DESIGN OF A GAS HOLDUP SENSOR FOR FLOTATION DIAGNOSIS

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MONTREAL, CANADA

AUGUST, 1998

A THESIS SUBMITTED TO THE FACULTY OF

GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE OF

MASTER OF ENGINEERING

0-612-50599-5

This thesis is dedicated to my wife Karen

And my son Javier who is learning to live

ABSTRACT

The mineral processing group of McGill University developed a novel gas holdup probe that consists of two conductivity flow cells: an open cell used to estimate dispersion (slurry + air) conductivity and a syphon cell used to estimate slurry conductivity. These two values are entered into Maxwell's model to calculate gas holdup.

In this work some design criteria for conductivity flow cells and the syphon cell are given. Effect of geometrical cell constant and electrode width on cell behaviour are analyzed. New dimensions for open and syphon cells are proposed. Conditions to prevent bubbles from being entrained into the syphon cell are established.

The new design of the gas holdup probe was tested successfully over a prolonged period at the INCO Matte Separation Plant (Copper Cliff, Ontario). Tests carried out in waste paper de-inking at BOWATER (Gatineau, Quebec) showed the gas holdup values given by the probe agreed with the values obtained from pressure. The noise associated with the gas holdup signal obtained by the probe could be used to diagnose sparger operation.

Gas holdup showed some degree of correlation with flotation efficiency of waste paper de-inking and flotation rate constant. Chemistry and rheology of the feed are other factors to be considered. Estimation of bubble surface area flux should consider rheology properties (liquid viscosity and density).

RÉSUMÉ

Le groupe de procédés des minerais de l'université McGill a développé une nouvelle sonde de fraction gazeuse qui consiste en deux cellules de conductibilité du débit: une cellule ouverte, utilisée dans l'estimation de la conductibilité de la dispersion (pulpe + air), et une cellule siphon, utilisée dans l'estimation de la conductibilité de la pulpe. Ces deux valeurs entrent dans le modèle de Maxwell utilisé, afin de calculer la fraction gazeuse.

Dans ce travail, quelques critères de design pour des cellules de conductibilité du débit, et la cellule siphon, sont donnés. Les effets de la constante géométrique de la cellule et de la largeur de l'électrode sur le comportement de la cellule sont analysés. De nouvelles dimensions pour des cellules ouverte et siphon sont proposées. Des conditions de prévention d'entraînement des bulles dans la cellule siphon sont établies.

Le nouveau design de la sonde de fraction gazeuse a été testé avec succès, sur une période prolongée, à l'usine INCO Matte Separation Plant (Copper Cliff, Ontario). Les tests effectués dans le désencrage de papier recyclé à BOWATER (Gatineau, Québec) ont démontré que les valeurs de fraction gazeuse obtenues par la sonde étaient en accord avec les valeurs obtenues des mesures de pression. L'interférence associée au signal de fraction gazeuse obtenu par la sonde pourrait être utilisée dans le diagnostic d'opération du barboteur.

La fraction gazeuse a démontré un certain degré de corrélation avec le rendement de flottation du désencrage du papier recyclé et la constante du

taux de flottation. La chimie et la rhéologie de l'alimentation sont d'autres facteurs à considérar. L'estimation du flux de surface des bulles devrait tenir compte des propriétés rhéologiques (viscosité et densité du liquide).

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Professor J.A. Finch and Dr. C.O. Gómez for their invaluable contributions and support of my work, especially, for the opportunity of participating in the McGill mineral processing group.

Also, I want to thank all members of the sensor/column flotation group at McGill University, and specially Mr. H. Hernández, Dr. R. Escudero, Dr. F. Tavera, Mr. G. Leichtle and Mr. C. Hardie for a most pleasant working atmosphere.

I want to express my gratitude to Mr. R. Agnew and Mr. C. Pollard for their constant support during the plant tests and all the staff and crew of the Matte Separation Plant, INCO ltd.

Finally, I want to thank the staff and crew at the waste paper de-inking plant, BOWATER Pulp and Paper Inc.

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NOMENCLATURE

A, B, C	parameters in equation 4.1
A_o, B_o, C_o	parameters in equation 4.2
A_s, B_s, C_s	parameters in equation 4.3
A_c	cross-sectional area of column, cm2
A_A	cross-sectional area in point A (Equation 2.11)
A_B	cross-sectional area in point B (Equation 2.11)
A_{cell}	cross-sectional area of conductivity cell
A_s	sparger surface area
A_w	electrode exposed area
c_f	final ink concentration, ppm
c_i	initial ink concentration
C	geometrical cell constant, cm
C_0	parameter in Equation 3.10
C_1	parameter in Equation 3.10
D	internal diameter of conductivity cell, cm
D_s	syphon cell internal diameter
D_o	open cell internal diameter
d_b	bubble diameter
d_c	column diameter
$d_{orifice}$	orifice diameter at syphon cell bottom
e_f	friction coefficient
E_f	friction losses, cm^2/s^2
f	fraction volumetric of dispersed phase
F.E.	de-inking flotation efficiency

g	gravitational acceleration, cm/s^2
h	length of vessel, cm
H	height difference, cm (Figure 3.5)
H_c	collection zone height
H_f	froth zone height
I	current, A
i	current density, A/cm^2
J	superficial velocity, cm/s
J_F	superficial feed velocity
J_g	superficial gas velocity
J_l	superficial liquid velocity
J_T	superficial tailings velocity
R_s	A_c/A_s
K	conductance, mS
k_c	collection zone rate constant, 1/min
L	gap between electrodes, cm
L_o	open cell gap
L_s	syphon cell gap
L_T	total syphon cell length, cm
M	parameter in Equation 2.24
P_A	pressure in point A, g cms^{-2}
P_B	pressure in point B
P_{A^*}	pressure in point A^*
P_{B^*}	pressure in point B^*
Q	heat, cm^2/s^2 (Equation 2.10)
Q	Volumetric flow rate, cm^3/s

R	Resistance, Ω
Re_b	Reynolds number of a single bubble (Equation 2.29)
Re_{bs}	Reynolds number of a bubble in a swarm (Equation 2.26)
R_c	collection zone recovery
R_f	froth zone recovery
R_{fc}	overall recovery
S_b	bubble surface area flux, 1/s
U_{sb}	slip velocity between gas and slurry, cm/s
U_t	bubble terminal velocity
V_A	liquid velocity in point A, cm/s (Equation 2.10)
V_B	liquid velocity in point B (Equation 2.10)
w	fluid work, cm^2/s^2
W	electrode width, cm
W_o	open cell electrode width
W_s	syphon cell electrode width
Z_A	position in point A, cm
Z_B	position in point B

GREEK LETTERS

α	bubble surface area moving through a vessel, cm^2/s
β	parameter in equation 2.6
β_A	parameter in equation 2.10
β_B	parameter in equation 2.10
γ	apparent relative conductivity
ε_g	gas holdup

κ	conductivity, mS/cm
κ_d	dispersion conductivity
κ_m	apparent conductivity (Equation 2.6)
κ_l	liquid conductivity (Equation 2.6)
κ_{sl}	slurry conductivity
κ_1	conductivity of continuous phase (Equation 2.7)
κ_2	conductivity of dispersed phase (equation 2.7)
ρ_b	bubble density, g/cm^3
ρ_{sl}	slurry density
τ	residence time
τ_α	time taken α passing through a length h, s
τ_α^o	time taken α passing through a length d_b
ν	potential, volt
ν_A	potential in electrode A, volt
ν_B	potential in electrode B
μ_{sl}	slurry viscosity, g/cm s

CHAPTER 1: INTRODUCTION

1.1 Understanding the Problem

For many years a relationship between the performance of the flotation process and some process variables has been sought. One of the latest attempts suggests that the bubble superficial surface flux (or bubble surface area rate) has a linear relationship with the flotation rate constant [1]. The bubble superficial surface flux, S_b is defined by the gas superficial velocity and bubble diameter. The bubble superficial surface rate is difficult to calculate because of the difficulty in obtaining a good estimation of the bubble diameter in a 3-phase system. The gas holdup, an easier variable to estimate, could be related to S_b.

When gas is introduced in the column, liquid (or slurry) is displaced. The volumetric fraction displaced is called the gas holdup, ε_g. The role of gas holdup in the flotation process has long been discussed but no relationship has been found yet because of the lack of reliable industrial data. In theory, gas holdup is defined by bubble size, liquid flow rate, solids content and mixing patterns [2-3]. Gas holdup defines flotation kinetics and carrying capacities, which are associated with the performance of a flotation device, Figure 1.1.

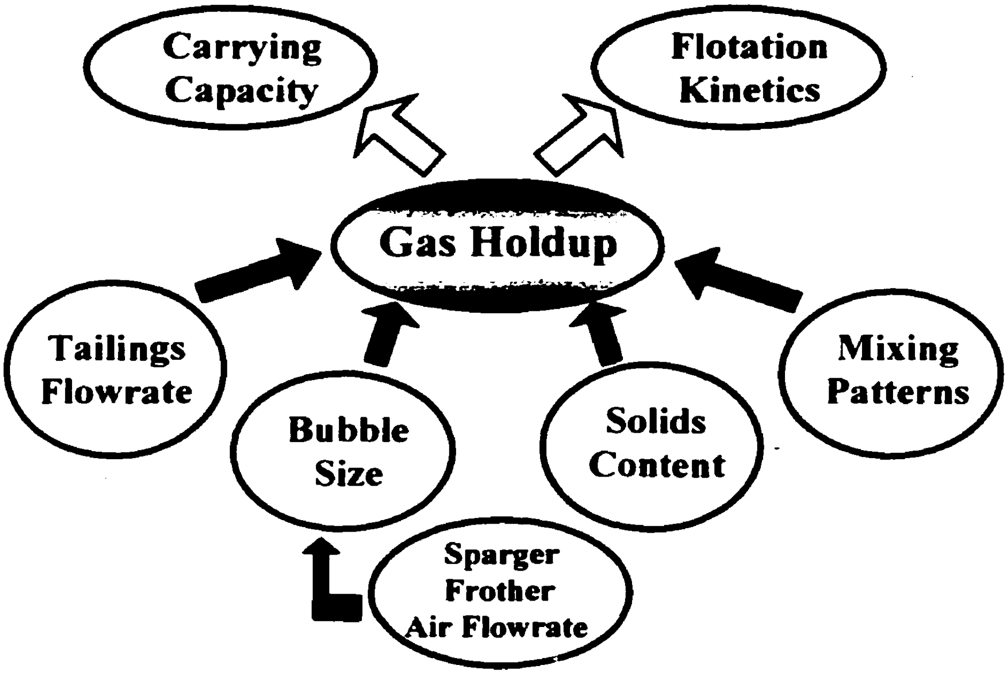
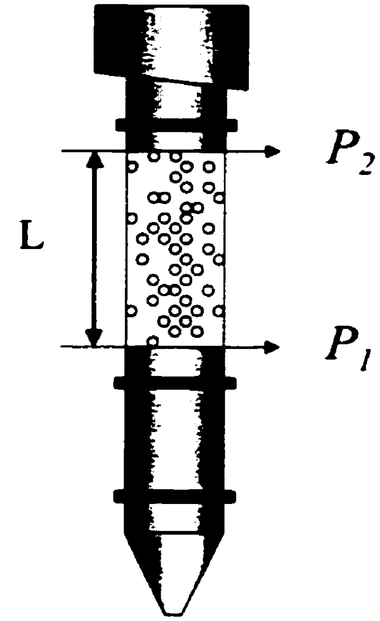


Figure 1.1. Gas holdup in flotation

These facts have generated the following questions:

- How can we obtain a good measurement of gas holdup?
- Is gas holdup related to flotation performance?
- Is there an optimum gas holdup?

The first question is raised because we do not have a reliable gas holdup sensor for industrial applications. The common method to measure gas holdup is based on pressure and estimations of the slurry density. A description of this method is presented in Figure 1.2. The main disadvantage is the difficulty of obtaining the slurry density.



$$\Delta P = \rho_{sl} g L (1 - \varepsilon_g)$$

$$\varepsilon_g = 1 - \frac{\Delta P}{\rho_{sl} g L}$$

Figure 1.2. Gas holdup estimation using pressure values [2].

In an effort to solve the lack of a reliable sensor, the mineral processing group at McGill University developed a sensor based on conductivity to estimate gas holdup, using Maxwell's model [4-5].

Electrical conductivity is an intensive property, which is a function of the concentration of the different phases present in a dispersion. According to Maxwell's model, if we have a dispersion (slurry plus air), we can determine the volume concentration of the non-conducting phase (in this case air), if we know the dispersion conductivity and slurry conductivity. In Figure 1.3 we can see a conceptual description of Maxwell's model.

To fulfill the requirements of Maxwell's model, the gas holdup probe applies the principle of separation of phases. The probe consists of two flow cells: an open cell and a syphon cell. A flow cell is defined as one that allows a fluid or dispersion to flow through freely while the electrical conductivity is measured [4].

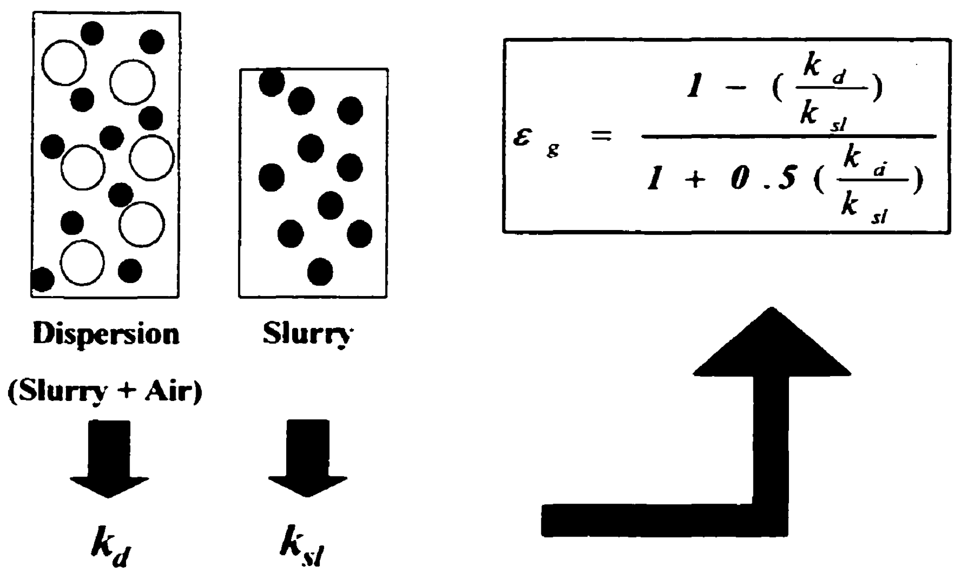


Figure 1.3. Gas holdup estimation using Maxwell's model.

The open cell measures the slurry-air dispersion conductivity by allowing a relatively free flow of the dispersion through the cell. The syphon cell measures the conductivity of the slurry only, which requires the exclusion of bubbles. This is achieved by having the upper end open and the lower end constricted. With this design, air bubbles are prevented from entering the cell, which causes the density of the cell contents to exceed that outside, thus inducing a syphon effect. This means that fresh slurry is drawn in at the top, replenishing the cell contents and, on its exit through the constriction (orifice), further ensures the exclusion of bubbles [5]. Figure 1.4 shows a schematic representation of the gas holdup probe (open and syphon cell).

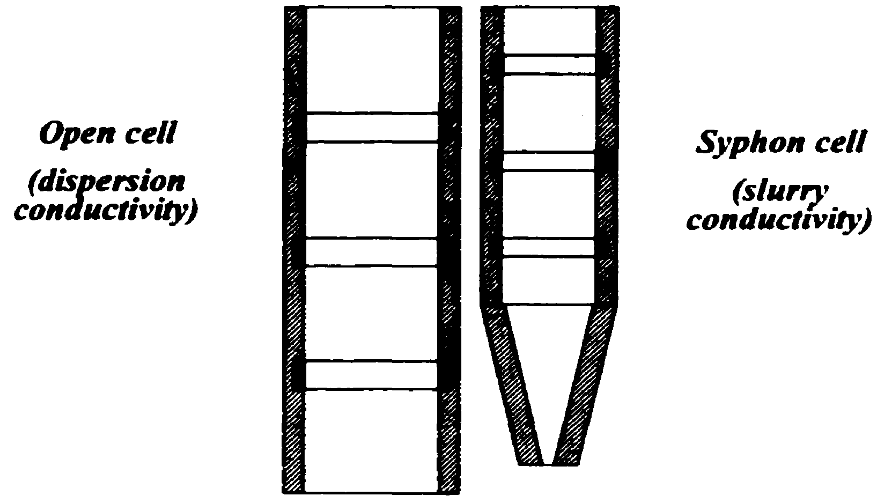


Figure 1.4. Schematic representation of gas holdup probe.

1.2 Objectives and Organization of the Thesis

1.2.1 Objectives

The main objectives of this project can be summarized as follows:

- Re-design of sensor to avoid plugging (syphon cell).
- Establish some design criteria for the sensor.
- Conduct long term testing of the gas holdup sensor at industrial level.
- Study the relationship between gas holdup and flotation performance.

1.2.2. Organization

The thesis is organized into 7 chapters. Chapter 2 examines the background to conductivity measurements and conductivity cell design, requirements of sensor design and the relationship of flotation to some flotation variables.

Chapter 3 describes the design criteria for conductivity cells and critical sensor parameters. An example of a complete design is given.

Chapter 4 examines the experimental setup for two industrial applications: mineral flotation (Copper Cliff, INCO) and de-inking (Gatineau, BOWATER). Chapters 5 and 6 give the results obtained at these two sites.

Finally, Chapter 7 is devoted to discussion and conclusions with suggestions for further work.

CHAPTER 2: BACKGROUND

This chapter defines conductivity and describes Maxwell's model, which relates the volumetric concentration of air (gas holdup) in a dispersion to the conductivity values of the dispersion and the slurry (dispersion without air). Conductivity flow cells are described. The principles of the components of the gas holdup sensor are described: the open cell, used to measure the dispersion conductivity, and the syphon cell, used to measure slurry conductivity. The effects of operating and design variables on gas holdup are also presented. Finally, the role of gas holdup in flotation performance is discussed.

2.1. Definition of Conductivity

Electrical conductivity, also called specific conductance [6-8], specific conductivity [9-10], or conductivity [11-17], is the ability of a substance to conduct electric current. In this thesis, the term conductivity and the symbol κ will be used.

The conductivity is the proportionality constant in Ohm's law [18]:

$$i = -\kappa \Delta v \qquad 2.1$$

where i is the current density (A/cm^2), Δv is the potential gradient (volt/cm), and κ is the conductivity (Ω^{-1}/cm). In fact, the conductivity is the reciprocal of the resistivity (Ωcm) and the conductance is the reciprocal of the resistance (Ω). The SI unit name for the conductance is the Siemens (S): 1 S $\equiv$ 1 Ω^{-1}. Thus the SI units of conductivity are S/m. For convenience, the cgs unit S/cm (or mS/cm) will be used in this thesis.

The conductivity is an intensive property that may be thought of as the conductance of a cube of 1 cm edge, assuming the current is perpendicular to opposite faces of the cube [13, 18].

2.2. Measuring Conductivity

All substances conduct electricity to some degree. Some materials are good conductors (such as metals) and others are poor conductors (insulators). In this work, we will discuss the conduction of electric energy in an aqueous electrolyte solution.

