT EQUAL INTERVALS OF TIME(PPM)
T = CORRESPONDING SUCCESSIVE TIME (MIN)

SYSTEM: ZINC AND NALS

CONCENTRATION OF ZINC = 10.0 PPM
CONCENTRATION OF NALS = 0.5 G./L
G = 90 ML/MIN
PH = 4.0 ± 0.1

RUN	HFL	YF				T			
1	36	10.00	12.31	9.87	11.85	2	2	2	2
2	35	12.34	13.05	13.22	12.99	2	2	2	2
3	34	16.05	17.21	17.34	16.00	4	4	4	4
4	33	16.00	17.05	17.22	16.11	4	4	4	4
5	32	20.01	20.02	20.02	20.01	4	4	4	4
6	31	21.50	21.90	22.01	22.01	4	4	4	4
7	30	34.99	36.08	36.11	37.98	4	4	4	4
8	28	46.02	49.98	52.02	51.88	4	4	4	4
9	26	64.05	65.00	66.04	69.89	4	4	4	4
10	23	125.64	127.88	129.05	0.00	10	10	10	0
11	20	157.64	160.01	166.12	0.00	10	10	10	0
12	15	279.85	286.59	0.00	0.00	15	15	0	0

TABLE.NO: 5.2

EFFECT OF AIR FLOW RATE ON SURFACE EXCESS

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS
ZINC CONC. = 10 PPM
NALS CONC. = 0.5 G./L
PH = 4.0 ± 0.1

(VF/S)RATIO IS VARYING

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
13	0.366	21.250	10.000	20.000	0.211	4050	567.966	1.109	4.025	6.444
14	0.764	21.100	9.999	40.000	0.222	6950	1079.408	1.202	4.050	7.078
15	1.146	21.080	9.998	60.000	0.245	7820	1471.140	1.321	4.050	7.790
16	1.689	20.250	9.998	80.000	0.255	9210	1882.048	1.407	4.000	8.974
17	1.977	20.010	9.998	90.000	0.256	10200	2106.263	1.438	4.025	9.386
18	2.211	19.660	9.997	100.000	0.263	10450	2277.838	1.435	4.100	9.707
19	2.352	19.700	9.997	110.000	0.270	10690	2445.711	1.427	3.975	9.617
20	2.641	18.880	9.997	120.000	0.275	11010	2617.384	1.371	3.988	10.090
21	2.992	18.450	9.997	140.000	0.290	11020	2901.550	1.333	4.000	10.312
22	3.086	18.100	9.997	160.000	0.316	9700	3039.634	1.258	4.025	10.153
23	3.846	16.750	9.997	180.000	0.350	8000	3083.395	1.289	4.000	12.473
24	4.259	16.350	9.997	200.000	0.366	7780	3277.158	1.263	4.000	12.996

TABLE.NO: 5.3

EFFECT OF AIR FLOW RATE ON SURFACE EXCESS
(CORRECTED RESULTS)

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 10 PPM
NALS CONC. = 0.5 G./L
PH = 4.0 ± 0.1
(VF/S)RATIO = $(9.35 \pm 0.2)\times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
25	1.379	19.984	9.998	60.000	0.245	7820	1471.140	1.432	4.000	9.374
26	1.762	20.004	9.998	80.000	0.255	9210	1882.048	1.433	4.033	9.362
27	2.139	19.993	9.997	100.000	0.263	10450	2277.838	1.436	4.050	9.390
28	2.268	20.056	9.997	110.000	0.270	10690	2445.711	1.427	4.025	9.273
29	2.466	19.884	9.997	120.000	0.275	11010	2617.384	1.425	4.011	9.422
30	2.739	19.906	9.997	140.000	0.290	11020	2901.550	1.431	4.000	9.440
31	2.799	20.133	9.996	160.000	0.316	9700	3039.634	1.428	4.000	9.208
32	2.867	20.078	9.996	180.000	0.350	8000	3083.395	1.434	4.089	9.298
33	3.062	20.014	9.996	200.000	0.366	7780	3277.158	1.432	4.100	9.343

TABLE.NO: 5.4

EFFECT OF AIR FLOW RATE ON DHFL

G = AIR FLOW RATE(ML/MIN)
HFL = HEIGHT OF THE FOAM/LIQUID INTERFACE ABOVE THE BUBBLER (CM)
DHFL = CHANGE IN HFL (CM) = HFL-32

S.NO.	G	HFL	DHFL
1	60	32.50	+0.50
2	80	32.25	+0.25
3	90	32.00	0.00
4	100	31.85	-0.15
5	110	31.75	-0.25
6	120	31.50	-0.50
7	140	31.25	-0.75
8	160	31.00	-1.00
9	180	30.80	-1.20
10	200	30.75	-1.25

SYSTEM: ZINC/NALS

ZINC: 10 PPM
NALS: 0.5 G./L

$PH = 4.0 \pm 0.1$

$(VF/S)RATIO = (9.35 \pm 0.2)\ 10^{-4}$

N = 5

TABLE.NO: 5.5

EFFECT OF PH ON SURFACE EXCESS(N=5)

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 10 PPM
NALS CONC. = 0.5 G./L
G = 90 ML/MIN