The resistance of an electrolyte solution cannot be measured using direct current, because it changes the concentration of the electrolyte. The accumulation of electrolysis products at the electrodes also alters the resistance of the solution. Instead of direct current, an alternating current is used to overcome these effects [18].

In a conductivity cell with facing plate electrodes, it is assumed that the current flux is at right angles to, and constrained by, the area of the plates; under this assumption, the resistance of the electrolyte is given by:

$$R = \frac{drop \quad of \quad potential}{current} = \frac{(v_A - v_B)}{I} \qquad 2.2$$

where v_A and v_B are the potentials on the plates electrodes A and B, respectively, and I is the current in the electric circuit. In the case of a linear conductor, the current density, i, on any equipotential surface is constant. Therefore,

$$I = \int_{A_{cell}} i dA_{cell} = iA_{cell} \qquad 2.3$$

$$v_A - v_B = -(v_B - v_A) = -\int_a^b \Delta v dL = -\Delta v(b - a) = -\Delta v L \qquad 2.4$$

where A_{cell} is the cross sectional area of the cell, L is the length of the cell, and a and b are the positions of the electrodes A and B, respectively. Substituting Equations 2.1, 2.3 and 2.4 into equation 2.2, yields:

$$K = \frac{1}{R} = \frac{I}{v_A - v_B} = \frac{-i}{\Delta v}\left(\frac{A_{cell}}{L}\right) = \kappa \frac{A_{cell}}{L} \qquad 2.5$$

where K is the conductance of the electrolyte. In Equation 2.5 the term A_{cell}/L is referred to as the cell constant, expressed in cm.

2.3. Maxwell's Model

The conductivity method is a technique to measure the gas holdup in a gas-liquid system. Generally, the conductivity of a gas–liquid dispersion (a continuous liquid phase with a dispersed gas phase) depends on the conductivities of the two phases and their relative amounts. However, the relationship between the conductivity of the dispersion and the concentration of the dispersed phase is not linear [19].

Maxwell considered a large sphere (continuous phase) containing many small spheres (dispersed phase) of different conductivity. Assuming the distance between small spheres is large enough so that their effect in disturbing the path of the current may be taken as negligible, the apparent conductivity of this large sphere is given by [19-20]:

$$\kappa_m = \kappa_1 \frac{1 + 2\beta f}{1 - \beta f} \qquad 2.6$$

where κ_1 is the conductivity of the continuous phase, f is the volumetric fraction of the dispersed phase of conductivity κ_2, and β is given by:

$$\beta = \frac{\kappa_2 - \kappa_1}{\kappa_2 + 2\kappa_1} \qquad 2.7$$

Recent research has found that this model can be used to estimate the gas holdup in three-phase flotation systems [3-5]. Adapting Maxwell's model by treating the slurry (solid plus water) as the continuous phase, then,

$\kappa_m = \kappa_d$, apparent conductivity of the mixture (dispersion) for any ε_g;

$\kappa_1 = \kappa_{sl}$, conductivity of the slurry ($\varepsilon_g = 0$);

$\kappa_2 = 0$, conductivity of air;

$f = \varepsilon_g$, fractional gas holdup;

Thus, the gas holdup can be expressed in terms of apparent relative conductivity γ,

$$\varepsilon_g = \frac{1-\gamma_l}{1+0.5\gamma} \qquad 2.8$$

where

$$\gamma = \frac{\kappa_d}{\kappa_{sl}} \qquad 2.9$$

2.4. Conductivity Flow Cells

From experiments, it was shown that the design of a conductivity cell used to measure the conductivity of a dispersion is important [3-5, 21-23]. Uniform and parallel current lines between two opposite electrodes in the cell are essential. Once this condition is met, Equation 2.8 is satisfied.

A flow cell is defined as one that allows a fluid or dispersion to flow through freely while the electrical conductivity is measured. One of the most important features of a flow cell is the cell constant. The cell constant has been defined as the ratio of the effective surface area used to transfer electrical energy (normal to the flux of electric current) to the distance between two points where the electrical energy is transferred [4]. Figure 2.1 shows a schematic of a conductivity flow cell.

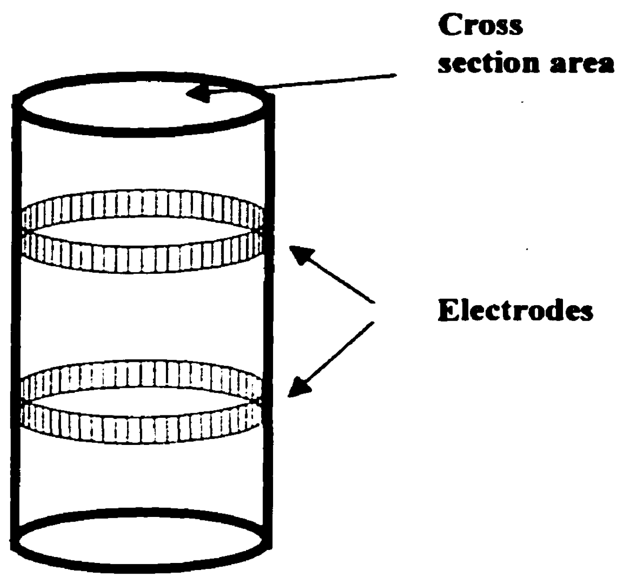


Figure 2.1. Schematic diagram of a conductivity flow cell.

Experimental data on open cells indicate that the electric field formed inside the cell extends beyond the edges of the electrodes [4]. This is because the isopotential planes formed between the electrodes are not parallel but concave to the cross section area of the cell. This extension of the electric field increases with increasing conductivity of the aqueous media, as reflected in a decrease of the cell constant.

The cell constant of a flow cell is determined by calibration against electrolyte solutions of known conductivity. The cell constant depends mainly on cell dimensions; the experimental observations suggest that the cell constant is independent of the type of electrolyte [4].

The effect of the addition of non conductive bodies in the flow cell has been verified experimentally. It is concluded that the cell constant is not affected by the presence of these bodies [4].

A three-ring arrangement was proposed to limit the electric field to the volume in between the top and bottom rings: by maintaining these two electrodes at the same potential and the central electrode at opposite polarity, a current path outside this volume is avoided [3-4].

2.5. Gas Holdup Probe: McGill Prototype

An industrial prototype was built at McGill University based on the direct measurement of the air-free dispersion conductivity. As described, the simultaneous measurement of the dispersion conductivity and the liquid conductivity can be accomplished by using a combination of two conductivity flow cells (open and syphon cells):

Open cell: a vertical cylinder open at both ends, with three internal ring electrodes flush mounted to the wall, and used to measure the conductivity of the dispersion (κ_d).

Syphon cell: a vertical cylinder with a conical bottom end, opened at the top and having a small opening (orifice) at the bottom. Again, three internal ring electrodes flush mounted to the wall were used. This cell was used to measure the liquid conductivity (κ_{sl}).

The prototype was built by combining these two cells in a single unit. Figure 2.2 shows a schematic of the gas holdup probe.

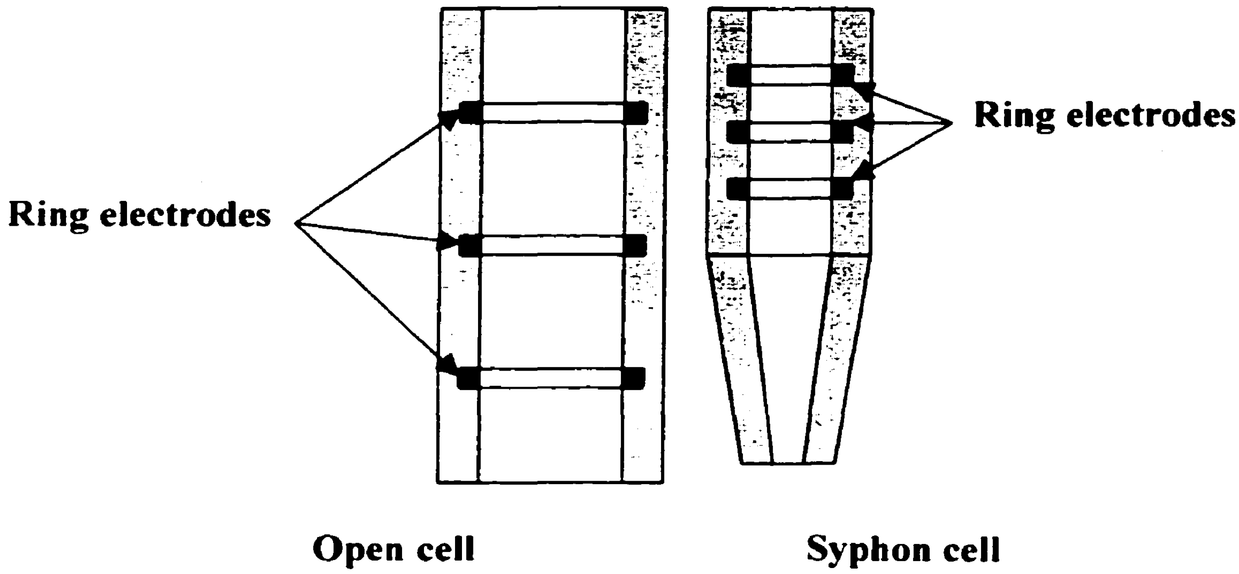


Figure 2.2. The combination of "open" and "syphon" conductivity cells to form the gas holdup sensor.

2.6. Principles of the Syphon cell

When a swarm of air bubbles passes through a column of water, the bubble-water dispersion presents a lower (dispersion) density relative to that of water with no air bubbles. This difference in density was exploited to develop a technique to separate the continuous phase (water, in two-phase systems; slurry in three–phase systems) of the dispersion and allow the measure of its conductivity [4].

Because the syphon cell has a small hole at the bottom, it does not allow the ascending air bubbles to enter the cell; therefore, the cell becomes filled with liquid (slurry) without air, creating a hydrostatic pressure difference between the orifice at the bottom of the cell and the surroundings which causes the liquid to flow out. This liquid flow increases until the pressure difference is equal to zero. At steady state, a continuous replenishment of fresh liquid takes place from the top of the cell creating, in the end, a syphon effect.

Successful operation requires that the liquid velocity at the top of the cell be lower than the terminal velocity of the rising bubbles outside the cell, otherwise air bubbles could be drawn into the cell.

Figure 2.3 shows a schematic representation of the syphon cell in an air-liquid (slurry) dispersion. The conservation of energy between points A and B is given by:

$$\left(\frac{P_B - P_A}{\rho_{sl}}\right) + \left(\frac{V_B^2}{2\beta_B} - \frac{V_A^2}{2\beta_A}\right) + g(Z_B - Z_A) - Q - w + E_f = 0 \qquad 2.10$$

where Q = 0; w = 0; β = 0.5 for laminar flow and β = 1 for turbulent. From the mass conservation law we have that:

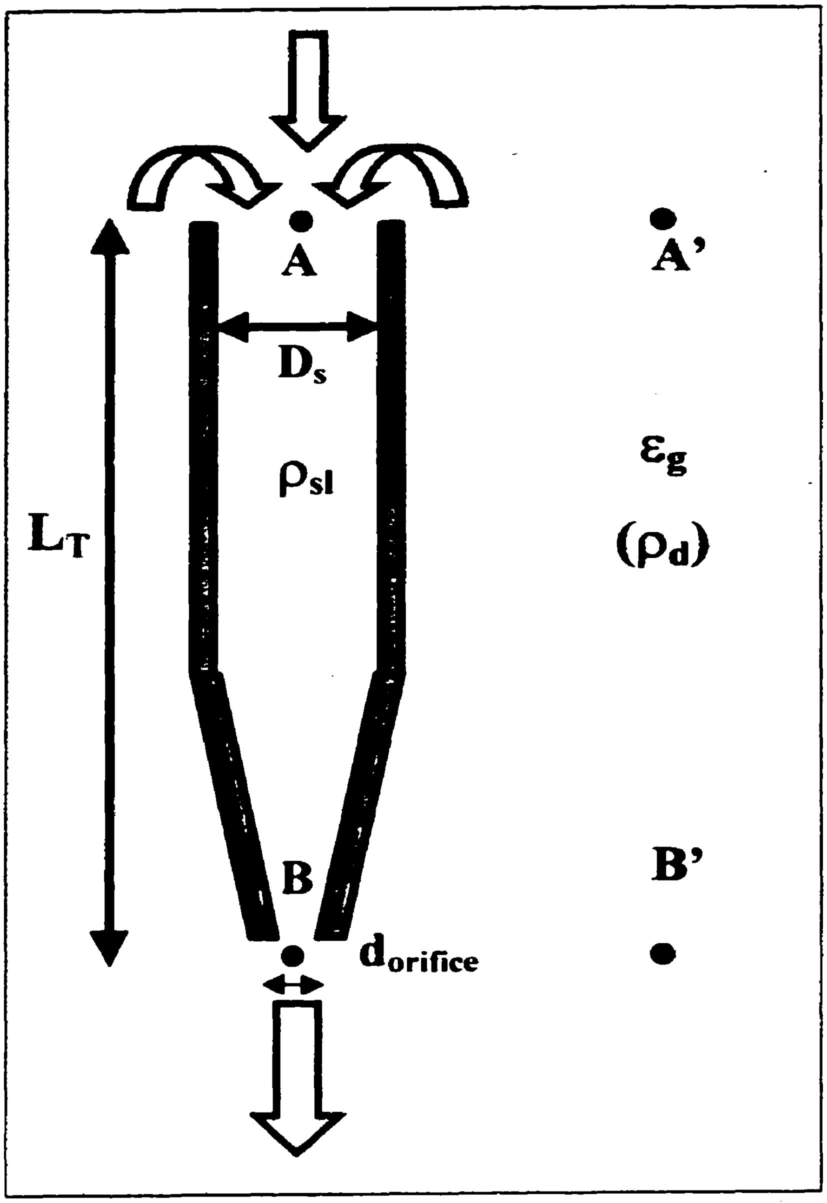


Figure 2.3. Schematic representation of the syphon cell in an air-liquid dispersion.

$$\rho_{sl} A_A V_A = \rho_{sl} A_B V_B \tag{2.11}$$

As the fluid at both points A and B is in contact with the dispersion, we have that:

$$P_B - P_A = P_{B'} - P_{A'} \tag{2.12}$$

and applying Bernoulli's principle between points A' and B',

$$P_{B'} - P_{A'} = g\rho_{sl}(1-\varepsilon_g)(Z_{A'} - Z_{B'}) \qquad 2.13$$

where $(Z_T\text{-}Z_B) = (Z_{T'}\text{-}Z_{B'}) = L_T$. Now substituting Equations 2.11, 2.12, and 2.13 in Equation 2.10:

$$\frac{V_A^2}{2}\left[\left(\frac{A_A}{A_B}\right)^2 \cdot \frac{1}{\beta_B} - \frac{1}{\beta_A}\right] + E_f = gL_T\varepsilon_g \qquad 2.14$$

The friction loss, E_f, can be defined as:

$$E_f = 2f(L_T / D_s)V_A^2 + \frac{1}{2}e_f V_B^2 \qquad 2.15$$

neglecting the term containing V_A;

$$\frac{V_A^2}{2}\left[\left(\frac{A_A}{A_B}\right)^2\left(\frac{1}{\beta_B} + e_f\right) - \frac{1}{\beta_A}\right] = gL_T\varepsilon_g \qquad 2.16$$

as $A_A = \pi D_s^2/4$ and $A_B = \pi d_{orifice}^2/4$, V_A is given by:

$$V_A = \sqrt{\frac{2gL_T\varepsilon_g}{\left[\left(\frac{D_s}{d_{orifice}}\right)^4\left(\frac{1}{\beta_B} + e_f\right) - \frac{1}{\beta_A}\right]}} \qquad 2.17$$

Equation 2.17 relates the velocity of the fluid at the top of the cell with the length of the syphon cell and the gas holdup of the system.

2.7. Description of Flotation Column

Column flotation consists of tall vertical reactors where gas bubbles are generated with spargers at the bottom and wash water is added at the top. The main advantages of columns include: improved separation performance, low capital and operational costs, low floor space requirements, and adaptability to automated control [24]. Many different types of column cell configuration exist. The conventional, or open flotation column, is illustrated in Figure 2.4.

In column flotation, rising gas bubbles interact with the descending slurry (or pulp) in the collection zone (H_c). Gas bubbles are normally generated with internal spargers, such as porous stainless steel pipes or variable gap jet spargers.

Wash water is added to stabilize the froth, by replacing the water that naturally drains from the froth. The remainder of the wash water flows through the froth and cleans the entrained particles. Therefore, the froth zone is also called the cleaning zone (H_f). The flow of water moving through the froth is called the bias water, a positive value corresponding to a net flow downwards. For efficient cleaning of entrained particles bias rate must be positive.

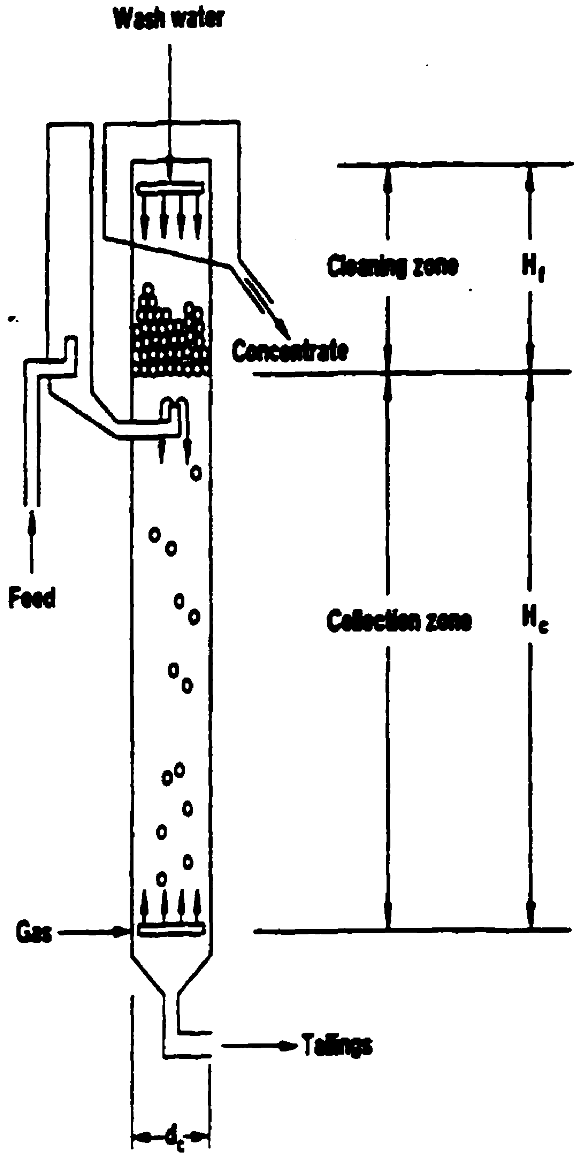


Figure 2.4. Schematic diagram of a conventional flotation column. From Finch and Dobby [2].

The overflow is rich in the floatable (hydrophobic) material, which often forms the concentrate in mineral systems. The unfloatable (hydrophilic) material is collected as underflow from the bottom of the column. De-inking is a reverse flotation process where the valuable (fibre) material (the accepts) forms the underflow, the overflow consisting of the waste (ink) material (the rejects).

The flow rates of the different streams in a column are normally expressed as superficial velocities (or rates). Superficial velocity is the volumetric flow rate of a particular steam divided by the column cross sectional area:

$$J_i = \frac{Q_i}{A_c} \tag{2.18}$$

where i can be gas (G), feed (F), wash water (W), bias (B), or tailings/accepts (T). Superficial velocities are useful for comparing columns of different diameters and are usually expressed in cm/s.

When the transport in the collection zone is described by the plug flow model with residence time τ, the overall recovery, when using the collection zone rate constant k_c (1/min), is given by [2]:

$$R_{fc} = \frac{(1-e^{-k_c\tau})R_f}{(1-e^{-k_c\tau})R_f + 1 - (1-e^{-k_c\tau})} \tag{2.19}$$

where R_f is the recovery in the froth zone. If we take R_c as the collection zone recovery, the overall flotation column recovery R_{fc} is [2]:

$$R_{fc} = \frac{R_c R_f}{R_c R_f + 1 - R_c} \tag{2.20}$$

For de-inking, flotation efficiency (F.E.) is used to define flotation performance. Flotation efficiency in this thesis is defined as:

$$F.E. = \frac{c_i - c_f}{c_i} \qquad 2.21$$

where c is the concentration of ink and the subscripts i and f are for initial and final, respectively. In order to estimate the flotation rate constant in Equation 2.19, flotation efficiency can be taken as recovery.

2.8. Effect of Operating and Design Variables on Gas Holdup

2.8.1 Operating variables

Superficial Gas Rate (J_g)

Volumetric gas flow varies with the static head. Unless noted otherwise, values of gas rate are referred to the column overflow, i.e., at atmospheric pressure. Figure 2.5 shows the general relationship between ε_g and J_g. Gas holdup increases approximately linearly then deviates from linearity above a certain range of J_g. The linear section is characterized by a homogeneous distribution of bubbles of fairly uniform size, rising at a fairly uniform rate. This is called the bubbly flow regime. Above the transition J_g, gas holdup becomes unstable and the flow is characterized by large bubbles rising rapidly, displacing water and small bubbles downward. This is the churn-turbulent flow regime. The desirable column operation regime is the bubbly flow [2].

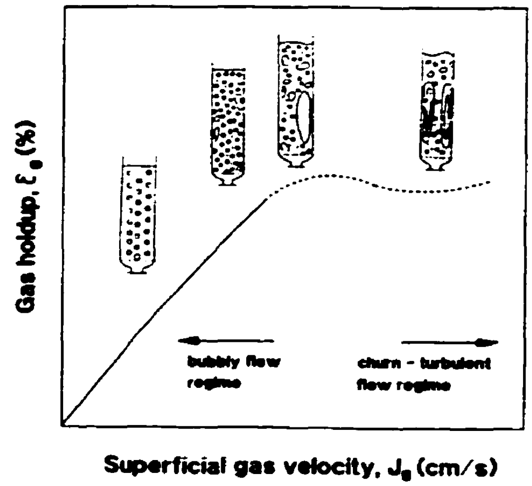


Figure 2.5. Gas holdup as a function of gas rate. general relationship. From Finch and Dobby [2].

Superficial Liquid Rate (J_L or J_T)

Figure 2.6 shows the result of increasing J_L countercurrently to the bubbles (the usual column operation). As J_L increases for a given J_g, ε_g increases. This is expected since the bubble rise velocity (relative to a stationary observer) decreases. Increasing J_L decreases the maximum J_g that can be tolerated for operation to remain in the desired bubbly flow regime.

Frother Concentration (Bubble Size)

The addition of frother up to a certain concentration has a pronounced impact on reducing bubble size. A reduced bubble size means reduced bubble rise velocity and consequently a gas holdup increase. The impact of frother concentration is shown in Figure 2.7.

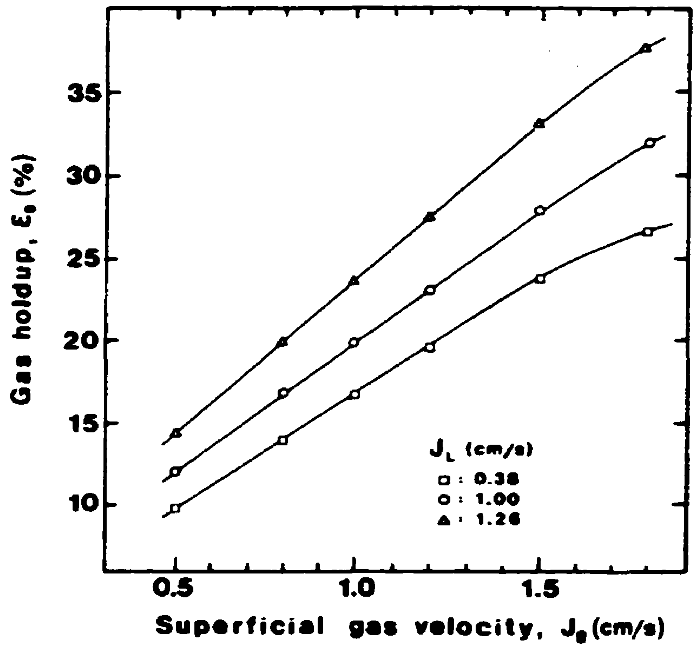


Figure 2.6. Gas holdup versus gas rate, effect of downward liquid velocity. From Finch and Dobby [2].

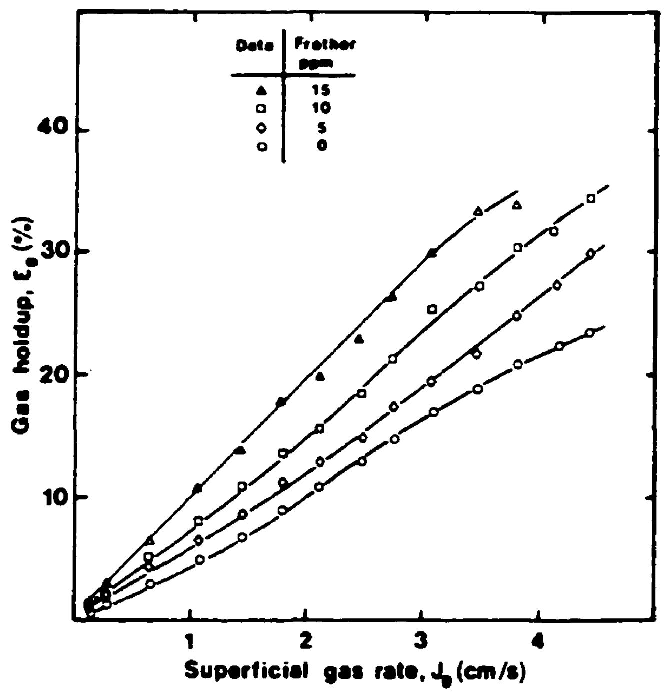


Figure 2.7. Gas holdup versus gas rate, effect of frother dosage. From Finch and Dobby [2].

Solids Concentration

The role of solids is difficult to describe. A general consideration is that solid particles may promote or retard coalescence depending upon their surface properties. Specific to flotation is that the solids distribute between the liquid phase (i.e., remain in suspension) and the gas phase (i.e., attach to the bubble).

Mineral solids in suspension generate a slurry density, ρ_{sl}, and a slurry viscosity, μ_{sl}, which have opposite effects on the bubble rise velocity. A higher slurry density increases the bubble rise velocity while decreasing ε_g. On the other hand, higher slurry viscosity decreases the bubble rise velocity and increases ε_g. Finally, solids attached to the bubble yield a bubble-particle aggregate density, ρ_b, greater than zero, causing the bubble rise velocity to decrease and, gas holdup to increase [2].

A general observation in flotation columns is that increasing the percent solids decreases gas holdup [25-26].

2.8.2. Design Variables

Sparger surface (internal spargers)

It is known that gas holdup decreases as the ratio R_s (= A_c/A_s) increases (see Figure 2.8), i.e., the bubble diameter increases as R_s increases. As R_s increases there is also a tendency to produce a less uniform bubble size, and,

ε_g versus J_g, starts to deviate from linearity. This is evidence of a transition from bubbly flow to churn-turbulent flow [27].

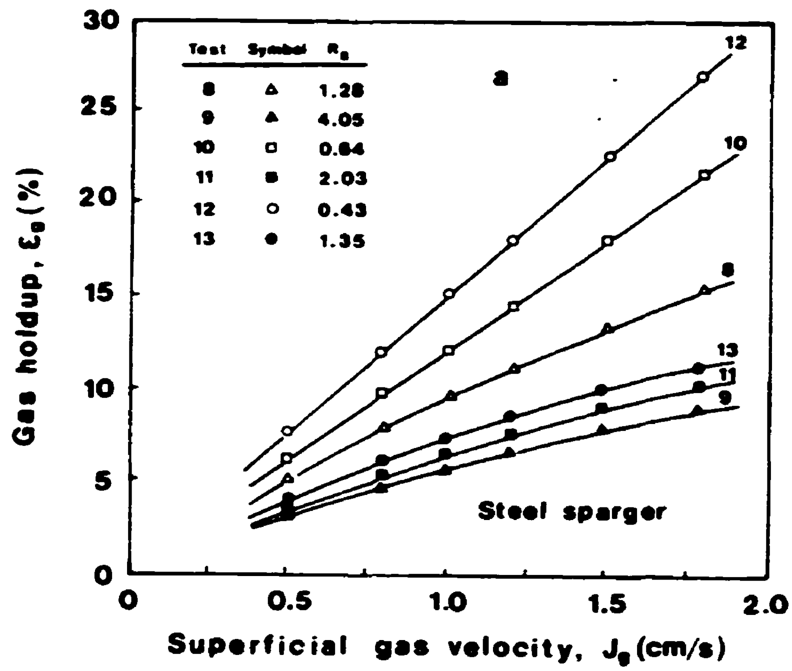


Figure 2.8. Gas holdup versus gas rate as a function of R_s. From Finch and Dobby [2].

2.9. Gas Holdup Role on Flotation Performance

The effect of gas holdup on flotation performance is not clear. Some work suggests that gas holdup could strongly be related to flotation performance and that this relationship could be used to control the flotation process. Figure 2.9 shows a relationship between concentrate solids flow rate and gas holdup, for individual columns with similar recoveries (>95%). This relationship was developed in an attempt to design a control strategy [28-29].

Little or no correlation between flotation rate constant and the gas holdup has been reported for mechanical cells. Recent results have however shown a strong relationship between bubble surface area flux and the flotation rate constant [1, 30]. Bubble surface area flux is defined by:

$$S_b = 6\frac{J_g}{d_b} \qquad 2.22$$

From Equation 2.22 we can see that the main difficulty in calculating S_b is obtaining a reliable estimation of d_b. This is even more problematic if we consider that the bubbles have a size distribution rather than a unique size. Exploring the role of S_b in de-inking flotation columns, Leichtle has suggested a linear relationship between ε_g and S_b. Figure 2.10 shows the results obtained by Leichtle for laboratory and pilot columns [31].

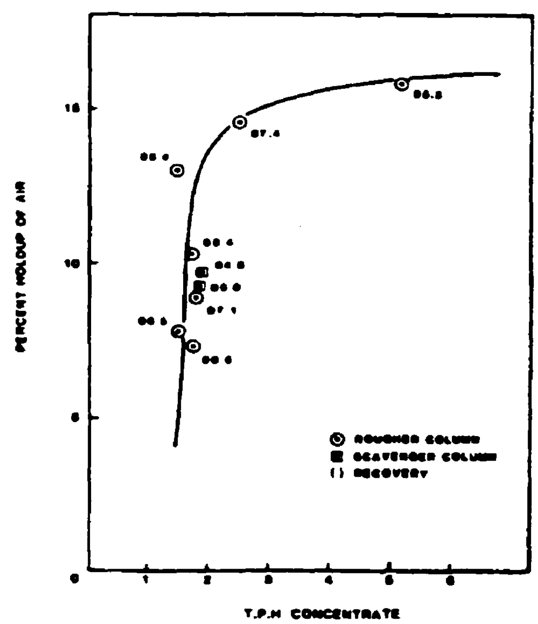


Figure 2.9. Gas holdup versus concentrate solids mass flow-rate for individual column recovery greater than 95% [28].

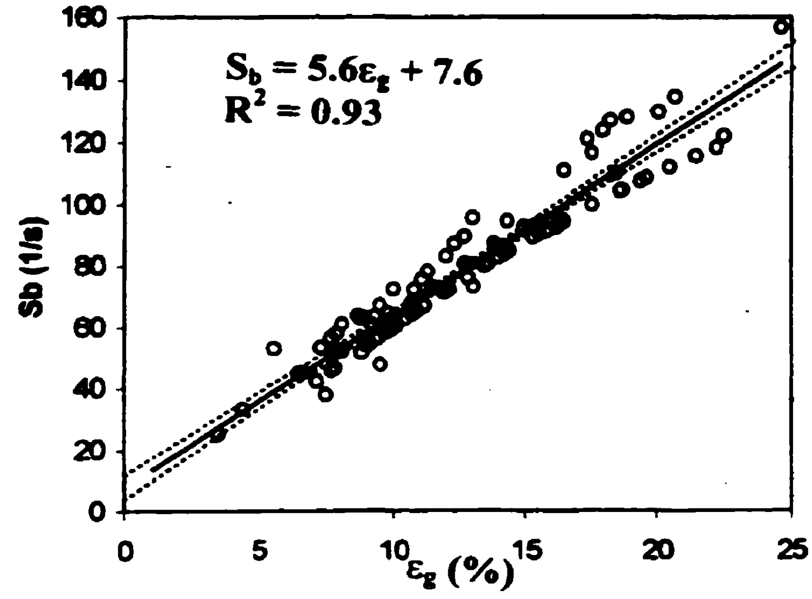


Figure 2.10. Comparison of S_b to ε_g using data points from all tests (i.e. laboratory and pilot scale columns) [31].

Apart from its possible direct role on flotation performance, gas holdup also has diagnostic applications. For example, a ruptured sparger is readily detected as the increase in bubble size will cause the gas holdup to drop suddenly.

2.10. Bubble Surface Area Flux Estimation

The bubble size can be estimated by using direct [1, 30, 32] or indirect methods. Drift flux analysis, an indirect method, has been applied to estimate bubble size in both two phase and three phase systems [2, 33-34]. A brief review of drift flux analysis, taken from Finch and Dobby [2], is included.

The slip (relative) velocity of gas and liquid in countercurrent systems with uniform bubbles is defined by:

$$U_{sb} = \frac{J_g}{\varepsilon_g} + \frac{J_l}{1-\varepsilon_g} \qquad 2.23$$

where upward flow is positive.

The slip velocity is related to the system variables. For bubble sizes of interest here, d_b =< 2 mm (Re =< 500), a suitable expression is an adaptation of the multi-species hindered settling equation of Masliyah [2], written below for the gas-slurry system:

$$U_{sb} = \frac{g d_b^2 (\rho_{sl} - \rho_b)(1-\varepsilon_g)^{m-1}}{18\mu_{sl}(1 + 0.15\,\mathrm{Re}_{bs}^{0.687})} \qquad 2.24$$

or

$$d_b = \left(\frac{18\mu_{sl} U_{sb}}{g(\rho_{sl} - \rho_b)(1-\varepsilon_g)^{m-1}} (1 + 0.15\,\mathrm{Re}_{bs}^{0.687}) \right)^{1/2} \qquad 2.25$$

where

$$\mathrm{Re}_{bs} = \frac{d_b U_{sb} \rho_{sl} (1-\varepsilon_g)}{\mu_{sl}} \qquad 2.26$$

and m is a function of the Reynolds number:

$$m = \left(4.45 + 18\frac{d_b}{d_c}\right)\mathrm{Re}_b^{-0.1} \qquad 1 < \mathrm{Re}_b < 200 \tag{2.27}$$

$$m = 4.45\,\mathrm{Re}_b^{-0.1} \qquad 200 < \mathrm{Re}_b < 500 \tag{2.28}$$

and

$$\mathrm{Re}_b = \frac{d_b U_t \rho_{sl}}{\mu_{sl}} \tag{2.29}$$

where U_t is the terminal rise velocity of a single bubble in an infinite pool (this is calculated using Equation 2.24 and assuming $\varepsilon_g = 0$).

Using drift flux analysis bubble size can be estimated from measurements of ε_g, J_g and J_l. Following is the step-by-step procedure.

1) Set $J_l = J_T$
2) estimate d_b;
3) calculate U_t, Equation 2.24 with $\varepsilon_g = 0$;
4) calculate Re_b, Equation 2.29;
5) calculate m, Equation 2.27 or 2.28;
6) calculate Re_{bs}, equation 2.29;
7) calculate d_b , Equation 2.25; iterate on d_b; Go to 2.

CHAPTER 3: DESIGN CRITERIA FOR GAS HOLDUP SENSOR

3.1 Introduction

The original sensor designed to measure gas holdup [3-5] experienced a serious problem in industrial application, with plugging of the syphon cell by mineral particles.

The design of the syphon cell had to overcome this problem while respecting such electrical criteria as cell constant, separation between electrodes, and electrode width.

3.2 Plugging

The original syphon cell was composed of a vertical cylinder (3.8 cm diameter) closed at its bottom end (45° angle) with a lateral opening (about 10 mm diameter) [3]. The first step was to modify the bottom of the cell to a conical shape (10° angle) with an orifice at the bottom. The second modification was to increase the cell diameter from 3.8 cm to 7.5 cm. With a larger diameter cell, we are in a position to increase the size of the (slurry discharge) orifice at the bottom. Given that the previous design successfully prevented bubbles from entering at both the top (entrained by the slurry entering the cell) and bottom, a similar slurry velocity inside the cell can now be obtained by increasing the orifice diameter. The larger orifice will reduce plugging by solid particles.

From experience the internal diameters of both cells were established at 9.6 cm (D_o: open) and 7.5 cm (D_s: syphon), while the lengths (L_T) were established at 50 cm (in the syphon case, this length includes the conical section).

3.3 Design Criteria for the Conductivity Cell

In the design of a gas holdup sensor, we have to know the values of the cell constants and how they relate to the electrode width and the separation between electrodes.

Figure 3.1 shows a schematic of the electrode arrangement using both the open and syphon cells. A three-ring electrode arrangement is seen: a central electrode at one polarity, with the two outer electrodes at opposite polarity. With this design, the current flux is constrained to flow only inside the cell, allowing for a more stable cell constant [4]. In Figure 3.1 W is the electrode width, D, the internal cell diameter, and L, the separation between electrodes.

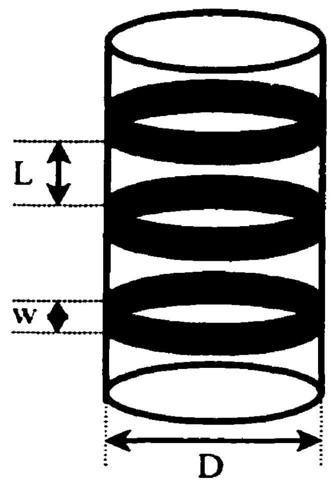


Figure 3.1. Schematic of a conductivity cell with a three-electrode arrangement.

In fact, the cell constant is constant throughout; the degree of deviation from ideality depends on the cell parameters (D, W and L). Figure 3.2 shows a typical conductivity cell behaviour.