$(VF/S)RATIO = (9.35 \pm 0.2) \times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
34	1.979	17.783	9.998	90.000	0.256	10200	2106.263	1.119	1.800	9.396
35	1.983	18.591	9.998	90.000	0.256	10190	2105.574	1.238	2.025	9.418
36	1.991	19.660	9.998	90.000	0.256	10200	2106.263	1.397	3.050	9.453
37	1.974	20.020	9.998	90.000	0.256	10200	2106.263	1.437	4.025	9.372
38	1.963	20.000	9.998	90.000	0.256	10200	2106.263	1.426	5.100	9.320
39	2.002	19.211	9.998	90.000	0.256	10190	2105.574	1.340	6.000	9.508
40	2.001	18.544	9.998	90.000	0.256	10200	2106.263	1.242	7.050	9.500
41	1.976	17.384	9.998	90.000	0.256	10200	2106.263	1.060	7.510	9.382

TABLE.NO:5.6

EFFECT OF PH ON SURFACE EXCESS(N=4)

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 10 PPM
NALS CONC. = 0.5 G/L
G = 90 ML/MIN

(VF/S)RATIO = $(9.25 \pm 0.2) \times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
42	1.843	17.729	9.998	90.000	0.269	8800	2005.118	1.087	1.800	9.191
43	1.845	18.505	9.998	90.000	0.269	8810	2005.878	1.197	2.025	9.198
44	1.827	19.310	9.998	90.000	0.269	8800	2005.118	1.298	3.050	9.112
45	1.853	19.841	9.998	90.000	0.269	8790	2004.359	1.392	4.025	9.245
46	1.842	19.789	9.998	90.000	0.269	8800	2005.118	1.376	5.100	9.186
47	1.865	19.127	9.998	90.000	0.269	8800	2005.118	1.299	6.000	9.301
48	1.824	18.542	9.998	90.000	0.269	8800	2005.118	1.189	7.050	9.097
49	1.849	17.288	9.998	90.000	0.269	8810	2005.878	1.028	7.510	9.218

TABLE NO: 5.7

EFFECT OF PH ON SURFACE EXCESS(N=3)

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 10 PPM
NALS CONC. = 0.5 G/L
G = 90 ML/MIN

(VF/S)RATIO = $(8.7 \pm 0.2) \times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
51	1.312	17.837	9.999	90.000	0.361	3660	1496.716	1.051	1.800	8.766
52	1.318	18.068	9.999	90.000	0.360	3670	1498.078	1.086	2.000	8.798
53	1.321	19.368	9.998	90.000	0.360	3670	1498.078	1.264	3.020	8.818
54	1.332	19.775	9.998	90.000	0.361	3660	1496.716	1.331	4.100	8.899
55	1.313	19.983	9.998	90.000	0.361	3660	1496.716	1.340	5.050	8.773
56	1.312	19.394	9.998	90.000	0.361	3660	1496.716	1.260	6.050	8.766
57	1.322	17.999	9.999	90.000	0.360	3670	1498.078	1.080	7.000	8.825
58	1.330	17.245	9.999	90.000	0.361	3660	1496.716	0.985	7.510	8.886

TABLE.NO: 5.8

EFFECT OF PH ON SURFACE EXCESS(N=2)

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 10 PPM
NALS CONC. = 0.5 G./L
G = 90 ML/MIN

(VF/S)RATIO = $(8.3 \pm 0.2) \times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
59	1.239	18.143	9.999	90.000	0.363	3580	1485.731	1.039	1.850	8.339
60	1.229	18.297	9.999	90.000	0.364	3570	1484.346	1.051	2.030	8.280
61	1.248	19.361	9.999	90.000	0.363	3580	1485.731	1.203	3.050	8.400
62	1.235	20.117	9.998	90.000	0.364	3570	1484.346	1.288	4.000	8.320
63	1.236	20.196	9.998	90.000	0.364	3570	1484.346	1.299	5.010	8.327
64	1.234	19.474	9.999	90.000	0.364	3570	1484.346	1.205	6.050	8.313
65	1.234	18.224	9.999	90.000	0.363	3580	1485.731	1.045	7.040	8.306
66	1.225	17.635	9.999	90.000	0.364	3570	1484.346	0.964	7.510	8.253

TABLE.NO: 5.9

EFFECT OF FH ON SURFACE EXCESS(N=4)
(CORRECTED RESULTS)

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 10 PPM
NALS CONC. = 0.5 G./L

(VF/S)RATIO = $(9.35 \pm 0.2) \times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	FH	(VF/S) x(1E4)
67	1.981	17.604	9.998	94.000	0.273	8840	2067.220	1.115	1.810	9.583
68	1.932	18.650	9.998	94.000	0.273	8840	2067.220	1.237	2.100	9.346
69	1.976	19.600	9.998	95.000	0.274	8860	2083.425	1.393	3.100	9.484
70	1.941	20.050	9.998	95.000	0.274	8860	2083.425	1.433	4.000	9.316
71	1.924	20.040	9.998	95.000	0.274	8860	2083.425	1.419	5.100	9.235
72	1.938	19.293	9.998	94.000	0.273	8840	2067.220	1.333	6.050	9.375
73	1.989	18.461	9.998	95.000	0.274	8860	2083.425	1.236	7.000	9.547
74	1.913	17.190	9.998	94.000	0.273	8840	2067.220	1.018	7.520	9.254