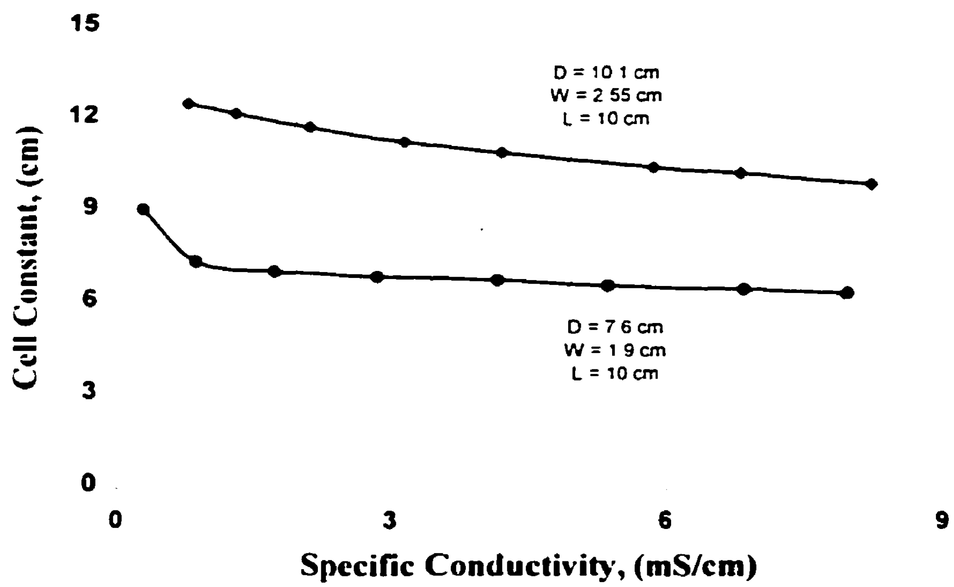


Figure 3.2. Cell constant behaviour in two different flow cells (see Appendix A. Table A.1). Data obtained by F. Tavera [4].

A simple relationship between the cell parameters and a geometrical cell constant, C, was proposed: Equation 3.1.

$$C = \frac{2A_{cell}}{(L + 2W)} \qquad 3.1$$

where

$$A_{cell} = \frac{\pi D^2}{4} \qquad 3.2$$

Using data obtained by F. Tavera during the development of the original gas holdup sensor (measured cell constants for different cell arrangements) [4], we can evaluate the effect of the cell parameters on the cell constant. From Figure 3.3 we can see that deviation from the geometrical value became less significant when the geometrical cell constant decreased. Thus, to ensure the closest possible estimation of the real cell constant, the smallest feasible geometrical value has to be used.

Another important parameter in the design of a conductivity cell is the electrode width (W). We will define the exposed electrode area by:

$$A_W = \pi D W \qquad 3.3$$

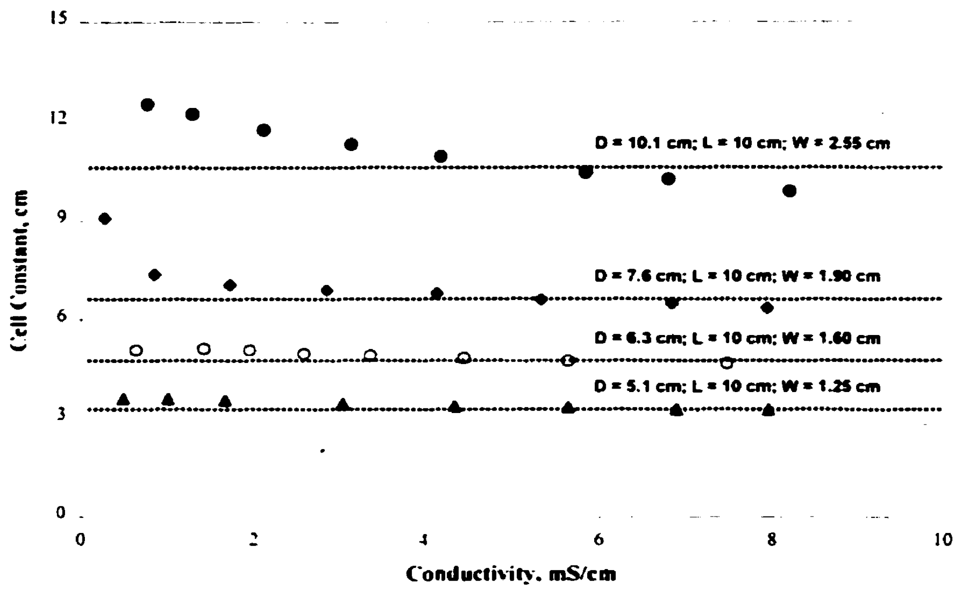


Figure 3.3. Deviation from geometrical cell constant for 4 cells with 3-electrode arrangement. (see Appendix A. Table A.2). Data obtained by F. Tavera [4].

Figure 3.4 shows the deviation from geometrical cell constant values (Equation 3.1) for cells with different ratios of A_{cell}/A_w. We can see that the deviation decreases if the ratio A_{cell}/A_w decreases. As a design criterion a ratio A_{cell}/A_w equal to 1 could be chosen, for which W is defined as:

$$W = \frac{D}{4} \tag{3.4}$$

Substituting Equation 3.3 and 3.5 in Equation 3.1 and rearranging terms, we get that the separation between electrodes necessary to yield a selected cell constant is given by:

$$L = \frac{D}{2C}(\pi D - C) \tag{3.5}$$

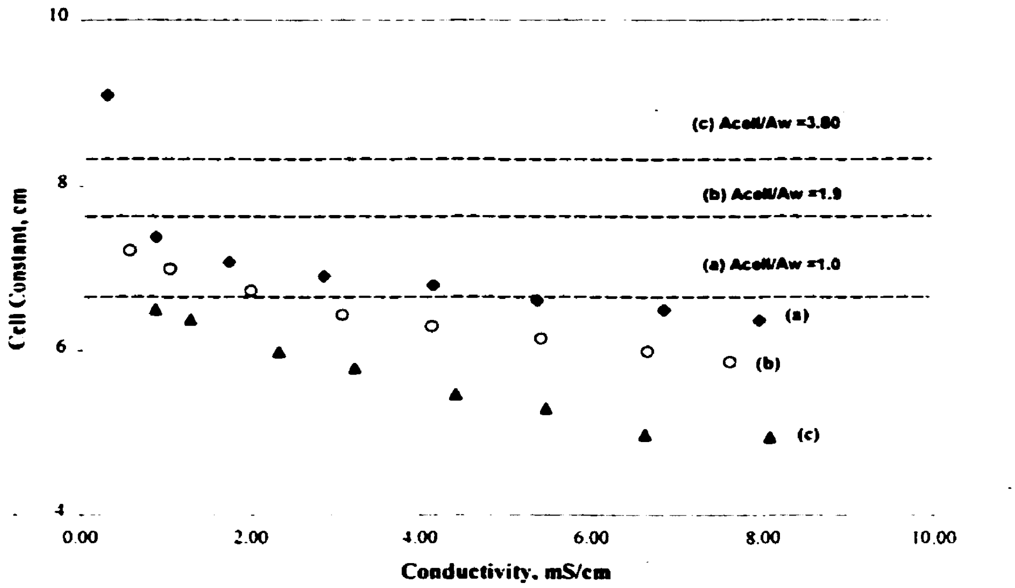


Figure 3.4. Effect of the ratio A_{cell}/A_w on deviation from the geometrical cell constant by using Equation 3.1 (see Appendix A. Table A.3). Data obtained by F. Tavera [4].

3.4. Design criteria for the Syphon Cell

Since the length and diameter of the syphon cell are already defined (see Section 3.1), the diameter of the orifice, $d_{orifice}$, at the bottom is the remaining critical parameter.

Figure 3.5 shows the experimental setup used to characterize different orifice diameters: 14, 16, 18, 20 and 22 mm. For each diameter, different water flow rates were passed through the cell until a steady value of H was obtained.

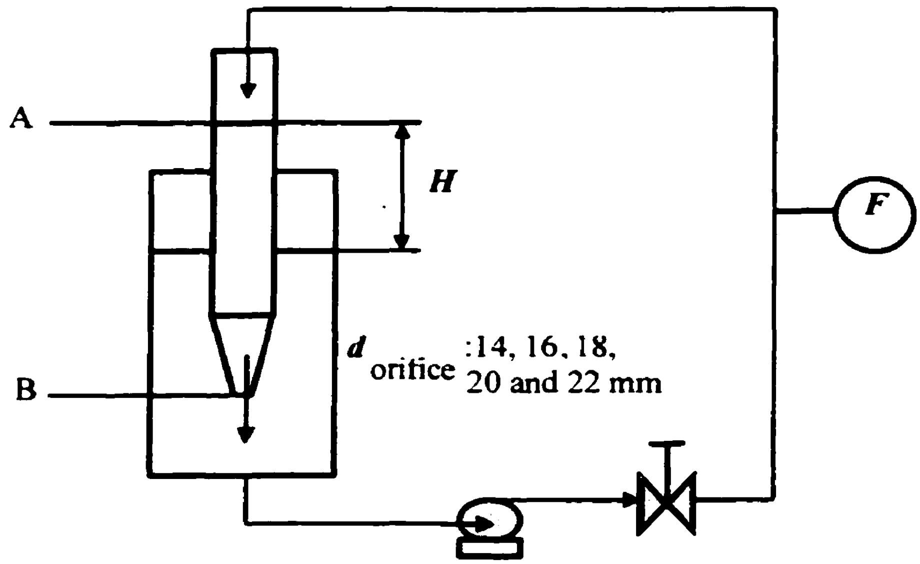


Figure 3.5. Experimental setup used to characterize the bottom orifice diameter of syphon cell ($d_{orifice}$).

If we apply Bernoulli's principle between point A (cell top) and B (cell bottom) the water velocity at the top, V_A, is a function of H and is given by:

$$V_A = \sqrt{\frac{2gH}{\left(\frac{D_S}{d_{orifice}}\right)^4\left(\frac{1}{\beta_B}+e_f\right)-\frac{1}{\beta_A}}} \tag{3.6}$$

where g is the gravity acceleration. $\beta = 0.5$ for laminar flow, and $\beta = 1$ for turbulent flow. The syphon cell diameter is represented by D_S (in this case, $D_S = 7.5$ cm). Figure 3.6 shows the experimental data, V_A versus H, obtained for each orifice diameter.

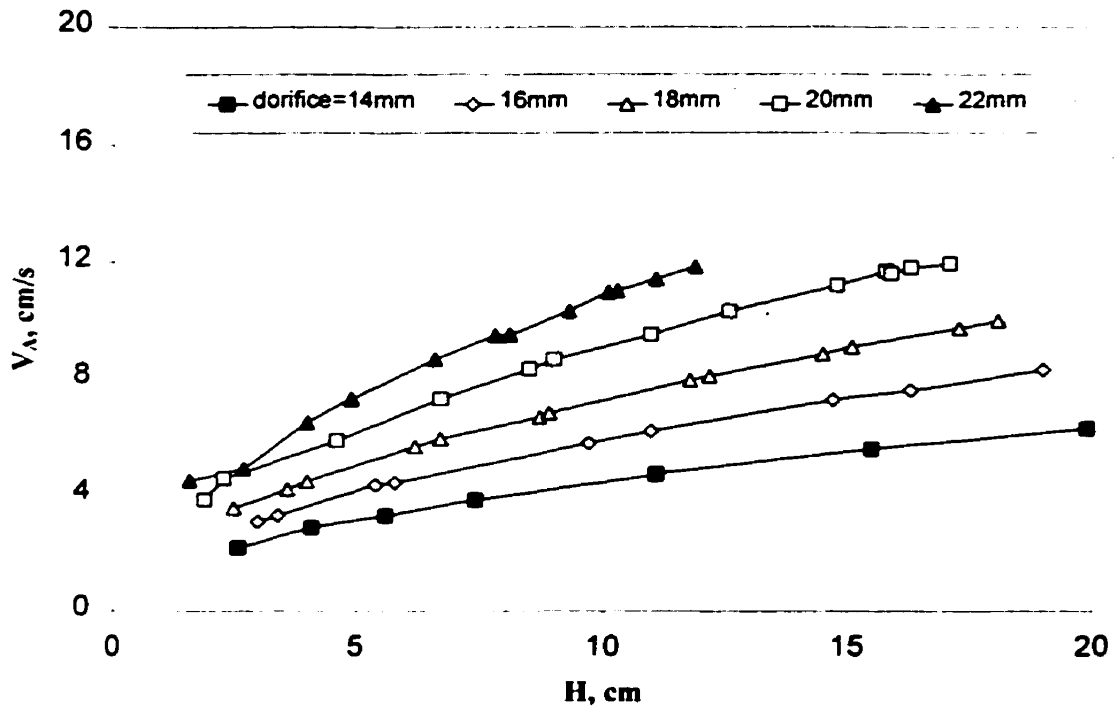


Figure 3.6. V_A as a function of H for each orifice diameter, $d_{orifice}$ (See Appendix A, Tables A.4.a and A.4.b).

From section 2.6, when a syphon cell is working in a dispersion of slurry and gas, V_A is related to the gas holdup, as follows:

$$V_A = \sqrt{\frac{2gL_T\varepsilon_g}{\left[\left(\frac{D_c}{d_{orifice}}\right)^4\left(\frac{1}{\beta_B}+e_f\right)-\frac{1}{\beta_A}\right]}} \qquad 2.17$$

where L_T is the syphon cell length (in this case 50 cm). Taking equations 3.6 and 2.17 the gas holdup is related to H for a given V_A by:

$$\varepsilon_g = \frac{H}{L_T} \qquad 3.7$$

An important parameter to be considered for a particular application, is the bubble terminal velocity, U_t. A method to estimate this parameter is presented in Equations 3.8 and 3.9 [2].

$$U_t = \frac{g d_b^2 (\rho_{sl} - \rho_b)}{18 \mu_{sl} (1 + 0.15 Re_b^{0.687})} \qquad 3.8$$

where

$$Re_b = \frac{d_b U_t \rho_{sl}}{\mu_{sl}} \qquad 3.9$$

Figure 3.7 shows the curves V_A versus ε_g (using Equation 3.7), and the bubble terminal velocity, for three different bubble diameters (0.5, 1.0 and 1.5 mm). The bubble terminal velocities were calculated for a water-air system. For a given application (where ε_g and d_b are known), Figure 3.7 indicates that every orifice diameter that gives a V_A value lower than U_t (defined by d_b) would allow a bubble-free environment inside the cell.

As an example, for a bubble diameter of 1.5 mm, all five orifice diameters could be used (for any ε_g) because all five curves are under the terminal velocity line for a 1.5 mm bubble. If we have a system with ε_g = 20 % and d_b = 0.5 mm, we can use only an orifice smaller than 14 mm.

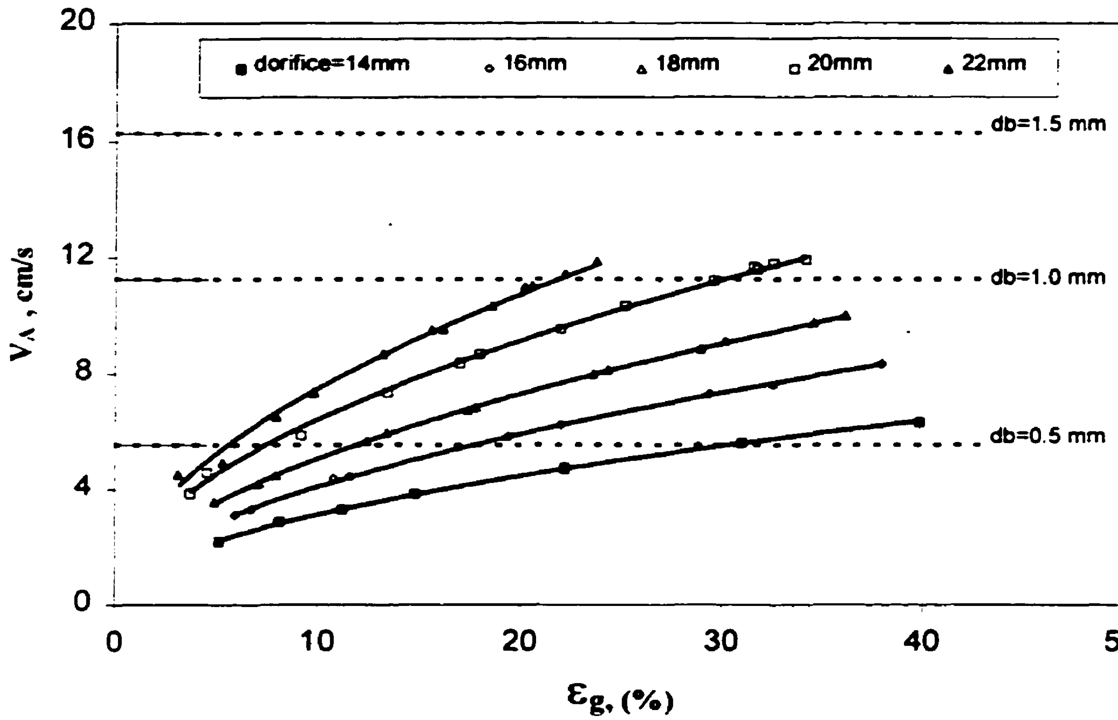


Figure 3.7. V_A as a function of ε_g for each orifice diameter (L_T=50 cm). Bubble terminal velocities were estimated using Equations 3.8 and 3.9 (water-air system. d_b=1.5. 1.0 and 0.5 mm)(see Appendix A. tables A.4.a and A.4.b).

Rearranging Equation 3.6 yields:

$$\left(\frac{D_s}{d_{orifice}}\right)^2 \overbrace{\left(\frac{1}{\beta_g}+e_f\right)}^{C_0}-\overbrace{\left(\frac{1}{\beta_t}\right)}^{C_1}=\frac{2gH}{V_t^2} \qquad 3.10$$

where C_0 and C_1 are constants which are independent of the orifice diameter. Figure 3.8 shows the determination of C_0 and C_1 using the data obtained for the orifices. Substituting these parameters in Equation 2.17, we can estimate the maximum orifice diameter as a function of the bubble terminal velocity and gas holdup (see Figure 3.9).