TABLE.NO: 5.10

EFFECT OF PH ON SURFACE EXCESS(N=3)
(CORRECTED RESULTS)

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 10 PPM
NALS CONC. = 0.5 G./L

(VF/S)RATIO = $(9.35 \pm 0.2)\times 10^{-4}$

RUN.	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
75	1.478	17.783	9.999	96.300	0.367	3720	1574.282	1.118	1.810	9.388
76	1.528	18.427	9.998	97.500	0.368	3740	1590.173	1.239	2.025	9.609
77	1.505	19.650	9.998	97.500	0.368	3740	1590.173	1.397	3.020	9.464
78	1.485	20.050	9.998	97.500	0.368	3740	1590.173	1.436	4.000	9.339
80	1.455	20.050	9.998	96.500	0.367	3730	1577.873	1.418	5.100	9.221
81	1.492	19.315	9.998	96.400	0.367	3735	1577.487	1.348	6.050	9.458
82	1.479	18.639	9.998	96.500	0.367	3730	1577.873	1.239	7.040	9.373
83	1.488	17.250	9.999	96.300	0.367	3720	1574.282	1.048	7.500	9.452

TABLE.NO: 5.11

EFFECT OF PH ON SURFACE EXCESS(N=2)
(CORRECTED RESULTS)

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 10 PPM
NALS CONC. = 0.5 G./L

(VF/S)RATIO = $(9.35 \pm 0.2)\times10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
84	1.501	17.700	9.999	99.500	0.373	3650	1598.811	1.106	1.805	9.388
85	1.537	18.474	9.998	101.000	0.375	3660	1616.313	1.233	2.025	9.509
86	1.535	19.680	9.998	102.000	0.376	3660	1626.964	1.397	3.050	9.435
87	1.522	20.050	9.998	102.000	0.376	3660	1626.964	1.438	4.020	9.355
88	1.499	20.090	9.998	101.000	0.375	3650	1614.839	1.433	5.100	9.283
89	1.488	19.108	9.998	99.500	0.373	3650	1598.811	1.297	6.000	9.307
90	1.532	18.599	9.998	102.000	0.376	3660	1626.964	1.239	7.000	9.416
91	1.482	17.048	9.999	99.000	0.373	3650	1593.450	1.003	7.500	9.301

TABLE NO:5.12

EFFECT OF BULK ZINC CONC. ON SURFACE EXCESS

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

NALS CONC. = 0.05 G./L
PH = 4.0 $\pm$ 0.1

(VF/S)RATIO = $(9.35 \pm 0.5)\times10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
92	1.856	5.285	0.499	90.000	0.256	10210	2106.951	0.645	4.100	8.809
93	1.876	6.694	0.999	90.000	0.256	10200	2106.263	0.776	4.033	8.907
94	1.964	8.770	1.998	90.000	0.256	10210	2106.951	0.966	4.025	9.322
95	1.982	13.424	4.998	90.000	0.256	10200	2106.263	1.213	4.025	9.410
96	1.977	17.630	7.998	90.000	0.256	10200	2106.263	1.383	4.050	9.386
97	1.959	20.115	9.998	90.000	0.256	10210	2106.951	1.439	4.050	9.298
98	1.968	22.055	11.998	90.000	0.256	10210	2106.951	1.437	4.050	9.341
99	1.982	24.665	14.998	90.000	0.256	10210	2106.951	1.391	4.000	9.407
100	2.024	29.093	19.998	90.000	0.256	10200	2106.263	1.337	4.000	9.609
101	2.043	33.665	24.998	90.000	0.256	10200	2106.263	1.286	4.000	9.700

TABLE.NO: 5.13

EFFECT OF BULK ZINC CONC. ON SURFACE EXCESS

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

NALS CONC. = 0.5 G./L
PH= 4.0 ± 0.1

(VF/S)RATIO = $(9.35 \pm 0.5)\times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
102	1.852	2.863	0.500	90.000	0.257	10180	2104.885	0.318	4.025	8.799
103	1.862	4.414	1.000	90.000	0.257	10180	2104.885	0.462	4.050	8.846
104	1.978	6.883	1.999	90.000	0.256	10230	2108.326	0.701	4.025	9.382
105	1.984	12.945	4.998	90.000	0.256	10230	2108.326	1.144	4.029	9.410
106	1.977	17.054	7.998	90.000	0.256	10230	2108.326	1.299	4.040	9.377
107	1.955	20.040	9.998	90.000	0.257	10180	2104.885	1.427	4.050	9.288
108	1.918	22.307	11.998	90.000	0.257	10180	2104.885	1.437	4.000	9.112
109	1.968	25.030	14.998	90.000	0.256	10190	2105.574	1.434	4.100	9.347
110	1.987	30.110	19.997	90.000	0.257	10180	2104.885	1.460	4.100	9.440
111	1.958	34.780	24.998	90.000	0.257	10180	2104.885	1.392	4.000	9.302

TABLE.NO: 5.14

EFFECT OF BULK ZINC CONC. ON DISTRIBUTION FACTOR

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

NALS CONC. = 0.05 G./L
PH = 4.0 ± 0.1

(VF/S)RATIO = $(9.35 \pm 0.5) \times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	DF	PH
92	1.856	5.285	0.499	90.000	0.256	10210	2106.951	0.645	8.452	4.10
93	1.876	6.694	0.999	90.000	0.256	10200	2106.263	0.776	5.080	4.03
94	1.964	8.770	1.998	90.000	0.256	10210	2106.951	0.966	3.159	4.02
95	1.982	13.424	4.998	90.000	0.256	10200	2106.263	1.213	1.587	4.02
96	1.977	17.640	7.998	90.000	0.256	10200	2106.263	1.384	1.132	4.05
97	1.959	20.115	9.998	90.000	0.256	10210	2106.951	1.439	0.941	4.05
98	1.968	22.055	11.998	90.000	0.256	10210	2106.951	1.437	0.783	4.05
99	1.982	24.665	14.998	90.000	0.256	10210	2106.951	1.391	0.606	4.00
100	2.024	29.093	19.998	90.000	0.256	10200	2106.263	1.337	0.437	4.00
101	2.043	33.665	24.998	90.000	0.256	10200	2106.263	1.286	0.336	4.00

TABLE.NO: 5.15

EFFECT OF BULK ZINC CONC. ON DISTRIBUTION FACTOR

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

NALS CONC. = 0.5 G./L
PH = 4.0 ± 0.1

(VF/S)RATIO = $(9.35 \pm 0.5) \times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMA×(1E10) (G.MOL/Q.CM)	DF	PH
102	1.852	2.863	0.500	90.000	0.257	10180	2104.885	0.318	4.158	4.02
103	1.862	4.414	1.000	90.000	0.257	10180	2104.885	0.462	3.020	4.05
104	1.978	6.883	1.999	90.000	0.256	10230	2108.326	0.701	2.293	4.03
105	1.984	12.945	4.998	90.000	0.256	10230	2108.326	1.144	1.496	4.03
106	1.977	17.054	7.998	90.000	0.256	10230	2108.326	1.299	1.062	4.04
107	1.955	20.040	9.998	90.000	0.257	10180	2104.885	1.427	0.933	4.05
108	1.918	22.307	11.998	90.000	0.257	10180	2104.885	1.437	0.783	4.00
109	1.969	25.030	14.998	90.000	0.256	10190	2105.574	1.435	0.626	4.10
110	1.987	30.110	19.997	90.000	0.257	10180	2104.885	1.460	0.477	4.10
111	1.958	34.780	24.998	90.000	0.257	10180	2104.885	1.392	0.364	4.00

TABLE NO: 5.16

EFFECT OF PH ON SURFACE EXCESS

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 1.0 PPM
NALS CONC. =0.5 G./L
G = 90 ML/MIN
COLLECTOR RATIO = 113.5

(VF/S) RATIO = $(9.35 \pm 0.5)\times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
112	1.883	4.202	1.000	90.000	0.256	10200	2106.263	0.438	2.950	8.940
113	1.852	4.444	1.000	90.000	0.256	10220	2107.638	0.463	4.020	8.787
114	1.893	4.253	1.000	90.000	0.256	10220	2107.638	0.447	5.050	8.982
115	1.898	4.033	1.000	90.000	0.256	10210	2106.951	0.418	6.110	9.008
116	1.920	3.848	1.000	90.000	0.256	10220	2107.638	0.397	7.100	9.110
117	1.897	2.699	1.000	90.000	0.256	10220	2107.638	0.234	8.120	9.001

TABLE.NO: 5.17

EFFECT OF PH ON SURFACE EXCESS

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 2 PPM
NALS CONC = 0.5 G./L
G = 90 ML/MIN
COLLECTOR RATIO = 56.7

(VF/S)RATIO = $(9.35 \pm 0.2) \times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
118	1.961	6.429	1.999	90.000	0.256	10200	2106.263	0.631	3.000	9.310
119	1.957	6.820	1.999	90.000	0.256	10210	2106.951	0.685	4.100	9.288
120	1.938	6.462	1.999	90.000	0.256	10210	2106.951	0.628	5.000	9.198
121	1.938	6.398	1.999	90.000	0.256	10210	2106.951	0.619	6.150	9.198
122	1.972	6.247	1.999	90.000	0.256	10220	2107.638	0.608	7.010	9.356
123	1.983	5.055	2.000	90.000	0.256	10210	2106.951	0.440	8.110	9.412

TABLE.NO: 5.18

EFFECT OF PH ON SURFACE EXCESS

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 25 PPM
NALS CONC. = 0.5 G./L
G = 90 ML/MIN
COLLECTOR RATIO = 4.5

(VF/S)RATIO = $(9.35 \pm 0.2)\times 10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
124	1.968	33.000	24.998	90.000	0.256	10210	2106.951	1.143	2.850	9.341
125	2.007	33.880	24.998	90.000	0.256	10220	2107.638	1.294	4.050	9.523
126	1.979	34.021	24.998	90.000	0.256	10220	2107.638	1.296	5.100	9.390
127	1.952	33.891	24.998	90.000	0.256	10220	2107.638	1.260	6.000	9.262
128	1.967	32.759	24.998	90.000	0.256	10220	2107.638	1.108	7.050	9.333
129	1.996	31.567	24.998	90.000	0.256	10210	2106.951	0.952	8.100	9.473