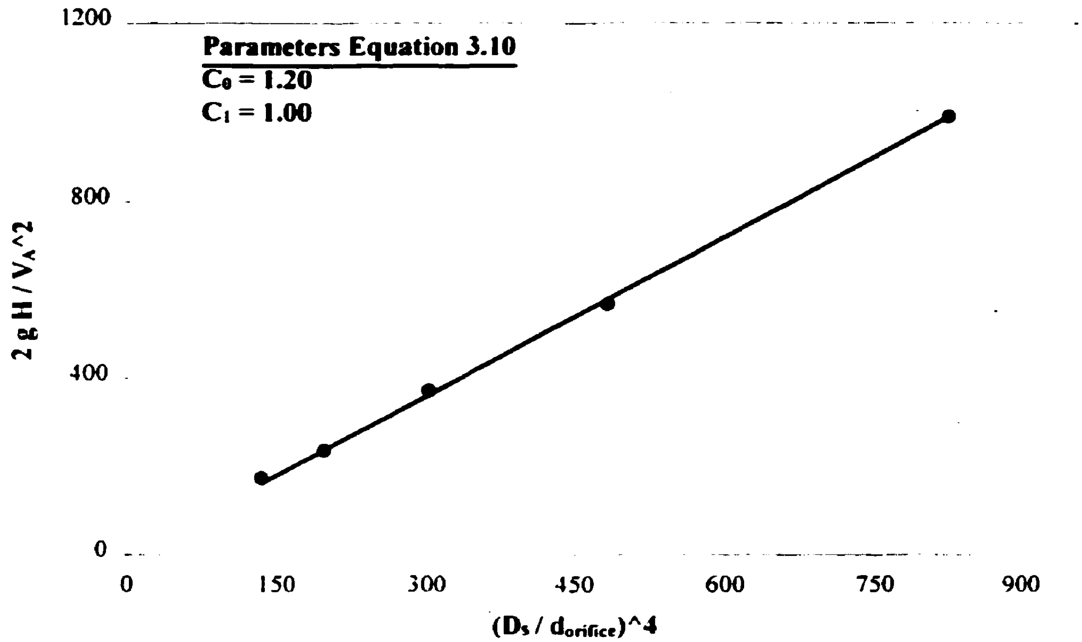


Figure 3.8. Determination of parameters C_0 and C_1 (Equation 3.10). Data obtained for 5 orifice diameters (14, 16, 18, 20, and 22 mm).

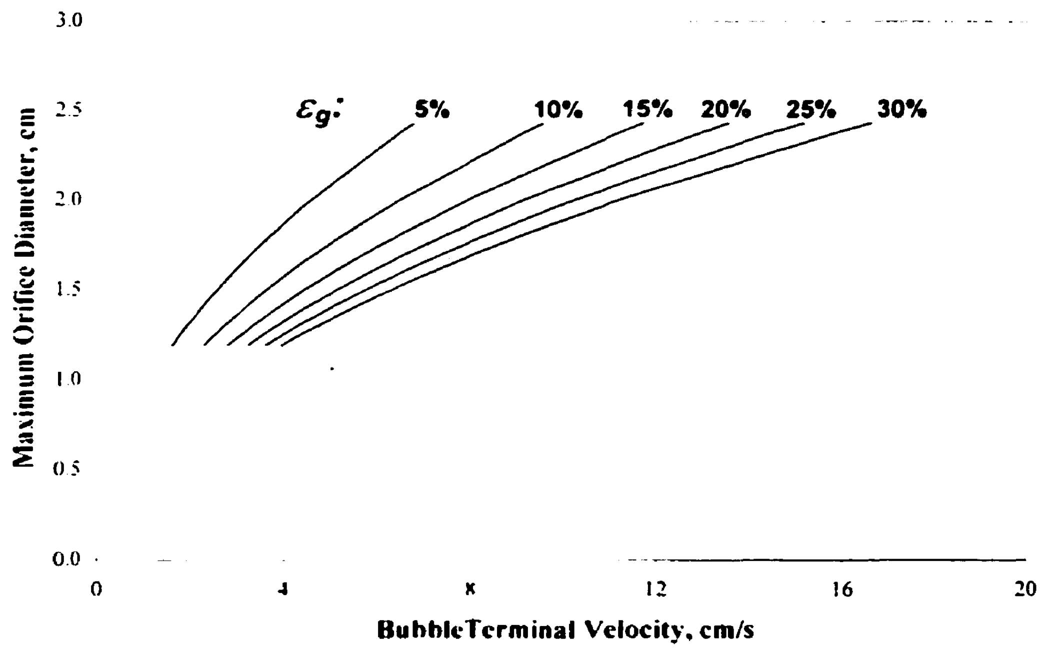


Figure 3.9. Maximum orifice diameter as a function of the bubble terminal velocity and gas holdup. Data obtained by substituting C_0 and C_1 in Equation 2.17.

3.5. Example of Design

A gas holdup sensor was designed for a flotation column application (mineral system): ε_g = 10% and d_b = 1.0 mm. From Section 3.2, D_o = 9.6 cm, D_s = 7.5 cm and L_T = 50 cm (for both cells).

Conductivity Cells

- The two cell constants must be the same to use the same conductivity meter.
- The lowest possible C in this case (L_T = 50 cm) is 8 cm.
- Substituting D_s and D_o in Equation 3.5: W_s = 1.9 cm and W_o = 2.4 cm.
- Substituting C, D_s and D_o in Equation 3.6: L_s = 7.3 cm and L_o = 13.3 cm.

Syphon Cell

- From Figure 3.7, all V_A values at ε_g = 10% are lower than U_t = 11.2 cm/s (d_b = 1.0 mm; water-air system). Considering that smaller bubbles (0.5 mm) could be present, a orifice diameter, $d_{orifice}$, of 15 mm is chosen.

Figure 3.10 is a schematic, with all dimensions, of the gas holdup sensor design for this application (ε_g = 10% and d_b = 1.0 mm).

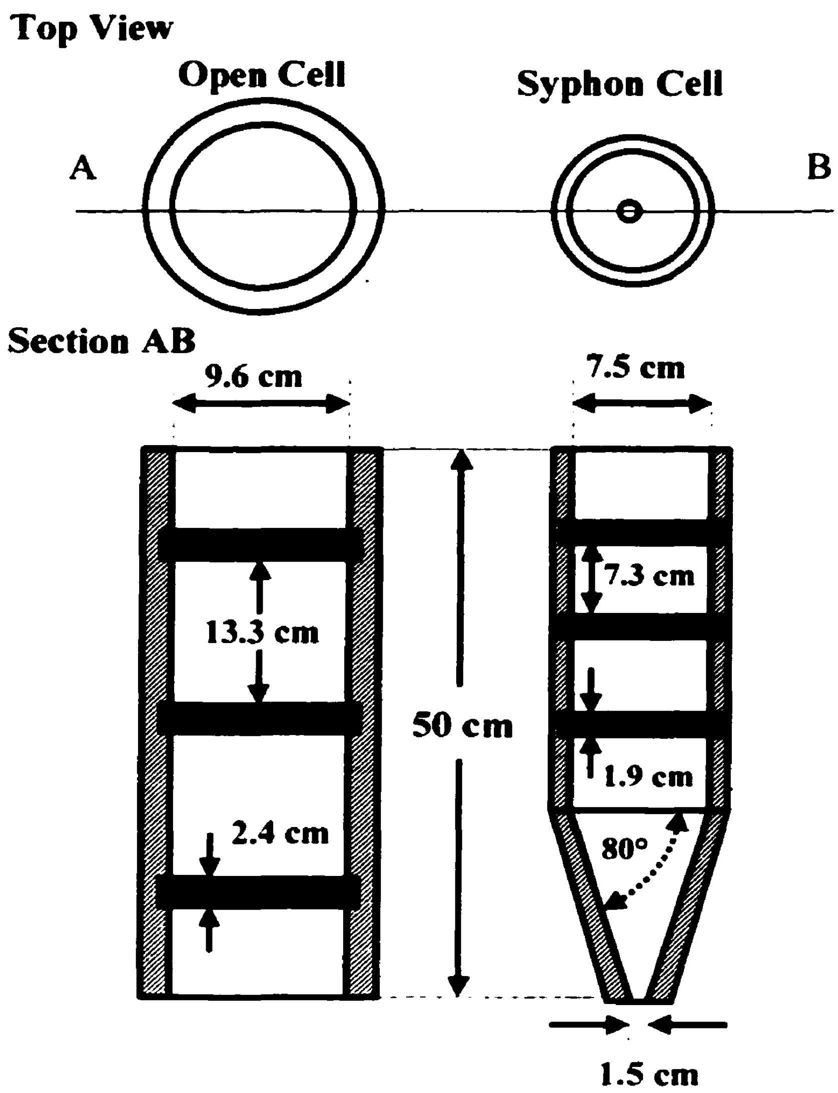


Figure 3.10. Schematic of the gas holdup probe designed for an application with ε_g = *10% and* d_b = *1.0 mm.*

CHAPTER 4: EXPERIMENTAL

4.1 Introduction

Two industrial applications in flotation were considered in this work: mineral concentration (INCO at Copper Cliff, Ontario) and de-inking of waste paper (BOWATER at Gatineau, Quebec). The same data acquisition system is used for both applications: a gas holdup sensor and an electronic interface that converts the rough signal from the sensor to a digital signal, which can be processed in any computer.

This chapter concerns the description of the electronic interface, data acquisition system calibration and the two processes. Three gas holdup sensor units were used. The three sensors have the same characteristics as the ones described in Figure 3.10 (with $d_{orifice}$ = 1.5 cm).

4.2. Data Acquisition System.

Figure 4.1 shows a schematic of the electronic associated with the gas holdup sensor. The sensor (open plus syphon cells) is placed inside the column. A relay board (Keithley Metrabyte, model REL-16) permits each of the conductivity cells to be measured independently by using a conductivity meter (Bailey, model TB440). The output of the conductivity meter, consisting of a signal between 0 and 10 volts, is converted to digital values by using an A/D converter (Keithley Metrabyte, model DAS-8). The relay board and the A/D converter are mounted inside a 386-33MHz computer.

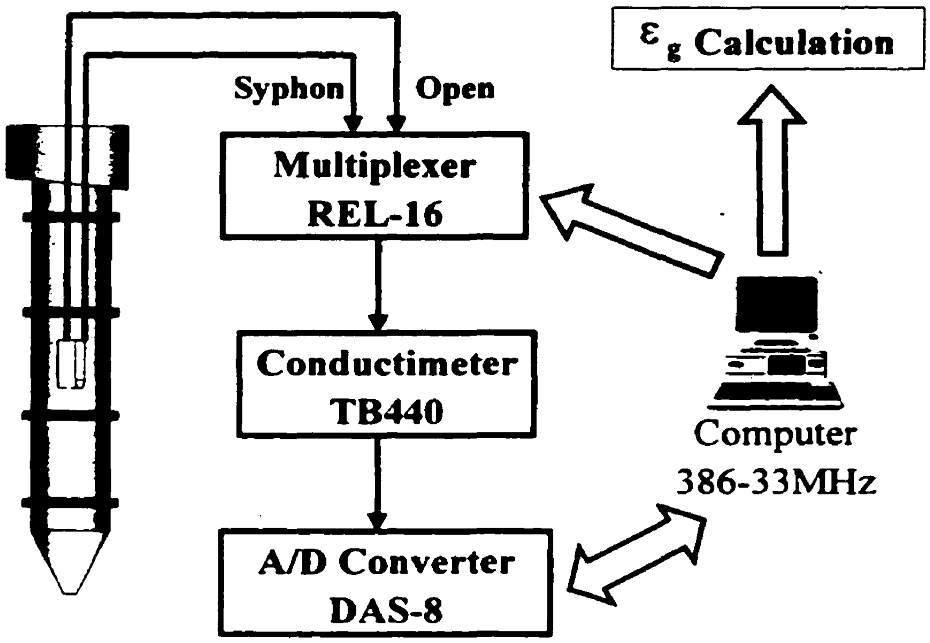


Figure 4.1. Schematic representation of the data acquisition system.

When the digital voltage value (v) is obtained, it is converted to conductance by using the calibration curve of the conductivity meter (quadratic equation) relating voltage to conductance, see Equation 4.1.

$$K = A + Bv + Cv^2 \qquad 4.1$$

This conductance value is transformed to conductivity by using the calibration curve of the specific cell that is being read (open or syphon cell). This cell calibration curve is also of the quadratic form. For the open cell, the equation is as follows:

$$\kappa_d = A_o + B_o K + C_o K^2 \qquad 4.2$$

and for the syphon cell:

$$\kappa_d = A_s + B_s K + C_s K^2 \qquad 4.3$$

The data acquisition process is driven by a program in Visual Basic 3.0 (Appendix B). Figure 4.2 shows the main menu of the data acquisition software.

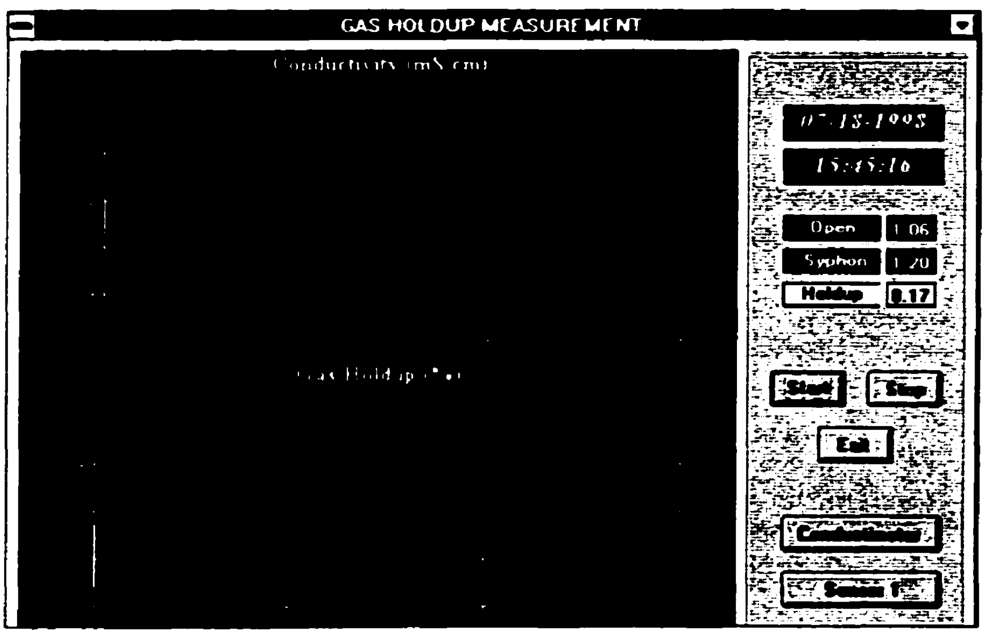


Figure 4.2. Main menu of the data acquisition software.

In order to control the REL-16 and DAS-8 boards, Visual Basic needs special drivers. To control the REL-16 board and to provide special graph features the driver package VTX (Keithley Metrabyte) was used. The DAS-8 board was controlled by using DRIVERLINX-DAS8/VB (Keithley Metrabyte).

4.3. INCO: Matte (Cu-Ni) Separation Plant, Column circuit

This plant is located at Copper Cliff, Ontario. The matte separation plant has five flotation columns (see Appendix C, Figure C.1). The main characteristics of the columns are presented in Table 4.1. All five columns use Minnovex variable gap jet spargers. Two gas holdup sensors were used in these tests.

The following experiments were carried out:

- Experiment 1: Sensor 2 was placed inside column 2 at a 4-meter depth for two weeks. The objective was to determine if the syphon cell could work continuously without plugging in an industrial environment.

- Experiment 2: Sensor 1 was placed inside column 3 at a 4-meter depth, and changes in the air flow rate were introduced. Samples of the feed, concentrate, and tailings, were obtained before and after every air flow rate change. Grades of Cu, Ni, Co and Fe were determined. Mass balances were carried out using a method described in the literature [35-36]. The objectives were to determine if the sensor was able to detect changes in gas holdup, induced by changes of the air flow rate, and whether changes in the column performance could be related to gas holdup.

Table 4.1

Characteristics of INCO matte separation plant

	Column			
	1	2 / 3	4	42"
Height (m)	11.6	11.6	11.6	11.6
Diameter (m)	1.83	1.83	2.13	1.07
Baffles	No	Yes / No	Yes	No
Sparger Type	Variable gap			
Number of spargers	4	4	6	2
Bubble size (mm)	2			
Air flow (std.m³/hr)	255	255	340	40
Gas holdup (%)	20 - 25			
Service	Midd. Rghr.	2nd Cu Clnr.	Ni Clnr.	Midd. Clnr.

- Experiment 3: both sensors were placed inside column 3, sensor 1 at a 4-meter depth and sensor 2 at a 7-meter depth. The objective was to determine if there were variations in gas holdup with depth.

Calibration: Conductivity meter and Sensor

The conductivity meter calibration was carried out by replacing the gas holdup sensor with a known resistor, R (Ω), and reading the voltage value displayed by the data acquisition software. Using several resistors, a set of conductance (1 / R) values versus voltage was obtained.

The calibration of both cell constants (open and syphon) was carried out by using electrolyte solutions of known conductivity (without air); the conductance in each cell was measured with the data acquisition software, using the conductivity meter calibration curve. The conductivity of each electrolyte solution was measured using a portable conductivity meter (VWR Scientific, model 2052). Calibration parameters for the conductivity meter, sensor 1 and sensor 2 used in Equations 4.1 to 3, are presented in Table 4.2.

Table 4.2

Calibration parameters for the conductivity meter, sensor1 and sensor2. (See Appendix C, Tables C.1 to C.5)

	Parameters		
	A	**B**	**C**
Conductivity meter	-9.34449	4.86954	0.07564
Sensor 1			
Open cell	-0.1745	0.12678	0.0005
Syphon cell	-0.17695	0.12717	0.00036
Sensor 2			
Open cell	-0.17476	0.12784	0.0002
Syphon cell	-0.16461	0.12175	0.00024

4.4. BOWATER: De-inking Pilot Flotation Column

The equipment was a pilot flotation column constructed of PVC, with an internal diameter of 50 cm and a height of 5.1 m. This column is described elsewhere [31,37]. The installed instrumentation consisted of mass air flow meters, magnetic liquid flow meters (2), pressure transducers (3), and centrifugal pumps (2) with control valves (2). The software used for data collection and control was FIX DMACS (32-bit) by Intellution. The I/O interface between the software and all instruments was an OPTO1 serial board by Transduction. The following parameters were continuously monitored and registered by FIX DMACS: feed and accepts (i.e., underflow) superficial flow rates, superficial gas rate, gas holdup obtained from pressure values, bottom pressure, middle pressure, and level.

One gas holdup probe was used in this application: sensor 3. Two kinds of bubble generating devices were used in these experiments: five sintered stainless steel powder (porous rigid) spargers and one variable gap (Minnovex) sparger.

The experiments carried out were:

- Experiment 1: the ε_g versus J_g was obtained by using the five porous rigid spargers for three different conditions ($H_f = 100$ cm; $\tau = 3$ min, $H_f = 100$ cm; $\tau = 6$ min, and $H_f = 50$ cm; $\tau = 6$ min). The flotation efficiency and brightness gain were measured.

- Experiment 2: from an initial condition with 5 porous rigid spargers, the system was evaluated after closing one sparger, and then two spargers. Two initial conditions were evaluated ($J_g = 2.5$ cm/s; $H_f = 100$ cm; $\tau = 3$ min, and $J_g = 2.5$ cm/s; $H_f = 100$ cm; $\tau = 6$ min). The objective was to determine the effect on gas holdup and column performance resulting from a sparger surface area (A_s) decrease.

- Experiment 3: from an initial condition with 5 porous rigid spargers, the system was evaluated after closing one sparger, and increasing J_g until the previous gas holdup with five spargers was reached. Two initial conditions were evaluated (J_g = 2.0 cm/s; H_f = 50 cm; τ = 6 min, and J_g = 1.5 cm/s; H_f = 50 cm; τ = 6 min). The objective was to determine if performance was the same for the same gas holdup obtained in different ways.

- Experiment 4: the ε_g versus J_g was obtained by using a variable gap sparger. For this experiment the air flow meter was set to the maximum (J_g = 3.5 cm/s) air flow rate for that gap. The objective of this experiment was to compare the response of the system to both sparger types.