TABLE.NO: 5.19

EFFECT OF PH ON SURFACE EXCESS

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
D = DIAMETER OF SINGLE BUBBLE(CM)
NN = BUBBLE GENERATION RATE(1/MIN)
S = SURFACE GENERATION RATE(SQ.CM/MIN)
GAMMA = SURFACE EXCESS(G.MOL/SQ.CM)
DF = DISTRIBUTION FACTOR(CM)

SYSTEM: ZINC AND NALS

ZINC CONC. = 113.5 PPM
NALS CONC. = 0.5 G./L
G = 90 ML/MIN
COLLECTOR RATIO = 1.0

(VF/S)RATIO = $(9.35 \pm 0.2)\times10^{-4}$

RUN	VF (G./MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	D (CM)	NN (1/MIN)	S (SQ.CM/MIN)	GAMMAx(1E10) (G.MOL/Q.CM)	PH	(VF/S) x(1E4)
130	1.958	116.045	113.500	90.000	0.256	10200	2106.263	0.362	1.750	9.296
131	1.971	114.269	113.500	90.000	0.256	10210	2106.951	0.110	2.000	9.355
132	1.952	113.824	113.500	90.000	0.256	10200	2106.263	0.046	3.100	9.268
133	1.984	113.771	113.500	90.000	0.256	10200	2106.263	0.039	4.050	9.420
134	2.007	113.808	113.500	90.000	0.256	10210	2106.951	0.045	5.100	9.526
135	1.975	113.730	113.500	90.000	0.256	10200	2106.263	0.033	6.000	9.377

TABLE.NO: 5.20

EFFECT OF PH ON ENRICHMENT RATIO AT VARIOUS COLLECTOR RATIOS

NOMENCLATURE:

VF = FOAM GENERATION RATE(G./MIN)
YF = FOAMATE CONCENTRATION(PPM)
XB = BULK CONCENTRATION(PPM)
G = AIR FLOW RATE(ML/MIN)
NN = BUBBLE GENERATION RATE(1/MIN)
CR = COLLECTOR RATIO
ER = ENRICHMENT RATIO

RUN	VF (G/MIN)	YF (PPM)	XB (PPM)	G (ML/MIN)	NN	CR	ER	PH
1	1.883	4.202	0.999	90.00	10200	113.500	4.206	2.950
2	1.852	4.444	0.999	90.00	10220	113.500	4.448	4.020
3	1.893	4.253	0.999	90.00	10220	113.500	4.257	5.050
4	1.898	4.033	0.999	90.00	10210	113.500	4.037	6.110
5	1.920	3.848	0.999	90.00	10220	113.500	3.852	7.100
6	1.897	2.699	0.999	90.00	10220	113.500	2.702	8.120
7	1.961	6.429	1.999	90.00	10200	56.700	3.216	3.000
8	1.957	6.820	1.999	90.00	10210	56.700	3.412	4.100
9	1.938	6.462	1.999	90.00	10210	56.700	3.233	5.000
10	1.938	6.398	1.999	90.00	10210	56.700	3.201	6.150
11	1.972	6.247	1.999	90.00	10220	56.700	3.125	7.010
12	1.983	5.055	1.999	90.00	10210	56.700	2.529	8.110
13	1.979	17.783	9.998	90.00	10200	11.340	1.779	1.800
14	1.983	18.591	9.998	90.00	10190	11.340	1.859	2.025
15	1.991	19.660	9.998	90.00	10200	11.340	1.966	3.050
16	1.974	20.020	9.998	90.00	10200	11.340	2.002	4.025
17	1.963	20.000	9.998	90.00	10200	11.340	2.000	5.100
18	2.002	19.211	9.998	90.00	10190	11.340	1.921	6.000
19	2.001	18.544	9.998	90.00	10200	11.340	1.855	7.050
20	1.976	17.384	9.998	90.00	10200	11.340	1.739	7.510
21	1.968	33.000	24.990	90.00	10210	4.500	1.321	2.850
22	2.007	33.880	24.990	90.00	10220	4.500	1.356	4.050
23	1.979	34.021	24.990	90.00	10220	4.500	1.361	5.100
24	1.952	33.891	24.990	90.00	10220	4.500	1.356	6.000
25	1.967	32.759	24.990	90.00	10220	4.500	1.311	7.050
26	1.996	31.567	24.990	90.00	10210	4.500	1.263	8.100
27	1.958	116.045	113.499	90.00	10200	1.000	1.022	1.750
28	1.971	114.269	113.499	90.00	10210	1.000	1.007	2.000
29	1.952	113.824	113.499	90.00	10200	1.000	1.003	3.100
30	1.984	113.771	113.499	90.00	10200	1.000	1.002	4.050
31	2.007	113.808	113.499	90.00	10210	1.000	1.003	5.100
32	1.975	113.730	113.499	90.00	10200	1.000	1.002	6.000

TABLE.NO: 5.21

COMPARISION OF (VF/S)RATIOS WITH OTHERS RESULTS

METAL CONCENTRATION = 10 PPM
COLLECTOR CONCENTRATION = 0.5 G./L

G = AIR FLOW RATE (ML/MIN)
VF = FOAM GENERATION RATE (G./MIN)
S = SURFACE GENERATION RATE (SQ.CM/MIN)

NALS = SODIUM LAURYL SULFATE
NADBS = SODIUN DODECYL BENZENE SULFONATE
NACL = SODIUN CHLORIDE

S.NO.	PRESENT RESULTS SYSTEM: ZINC/NALS					RESULTS OF DICK.W.L SYSTEM: COPPER/NALS				
	PH	G	VF	S	(VF÷S)RATIO x(1E+4)	PH	G	VF	S	(VF÷S)RATIO x(1E+4)
1	1.80	90.00	1.98	2106.3	9.40	1.09	64.00	1.22	1969.4	6.22
2	2.02	90.00	1.98	2105.6	9.42	1.75	64.00	1.40	1989.1	7.05
3	3.05	90.00	1.99	2106.3	9.45	2.88	64.00	1.42	1968.0	7.20
4	4.02	90.00	1.97	2106.3	9.37	3.20	64.00	1.47	1940.3	7.60
5	5.10	90.00	1.96	2106.3	9.32	4.39	64.00	1.47	1961.0	7.48
6	6.00	90.00	2.00	2105.6	9.51	6.00	64.00	2.33	1901.7	12.25
7	7.05	90.00	2.00	2106.3	9.50	4.58	64.00	1.38	1979.0	6.97
8	7.51	90.00	1.98	2106.3	9.38	5.43	64.00	1.31	2017.3	6.49

*** CONTINUED NEXT PAGE ***

TABLE.NO: 5.21 (CONTINUED)

S.NO.	RESULTS OF ST.ELOI SYSTEM: ZINC/NADBS/NACL					RESULTS OF SIY.R.D SYSTEM: ZINC/NADBS				
	PH	G	VF	S	(VF÷S)RATIO x(1E^{+}4)	PH	G	VF	S	(VF÷S)RATIO x(1E^{+}4)
1	1.60	106.76	0.84	2576.0	3.25	2.04	97.60	2.79	2398.0	11.63
2	1.86	75.83	0.80	1992.4	4.04	2.49	97.60	3.35	2384.7	14.04
3	2.00	121.95	0.94	2739.3	3.43	2.59	97.60	3.63	2366.1	15.35
4	2.38	106.76	1.07	2573.4	4.18	2.76	97.60	3.57	2368.7	15.06
5	2.54	75.83	0.77	1989.7	3.86	2.86	97.60	3.34	2363.2	14.15
6	2.46	75.83	0.96	2024.1	4.76	2.90	97.60	3.36	2372.8	14.14
7	3.10	106.76	0.85	2575.4	3.29	3.22	97.60	3.53	2369.5	14.92
8	3.48	75.83	1.03	2000.6	5.14	3.42	97.60	2.24	2301.8	9.75
9	3.85	75.83	0.87	1986.4	4.39	3.79	97.60	2.31	2352.5	9.83
10	4.05	106.76	0.88	2581.2	3.39	4.12	97.60	2.75	2359.3	11.67
11	5.00	106.76	0.85	2611.8	3.25	4.50	97.60	2.20	2325.9	9.48
12	5.15	75.83	1.02	1986.9	5.14	5.18	97.60	2.74	2401.1	11.42
13	6.12	75.83	1.14	2013.5	5.64	5.78	97.60	2.11	2341.1	9.00
14	6.13	106.76	0.86	2596.6	3.30	5.84	97.60	2.18	2430.0	8.99
15	7.05	106.76	0.91	2585.7	3.54	6.57	97.60	2.29	2308.0	9.93
16	7.49	106.76	0.86	2733.3	3.14	7.02	97.60	2.81	2400.2	11.72

TABLE.NO:5.22

TO COMPUTE CONCENTRATIONS OF SAMPLES BY CURVE-FITTING [FOR ATOMIC ABSORPTION SPECTROPHOTOMETER]

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THE CALIBRATED TRANSMITTANCE:
  7.100    11.650    15.990    23.280    50.050
THE CALIBRATED CONCENTRATIONS(PPM):
  6.000     5.000     4.000     3.000     1.000

THE LINEAR REGRESSION LINE IS:
  Y =    0.131 +    0.166 xX
 S   =   0.0158;  R =   0.9985

S.NO.  TRANSMITTANCE   ABSORBANCE   CONCENTRATION OF
                                     SAMPLES(PPM)

  1         28.17          0.55          10.09
  2         23.02          0.64          12.20
  3         28.47          0.55           9.98
  4         23.49          0.63          11.99
  5         28.41          0.55          10.00
  6         22.78          0.64          12.31
  7         28.77          0.54           9.87
  8         23.81          0.62          11.85
  9         22.72          0.64          12.34
 10         21.23          0.67          13.05
 11         20.88          0.68          13.22
 12         21.35          0.67          12.99
 13         15.93          0.80          16.05
 14         14.26          0.85          17.21
 15         14.08          0.85          17.34
 16         16.01          0.80          16.00
 17         16.01          0.80          16.00
 18         14.48          0.84          17.05
 19         14.25          0.85          17.22
 20         15.84          0.80          16.11
 21         10.91          0.96          20.01
 22         10.90          0.96          20.02
 23         10.90          0.96          20.02
 24         10.91          0.96          20.01
```

TABLE.NO: 5.23

TO COMPUTE CONCENTRATIONS OF SAMPLES BY CURVE-FITTING [FOR ATOMIC ABSORPTION SPECTROPHOTOMETER]