In order to limit errors, all the experiments were evaluated 15 minutes after the steady state was achieved (stable signals). To obtain the flotation efficiency and brightness gain, pads of feed and accept pulp were prepared according to the CPPA C.4U method [38]. An average of 10 ERIC values (ink concentration in the pad) were obtained for flotation efficiency calculations with an average of 10 brightness values for brightness gain.

Calibration: Conductivity meter and Sensor

The calibration procedure of the conductivity meter and the sensor for this application is the same as the one described in Section 4.3. Calibration parameters for the conductivity meter and sensor 3, used in Equation 4.1 to 3, are presented in Table 4.3.

Table 4.3

Calibration parameters for the conductivity meter and sensor 3.

(See Appendix C. Tables C.6 to C.8)

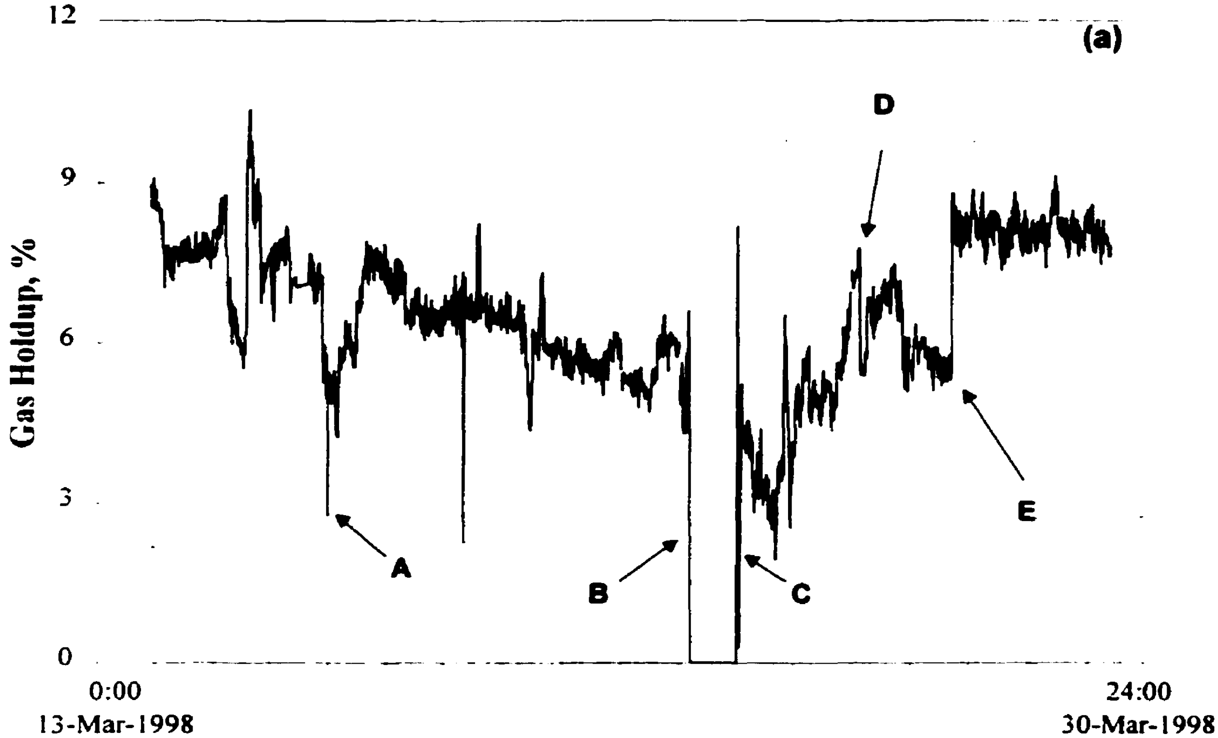
	Parameters		
	A	**B**	**C**
Conductivity meter	-7.63239	4.29777	0.07425
Sensor 3			
Open cell	-0.2756	0.14052	0.00015
Syphon cell	-0.23187	0.12879	0.00069

Chapter 5: INCO Results

This chapter describes the results obtained in columns 2 and 3 at the Matte Separation Plant, INCO limited (Copper Cliff, Ontario). Two gas holdup sensors were used in these tests. The main objective of these experiments was to evaluate the re-designed gas holdup sensor under industrial conditions (especially with regard to plugging of the syphon cell). One of the sensors was tested continuously for 17 days in column 2. A second test was run in column 3, to determine if the sensor was able to detect changes in gas holdup from changes in the air flow rate to the column. Finally, both sensors were installed in column 3, to determine variations of the gas holdup value with depth. The raw data are given in Appendix D.

5.1. Test of Reliability

Figure 5.1 shows the results obtained by gas holdup sensor 2 in column 2 from March 13 to March 30 (1998). Figure 5.1.a shows the gas holdup values and Figure 5.1.b, the conductivity values of the dispersion and slurry.



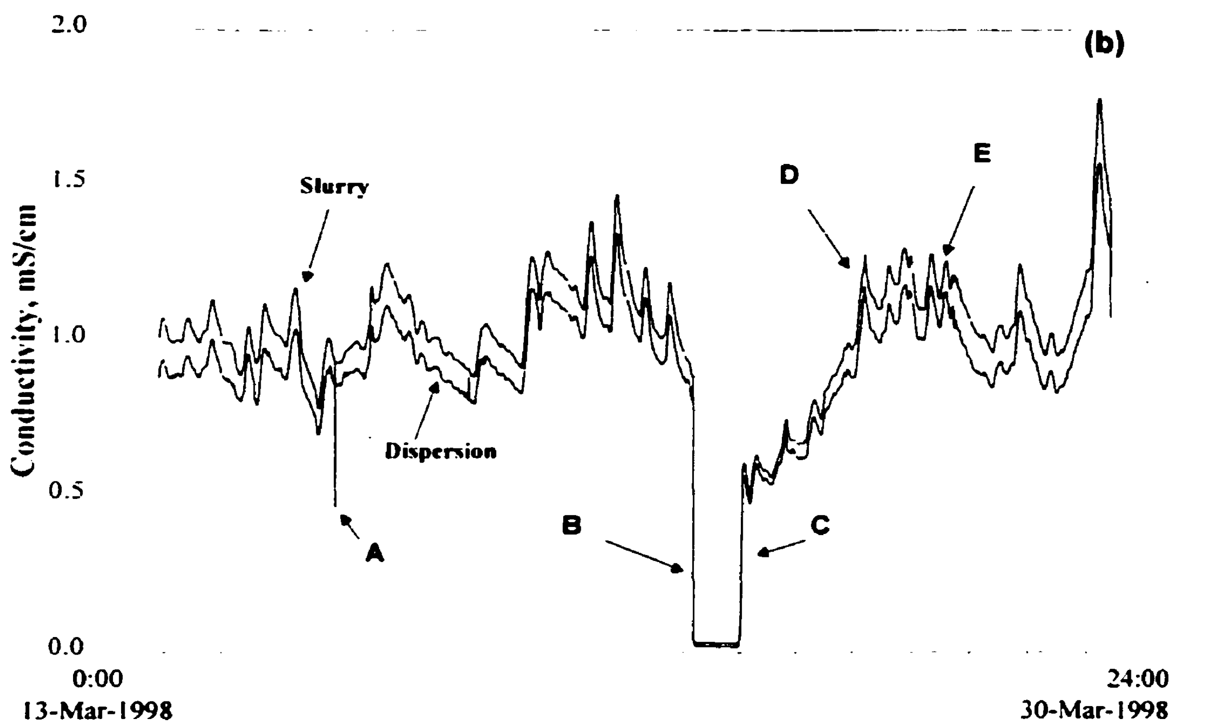


Figure 5.1. Results on column 2 from March 13 to March 30 (sensor 2): (a) gas holdup, (b) conductivity values (dispersion and slurry). See Appendix D, Tables D.1 to D.18.

All the values plotted in Figure 5.1 are the averages of fifteen minutes of operation. The actual rate of sampling is 1 value per minute. Point A in Figure 5.1 shows a spike, probably the level in the column was below the sensor position. The column quickly recovered normal operation, both conductivity values increasing (unsteady state situation). Between point B and point C (about 1 day) the column was shut down, both conductivity values were close to zero since the column was empty. At point C the column was re-started. Between point C and point D the plant was in unsteady operation. At point E the air flow was increased (gap between two conductivity values increases) leading to a gas holdup increase. After point E the gas holdup was stable around 8%, although the conductivity values continued to present notable changes.

During the test period, the syphon cell did not experience any sign of plugging, even though the column was shut down for almost one day. In the previous probe design a column shut down caused the syphon to plug. After the test, the sensor was checked with solutions of known conductivity and it did not show significant deviation from the readings prior to the test, i.e., the calibration (κ versus K) had not changed.

5.2. Response to a Change of the Air Flow Rate.

Figure 5.2 shows the gas holdup response to a change in the air flow rate injected into column 3. All the values plotted in Figure 5.2 are the averages of 5 minutes of operation (sampling rate: 1 value per minute). Sensor 1 was placed at a 4 meter depth.

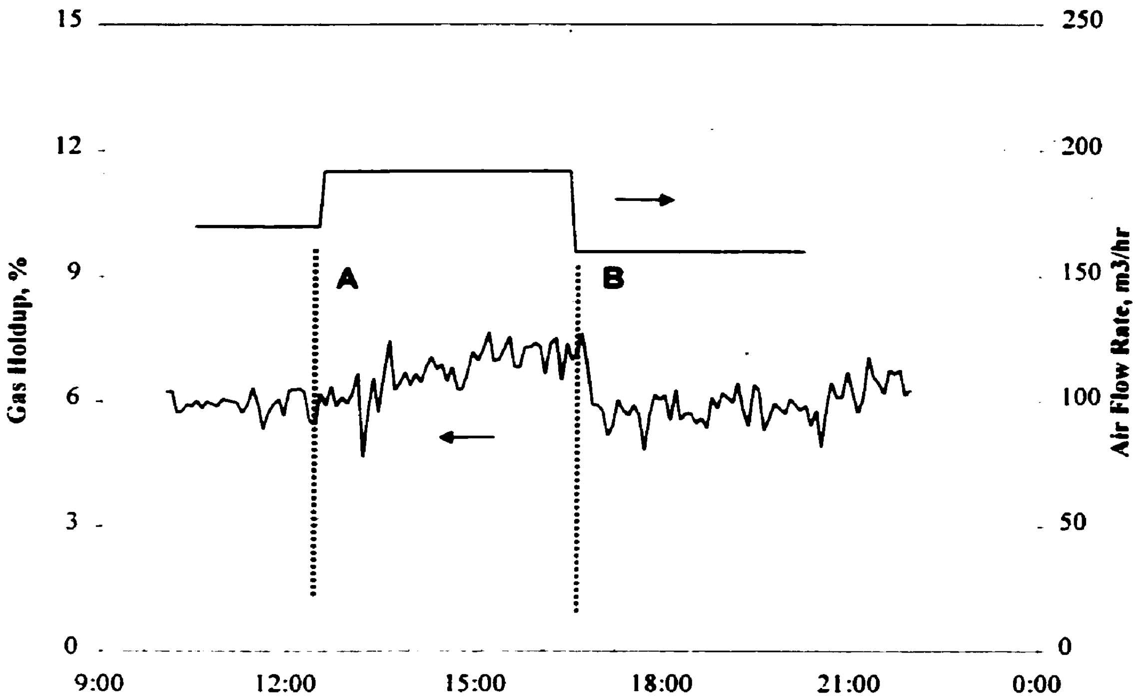


Figure 5.2. Gas holdup response to changes in the air flow rate to column 3 (31-March-1998). See Appendix D. Table D.19

At point A, a change in the superficial air rate was introduced: from 1.83 cm/s to 2.03 cm/s. The gas holdup response was slow, reaching a steady gas holdup after one hour. In contrast, when the air rate was decreased, from 2.03 cm/s to 1.69 cm/s (point B), the system quickly reached a new gas holdup.

The same data is presented in Figure 5.3, but in terms of conductivity values and ratio γ (dispersion conductivity, open cell, over slurry conductivity, syphon cell) responses to air flow rate changes. From this figure we can see that at point B, the dispersion conductivity decreased (increasing the difference between the two conductivities and giving a higher ratio γ).

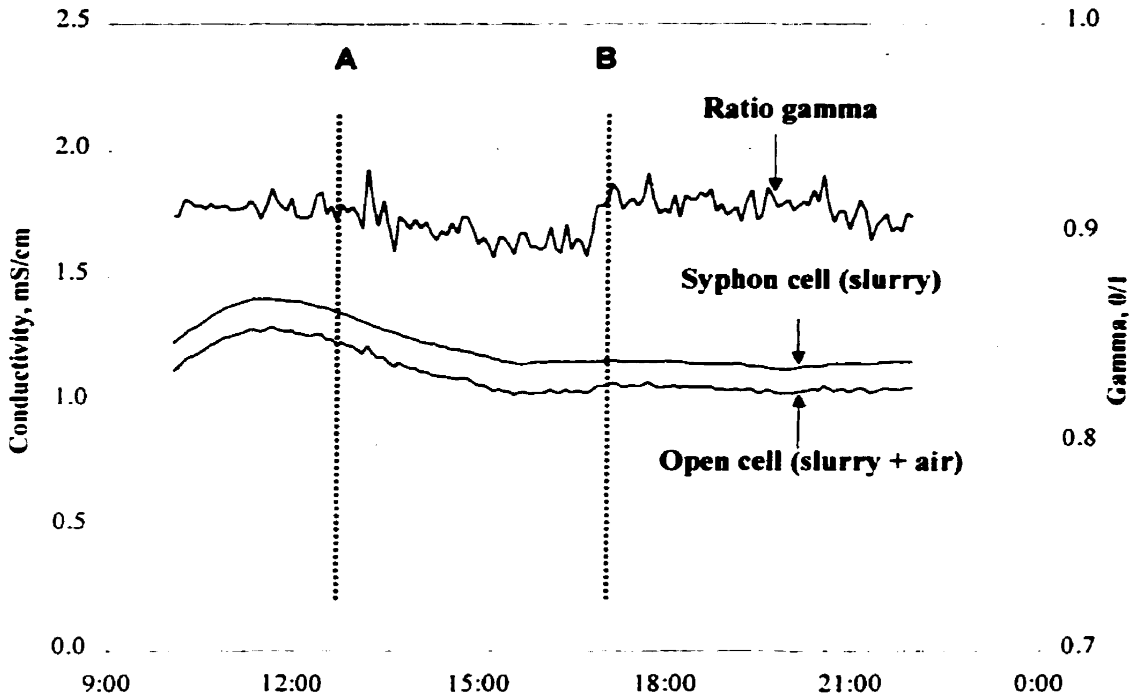


Figure 5.3. Conductivity values and ratio responses to changes in the air flow rate to column 3 (31-March-1998). See Appendix D, Table D.19.

Samples of the feed, concentrate and tailings were taken and the grades of Cu, Ni, Co, and Fe were obtained (see Appendix D, Table D.20). Representative samples of the three streams were analyzed 10 times for each of the 4 elements. This allowed an estimation of the relative standard deviations of each stream for mass balance calculation purposes (weight calculations, see Appendix D, Table D.21).

The adjusted grades, obtained from the mass balances, are presented in Appendix D, Table D.22. The recoveries and typical deviations (95% confidence interval) for each element are presented in Appendix D, Table D.23. Unfortunately, typical deviations of copper, cobalt and iron are high and conclusions based on these elements are avoided. Fortunately, nickel typical deviations are low, and can be used.

Figure 5.4 shows the recoveries of copper, nickel, cobalt and iron. All of the elements exhibit the same trend. Between A and B, we see a slight increase in the recoveries initially, with a larger decrease at the end. From Figure 5.2, we know that the gas holdup was increasing during this period.

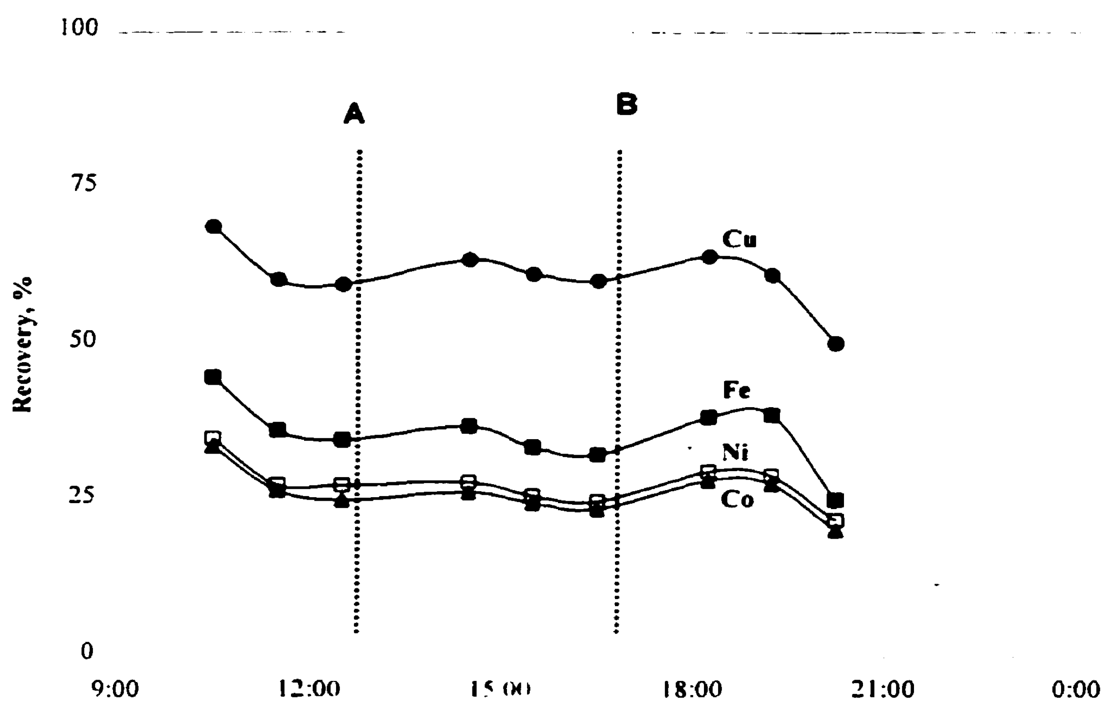


Figure 5.4. Recovery responses to changes in the air flow rate to column 3 (31-March-1998). See Appendix D, Table D 23

This could be explained by the observations in Figure 5.5. Figure 5.5 shows the variation in level (froth depth) during this experiment. From this figure we can see that the level increased strongly at the end of the period A-B. This could be related to the recovery decrease.