```
THE CALIBRATED TRANSMITTANCE:
  7.100    11.650    15.990    23.280    50.050
THE CALIBRATED CONCENTRATIONS(PPM):
  6.000     5.000     4.000     3.000     1.000

THE LINEAR REGRESSION LINE IS:
  Y =    0.131 +    0.166 ×X
 S   =   0.0158;   R =   0.9985

S.NO.  TRANSMITTANCE   ABSORBANCE   CONCENTRATION OF
                                     SAMPLES(PPM)
                                        X[I]×0.1

  1        52.91          0.28          3.499
  2        52.36          0.28          3.608
  3        52.35          0.28          3.611
  4        51.42          0.29          3.798
  5        47.61          0.32          4.602
  6        45.84          0.34          4.998
  7        44.96          0.35          5.202
  8        45.02          0.35          5.188
  9        40.07          0.40          6.405
 10        39.71          0.40          6.500
 11        39.32          0.41          6.604
 12        37.90          0.42          6.989
 13        22.37          0.65         12.502
 14        21.76          0.66         12.788
 15        21.52          0.67         12.905
 16        16.37          0.79         15.764
 17        16.01          0.80         16.001
 18        15.10          0.82         16.612
 19         5.09          1.29         27.985
 20         4.77          1.32         28.659
```

TABLE.NO:5.24

TO COMPUTE CONCENTRATIONS OF SAMPLES BY CURVE-FITTING [FOR ATOMIC ABSORPTION SPECTROPHOTOMETER]

```
THE CALIBRATED TRANSMITTANCE:
  7.200    11.850    16.000    23.550    50.050
THE CALIBRATED CONCENTRATIONS(PPM):
  6.000     5.000     4.000     3.000     1.000

THE LINEAR REGRESSION LINE IS:
  Y =    0.132 +    0.165 xX
 S  =   0.0167;   R =   0.9983

S.NO.   TRANSMITTANCE    ABSORBANCE    CONCENTRATION OF
                                         SAMPLES(PPM)

  1          9.82           1.01           21.250
  2          9.96           1.00           21.100
  3          9.97           1.00           21.080
  4         10.79           0.97           20.250
  5         11.04           0.96           20.010
  6         11.41           0.94           19.660
  7         11.37           0.94           19.700
  8         12.29           0.91           18.880
  9         12.80           0.89           18.450
 10         13.24           0.88           18.100
 11         15.05           0.82           16.750
 12         15.63           0.81           16.350
 13         11.07           0.96           19.984
 14         11.05           0.96           20.004
 15         11.06           0.96           19.993
 16         10.99           0.96           20.056
 17         11.17           0.95           19.884
 18         11.15           0.95           19.906
 19         10.91           0.96           20.133
 20         10.97           0.96           20.078
 21         11.04           0.96           20.014
```

TABLE.NO: 5.25

TO COMPUTE CONCENTRATIONS OF SAMPLES BY CURVE-FITTING [FOR ATOMIC ABSORPTION SPECTROPHOTOMETER]

```
THE CALIBRATED TRANSMITTANCE:
  7.300    11.950    16.200    23.600    50.100
THE CALIBRATED CONCENTRATIONS(PPM):
  6.000     5.000     4.000     3.000     1.000

THE LINEAR REGRESSION LINE IS:
  Y =    0.133 +    0.164 *X
 S   =   0.0163;   R =   0.9983

S.NO.  TRANSMITTANCE    ABSORBANCE    CONCENTRATION OF
                                        SAMPLES(PPM)

  1        13.77          0.86           17.783
  2        12.76          0.89           18.591
  3        11.53          0.94           19.660
  4        11.15          0.95           20.020
  5        11.17          0.95           20.000
  6        12.03          0.92           19.211
  7        12.81          0.89           18.544
  8        14.29          0.84           17.384
  9        13.84          0.86           17.729
 10        12.86          0.89           18.505
 11        11.92          0.92           19.310
 12        11.34          0.95           19.841
 13        11.39          0.94           19.789
 14        12.13          0.92           19.128
 15        12.82          0.89           18.542
 16        14.42          0.84           17.288
 17        13.70          0.86           17.837
 18        13.40          0.87           18.068
 19        11.86          0.93           19.368
 20        11.41          0.94           19.775
 21        11.19          0.95           19.983
 22        11.83          0.93           19.394
 23        13.49          0.87           17.999
 24        14.48          0.84           17.245
 25        13.31          0.88           18.143
 26        13.12          0.88           18.297
 27        11.86          0.93           19.361
 28        11.05          0.96           20.118
 29        10.97          0.96           20.196
 30        11.74          0.93           19.474
 31        13.21          0.88           18.224
 32        13.96          0.86           17.635
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                         TABLE.NO: 5.26

      TO COMPUTE CONCENTRATIONS OF SAMPLES BY CURVE-FITTING
          [FOR ATOMIC ABSORPTION SPECTROPHOTOMETER]

THE CALIBRATED TRANSMITTANCE:
  7.800    12.330    16.900    24.500    52.000
THE CALIBRATED CONCENTRATIONS(PPM):
  6.000     5.000     4.000     3.000     1.000

THE LINEAR REGRESSION LINE IS:
  Y =    0.121 +    0.162 *X
 S   =   0.0121;   R =   0.9991

S.NO.  TRANSMITTANCE    ABSORBANCE   CONCENTRATION OF
                                       SAMPLES(PPM)

  1        14.65           0.83           17.604
  2        13.29           0.88           18.650
  3        12.16           0.92           19.600
  4        11.66           0.93           20.050
  5        11.67           0.93           20.040
  6        12.51           0.90           19.293
  7        13.52           0.87           18.461
  8        15.23           0.82           17.190
  9        14.41           0.84           17.783
 10        13.57           0.87           18.427
 11        12.10           0.92           19.650
 12        11.66           0.93           20.050
 13        11.66           0.93           20.050
 14        12.49           0.90           19.315
 15        13.30           0.88           18.639
 16        15.14           0.82           17.250
 17        14.52           0.84           17.700
 18        13.51           0.87           18.474
 19        12.07           0.92           19.680
 20        11.66           0.93           20.050
 21        11.62           0.93           20.090
 22        12.74           0.89           19.100
 23        13.35           0.87           18.599
 24        15.43           0.81           17.048
```

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                 TABLE.NO: 5.27

     TO COMPUTE CONCENTRATIONS OF SAMPLES BY CURVE-FITTING
           [FOR ATOMIC ABSORPTION SPECTROPHOTOMETER]

THE CALIBRATED TRANSMITTANCE:
  7.900    12.410    17.000    25.100    52.890
THE CALIBRATED CONCENTRATIONS(PPM):
  6.000     5.000     4.000     3.000     1.000

THE LINEAR REGRESSION LINE IS:
  Y =    0.112 +    0.163 xX
 S   =  0.0111;  R =   0.9992

S.NO.  TRANSMITTANCE   ABSORBANCE   CONCENTRATION OF
                                     SAMPLES(PPM)

  1         47.09          0.33            5.285
  2         41.26          0.38            6.694
  3         33.96          0.47            8.770
  4         21.94          0.66           13.424
  5         14.79          0.83           17.630
  6         11.71          0.93           20.115
  7          9.77          1.01           22.055
  8          7.68          1.11           24.616
  9          5.05          1.30           29.093
 10          3.29          1.48           33.665
 11         59.10          0.23            2.863
 12         51.10          0.29            4.414
 13         40.53          0.39            6.883
 14         22.95          0.64           12.945
 15         15.61          0.81           17.054
 16         11.80          0.93           20.040
 17          9.54          1.02           22.307
 18          7.39          1.13           25.030
 19          4.59          1.34           30.110
 20          2.96          1.53           34.780
```

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                        TABLE.NO: 5.28

          TO COMPUTE CONCENTRATIONS OF SAMPLES BY CURVE-FITTING
              [FOR ATOMIC ABSORPTION SPECTROPHOTOMETER]

THE CALIBRATED TRANSMITTANCE:
  7.000    11.500    15.950    23.250    50.000
THE CALIBRATED CONCENTRATIONS(PPM):
  6.000     5.000     4.000     3.000     1.000

THE LINEAR REGRESSION LINE IS:
  Y =    0.129 +    0.167 xX
 S   =  0.0155;  R =  0.9986

S.NO.  TRANSMITTANCE    ABSORBANCE    CONCENTRATION OF
                                        SAMPLES(PPM)

  1         49.55           0.30            4.202
  2         48.41           0.32            4.444
  3         49.31           0.31            4.253
  4         50.37           0.30            4.033
  5         51.27           0.29            3.848
  6         57.28           0.24            2.699
  7         39.98           0.40            6.429
  8         38.51           0.41            6.820
  9         39.78           0.40            6.482
 10         40.10           0.40            6.398
 11         40.69           0.39            6.247
 12         45.64           0.34            5.055
 13          3.09           1.51           33.000
 14          2.84           1.55           33.880
 15          2.80           1.55           34.021
 16          2.83           1.55           33.891
 17          3.16           1.50           32.759
 18          3.55           1.45           31.567
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                    TABLE.NO: 5.29

      TO COMPUTE CONCENTRATIONS OF SAMPLES BY CURVE-FITTING
          [FOR ATOMIC ABSORPTION SPECTROPHOTOMETER]


THE CALIBRATED TRANSMITTANCE:
  7.000    11.500    15.950    23.250    50.000
THE CALIBRATED CONCENTRATIONS(PPM):
  6.000     5.000     4.000     3.000     1.000

THE LINEAR REGRESSION LINE IS:
  Y =    0.129 +    0.167 xX
 S   =   0.0155;   R =   0.9986

S.NO.  TRANSMITTANCE   ABSORBANCE   CONCENTRATION OF
                                      SAMPLES(PPM)
                                          X[I]x0.1

  1         24.28          0.61          11.605
  2         24.70          0.61          11.427
  3         24.81          0.61          11.382
  4         24.82          0.61          11.377
  5         24.81          0.61          11.381
  6         24.83          0.61          11.373
```