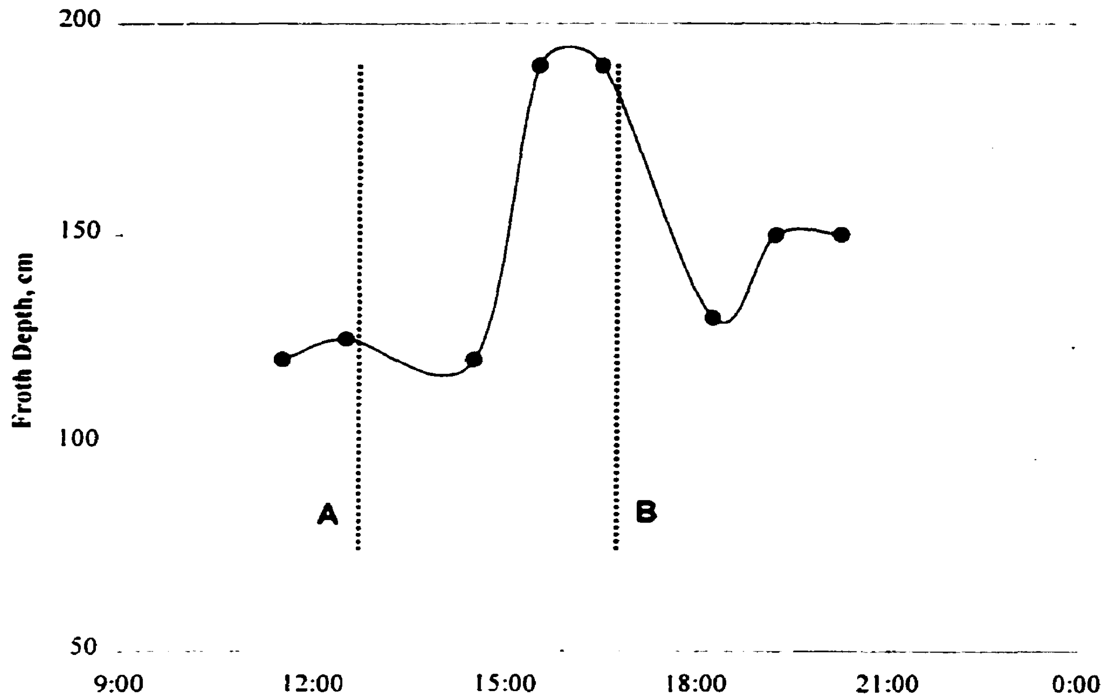


Figure 5.5. Froth depth variations at column 3 (31-March-1998). See Appendix D. Table D.24. Data obtained by using a conductivity probe to detect level.

5.3. Gas Holdup Readings at Two Different Depths.

Sensor 1 was placed at a 4-meter depth and sensor 2 at a 7-meter depth inside column 3. Figure 5.6 shows similar results for both sensors. The average gas holdup of sensor 1, at a 4-meter depth, was 4.7% ± 0.1% (95% confidence) and sensor 2, at a 7-meter depth, was 4.9% ± 0.1% (95% confidence). These results show that there was not a significant difference between the two measurements. This is in contrast with some of the previous work, showing a gas holdup decrease with increasing depth [3-5].

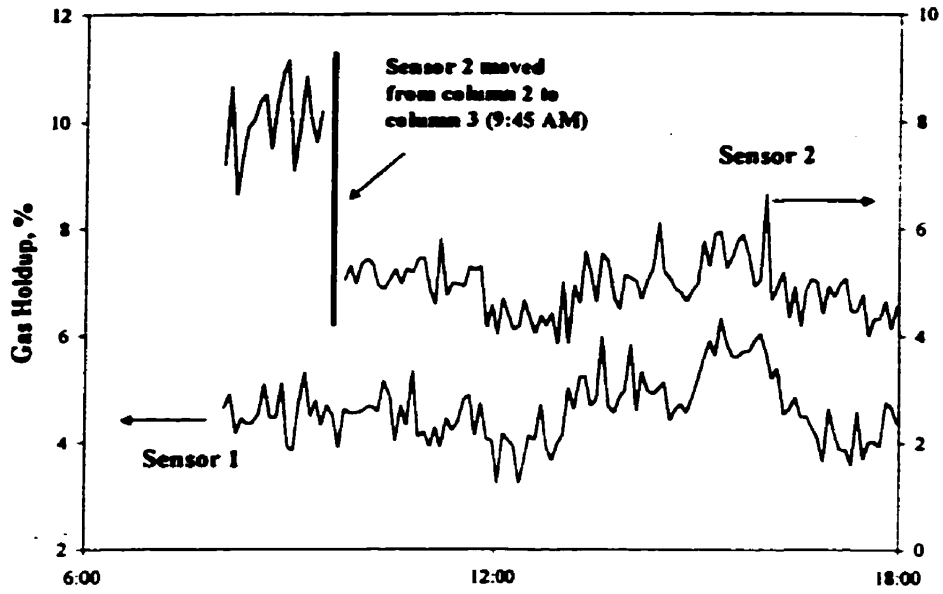


Figure 5.6. Gas holdup signals of sensor 1 and sensor 2 working at different depths inside column 3: sensor 1 at 4-meter depth; sensor 2 at 7-meter depth (3-April-1998). See Appendix D, Tables D.25.a to D.25.c.

CHAPTER 6: BOWATER RESULTS

This chapter describes the results obtained in the pilot column at the De-inking of Waste Paper Plant, BOWATER Pulp and Paper Inc (Gatineau, Quebec). Sensor 3 was used in these tests. One objective of the experiments was to evaluate the re-designed gas holdup sensor on fibre pulps, which are quite different from mineral slurries. Gas holdup values obtained from pressure and conductivity were compared. The effect of gas holdup on flotation efficiency was explored. The relationship between bubble surface area flux (derived from drift flux analysis) and gas holdup was tested. Changes in sparger surface area were induced to observe the gas holdup response and its effect on flotation performance. Finally, a jetting sparger (MINNOVEX) was tested. The raw data are given in Appendix E.

6.1. Gas Holdup Measurements from Pressure and Conductivity

Figure 6.1. summarizes the results including the ones for the jetting sparger. From Figure 6.1, some scatter is evident. One explanation is that conductivity gives a more local estimation than pressure, which is an

average between two points. Differences could be expected if gas holdup would be distributed uniformly in the column.

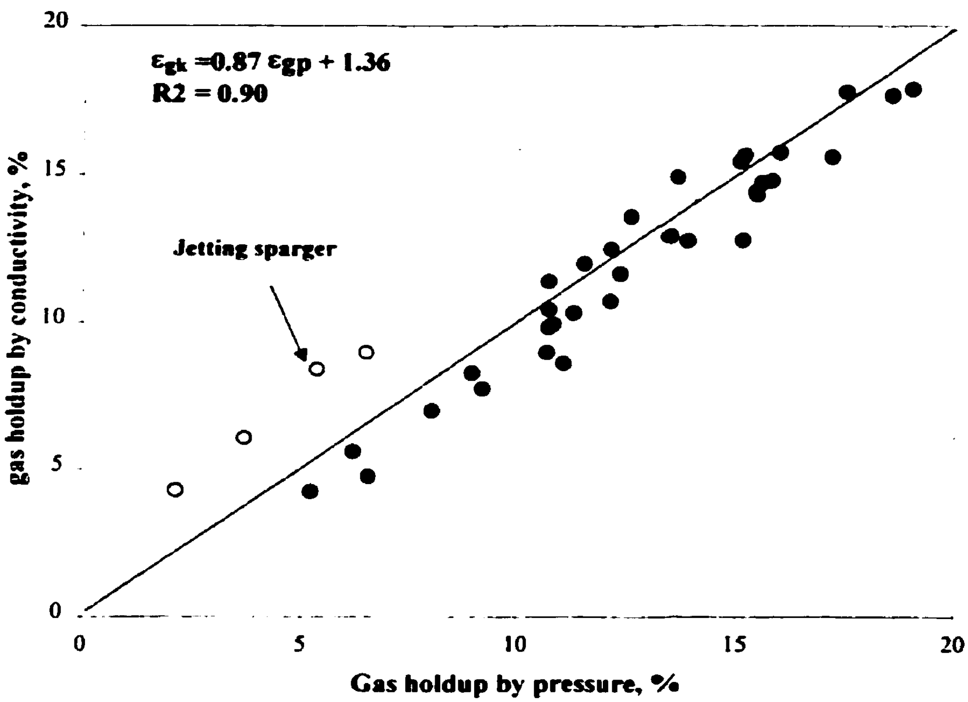


Figure 6.1. Gas holdup estimates from conductivity and pressure measurements for BOWATER tests. Every point is the average of 15 minutes of stable operation. See Appendix E, Table E.1.

To test it if the difference is significant, the t-student value for paired samples must satisfy $-2.03 < t\ (= 1.61) < 2.03$, where 2.03 is obtained for 95% confidence and 36 degrees of freedom (t distribution). From this analysis we can conclude that the gas holdup obtained from conductivity (11.42% ± 0.44%) is not different from the value given by pressure (11.77%). A slope analysis (m = 0.87 ± 0.02) suggests that the gas holdup obtained from conductivity, tends to underestimate the one obtained from pressure at low gas holdup, and to overestimate, at high values.

6.2. Effect of Gas Holdup on Flotation Efficiency

The relationship between flotation efficiency and gas holdup for two residence times (3 and 6 min) is shown in Figure 6.2. It is clear that gas holdup affects the flotation efficiency, but the latter is also affected by the residence time, as we expected from the discussion in Section 2.7.

Another factor that can affect flotation efficiency is the froth height. Figure 6.3 shows flotation efficiency versus gas holdup for two froth heights (50 and 100 cm). For this particular case, Figure 6.3 shows froth height does not seem to strongly affect the flotation performance. One might have expected a higher recovery in the 50-cm froth case.

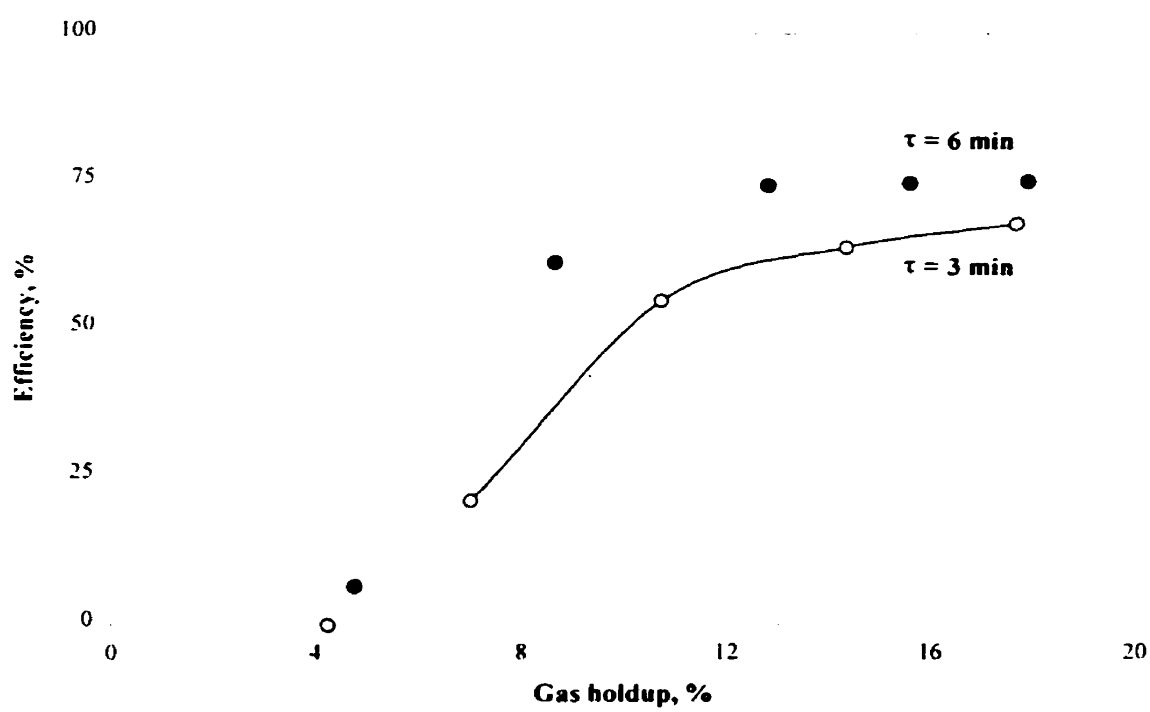


Figure 6.2. Gas holdup effect on flotation efficiency for two residence times (3 and 6 min). Froth height (H_f) is 100 cm. See Appendix E, Tables E.2 and E.3.

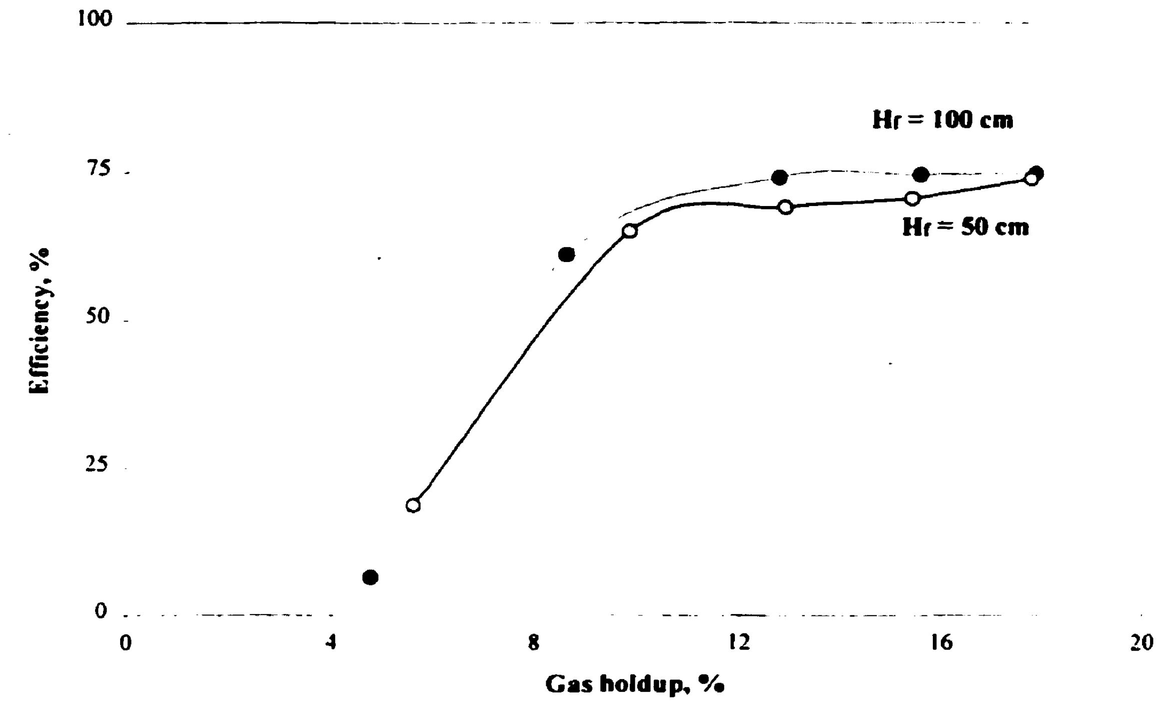


Figure 6.3. Gas holdup effect on flotation efficiency for two froth heights (50 and 100 cm). $\tau = 3$ min. See Appendix E. Tables E.2 and E.3.

The effect of sparger surface area, A_s, on gas holdup, for two conditions, is shown in Figure 6.4. When sparger surface area decreases, gas holdup decreases for the same J_g, as seen in Section 2.8.2. From this figure, we can see that the sensor reveals changes in the noise of the gas holdup signal. It implies that the signal noise is related to the bubble size, which increases as the number of spargers decreases. Thus, the gas holdup sensor could be a useful diagnostic tool to monitor the sparger.

A test was performed to evaluate if two similar values of gas holdup, obtained with different sparger surface areas, give similar flotation efficiency. Figure 6.5 shows the results for two initial conditions.

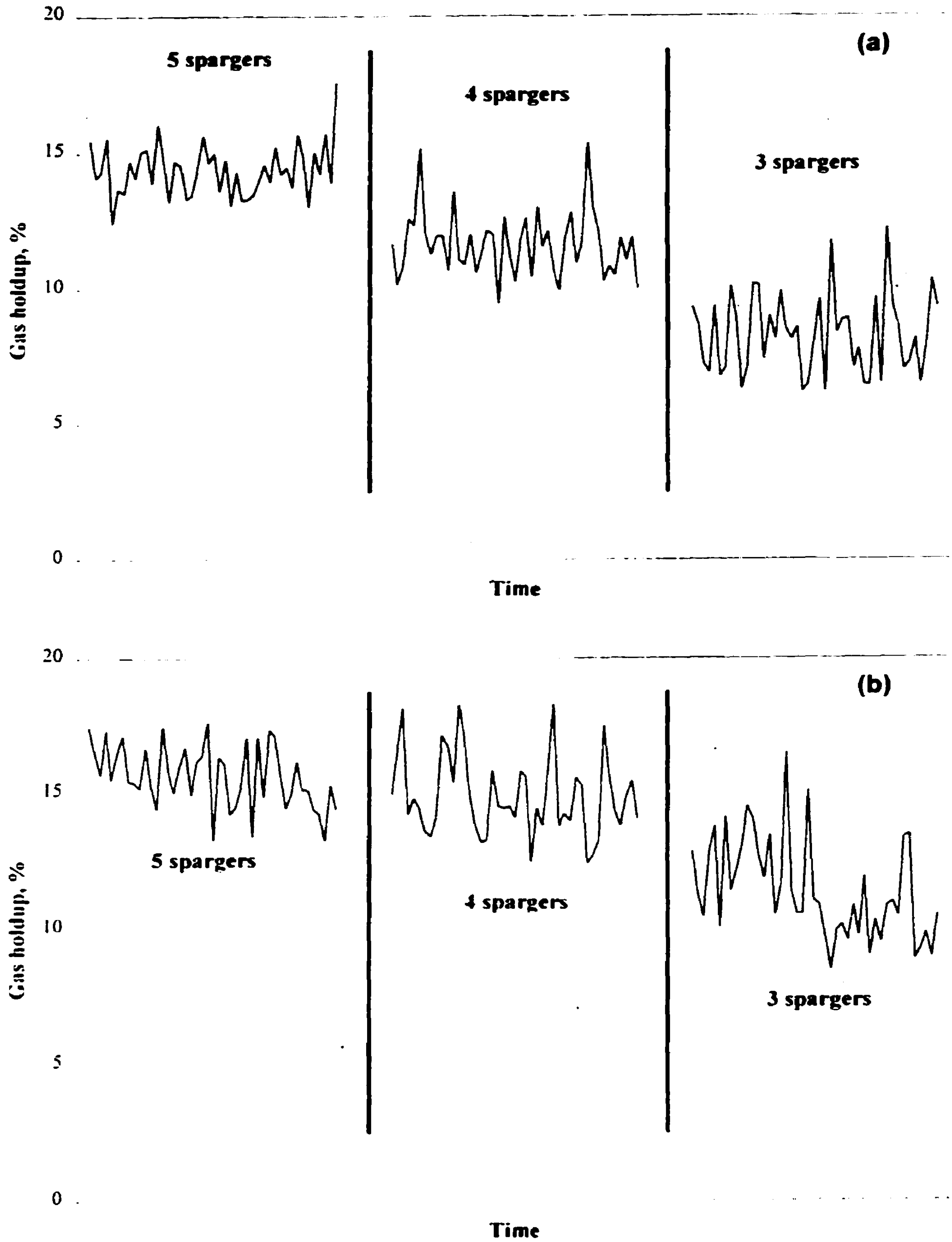


Figure 6.4. Effect of sparger surface area on gas holdup for two conditions: (a) H_f =100 cm; τ = 6 min; J_g = 2.5 cm/s (b) H_f = 100 cm τ = 3 min; J_g = 2.5 cm/s . See Appendix E, Tables E.3 to E.9.

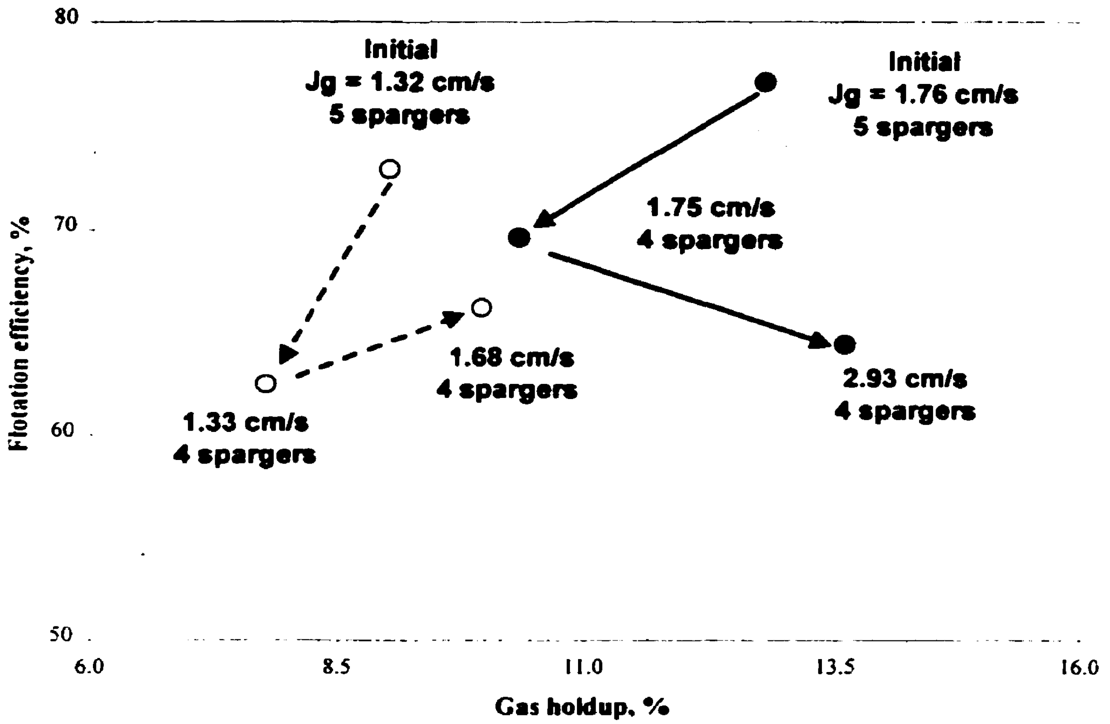


Figure 6.5. Effect of sparger surface area on flotation efficiency. $H_f = 50$ *cm;* $\tau = 7$ *min. See Appendix E, Tables E.2 and E.3.*

Figure 6.5 indicates that gas holdup alone cannot define flotation efficiency. From this figure we can see that a gas holdup even higher than the initial one, produces a lower flotation efficiency. We assume here that the system chemistry has not changed during the test, which should be verified in future work.

From Section 2.9, a relationship between gas holdup and flotation performance could be expected. Figure 6.6 presents flotation efficiency versus gas holdup for residence times close to 6 min. A relationship is suggested. A model fit is given with the parameters and a χ^2 statistic indicated.

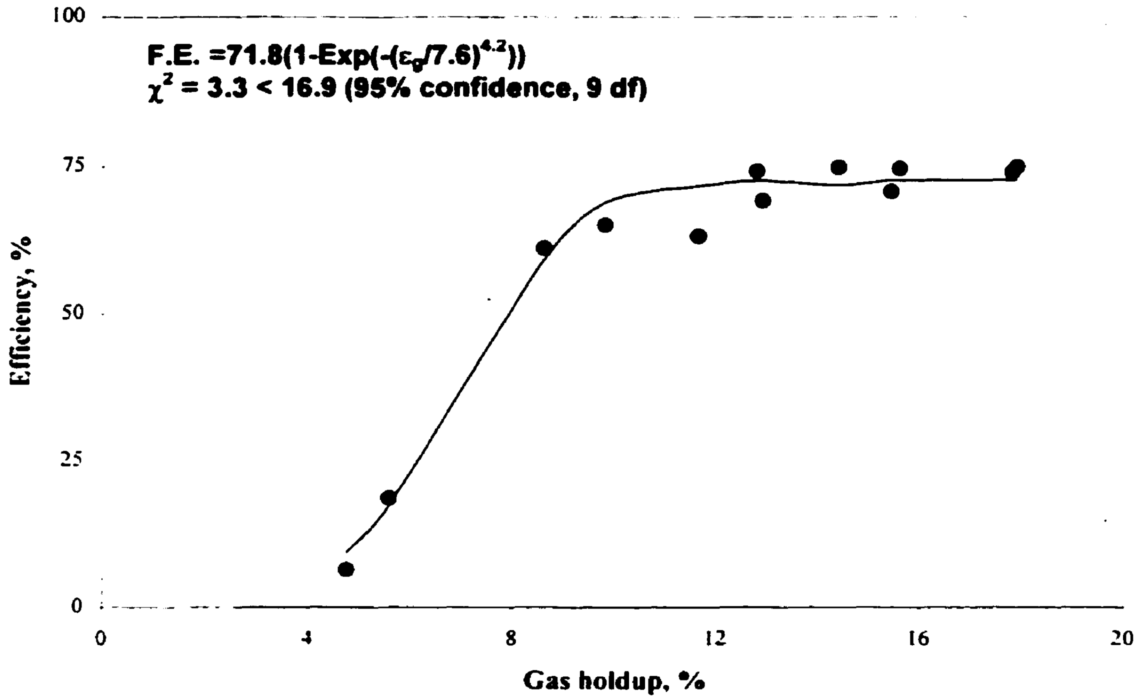


Figure 6.6.Flotation efficiency versus gas holdup for $\tau \approx 6$ min. See Appendix E, Tables E.2 and E.3.

A relationship between gas holdup and flotation rate constant has been reported in mechanical cells for particular cases [1]. Figure 6.7 shows the gas holdup versus the collection zone rate constant, k_c. The collection zone rate constant was estimated using the considerations outlined in Section 2.7 (plug flow), assuming R_f equal to 0.5 (same for froth height of 50 and 100 cm). All the results are shown in Appendix E, Table E.10.

It is evident from Figure 6.7 that there is some correlation (R^2 = 0.72) between the collection zone rate constant and the gas holdup. The scatter in the data could be explained by changes in the chemistry or rheology of the feed during the tests.

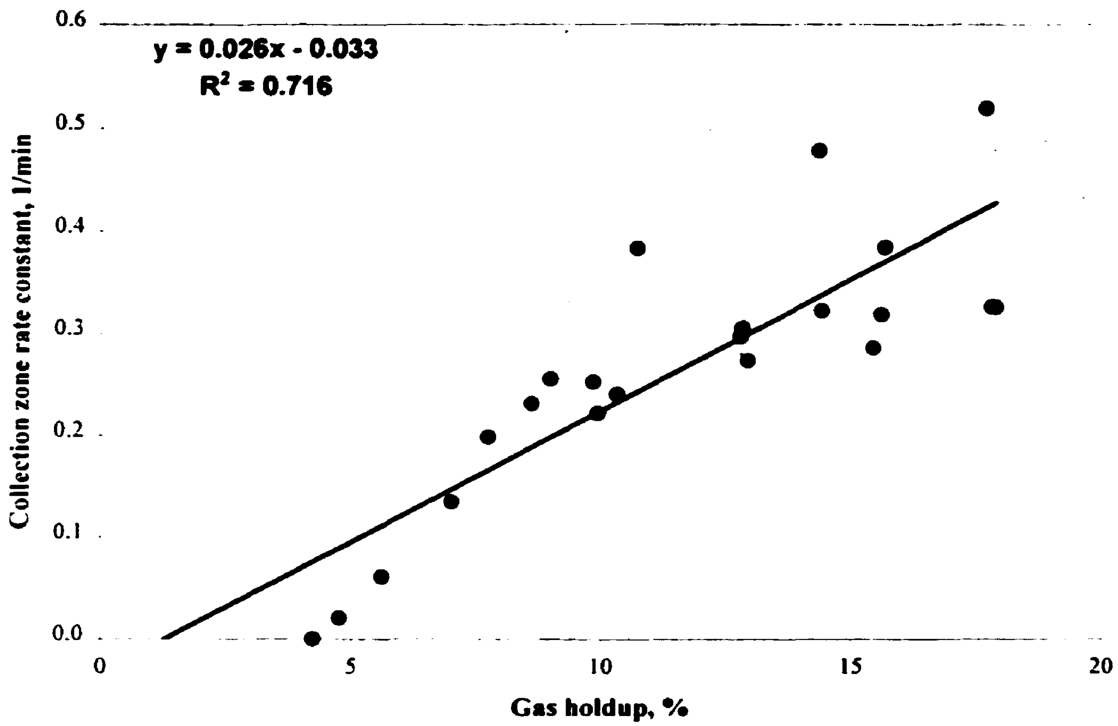


Figure 6.7. Collection zone rate constant versus gas holdup. Plug flow inside the column was assumed to calculate rate constant. Froth recovery, R_f, is equal 50%.. See Appendix E. Tables E.2 and E.10.

6.3. Relationship between S_b and ε_g

To estimate the bubble surface area flux, the bubble diameter was calculated using drift flux analysis (described in Section 2.10). The properties of the liquid were assumed to be those of water (μ_{sl} = 0.01 g/cms; ρ_{sl} = 1.0 g/cm^3) and bubbles were considered without a load of particles (ρ_b = 0 g/cm^3). Results giving bubble diameters bigger than 0.2 cm were discarded.

Figure 6.8 shows a linear relationship between gas the holdup and the bubble surface area flux, as expected from Section 2.9. This relationship shows a good fit (R^2 = 0.95).

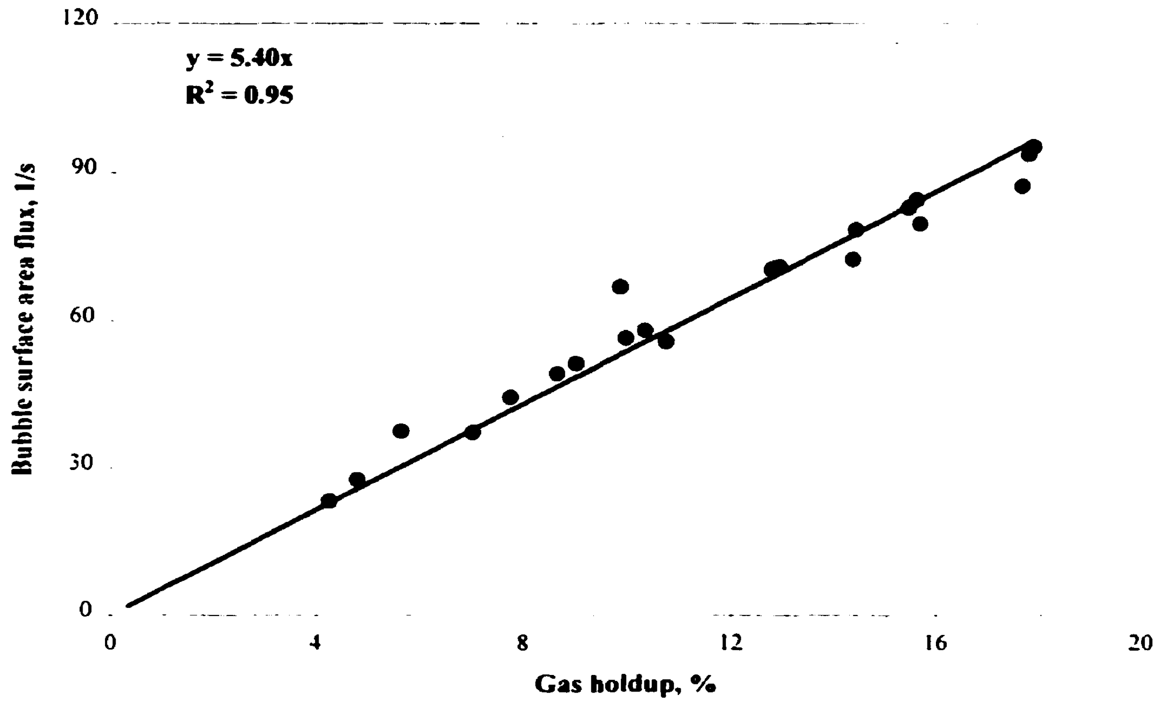


Figure 6.8. Bubble surface area flux versus gas holdup at 323 K and pressure P. Every point is the average of 15 minutes of stable operation. See Appendix E, Table E.10.

Following Figure 6.8, if we plot J_g/d_b (at a pressure and temperature of the gas holdup measurement) versus gas holdup, we obtain another linear relationship (see Figure 6.9). This time however, a slight improvement in the fit is observed ($R^2 = 0.96$). Such a relationship could be used to estimate the bubble diameter for a given application.

Bubble surface area flux has been reported having a linear relationship with the flotation rate constant [1]. From Figure 6.8 we could anticipate also a linear relationship between gas holdup and the flotation rate constant. But, as we saw in Figure 6.7, the gas holdup is not linearly related to the flotation rate constant.

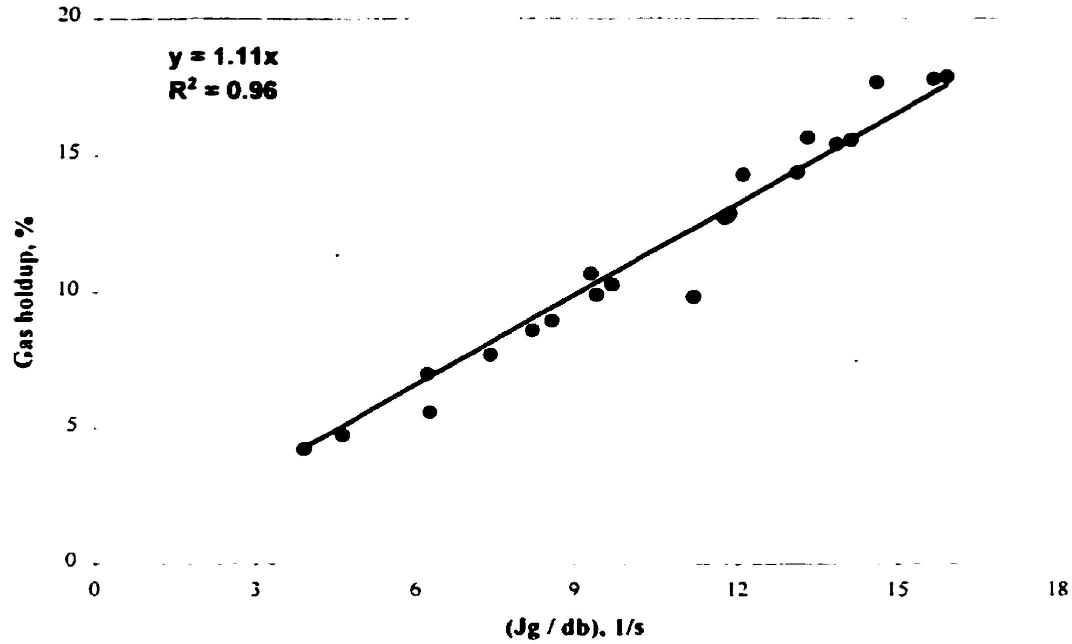


Figure 6.9. Gas holdup versus ratio Jg/db (at 323 K and pressure of measurement). Every point is the average of 15 minutes of stable operation. See Appendix E. Tables E.2 and E.3.

Figure 6.10 indicates some degree of correlation between bubble surface area flux and the collection zone rate constant. The intercept represents the minimal S_b required for overflow of the column ($S_b^o = 13$ 1/s).

To explain the linear relationship between gas holdup and bubble surface area evident in Figure 6.8, consider a bubble surface area moving through a vessel, α (m^2/s), and a section of the vessel of length h (m), with a gas holdup ε_g (%). Then, the time taken by α to pass through h, τ_α (s), is given by:

$$\tau_\alpha = \left(\frac{\pi d_b^2}{\frac{1}{6}\pi d_b^3} \right) \frac{A_c h \varepsilon_g}{100\alpha} = \frac{6}{100}\left(\frac{h}{d_b} \right) \frac{\varepsilon_g}{\alpha / A_c} = \frac{6}{100}\left(\frac{h}{d_b} \right) \frac{\varepsilon_g}{S_b} \qquad 6.1$$

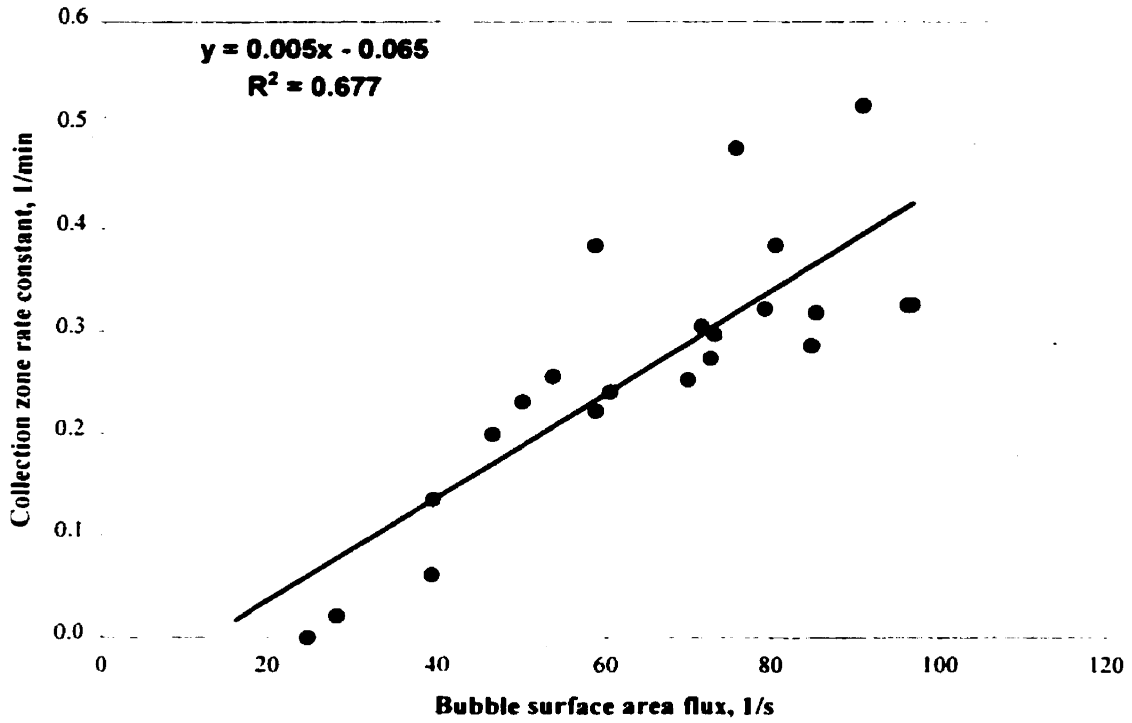


Figure 6.10. Collection zone rate constant versus bubble surface area flux (at 273 K and pressure P). Plug flow was assumed to calculate the rate constant. See Appendix E. Tables E.2 and E.10.

If we take h = d_b, then we have a τ_a'' that is independent of d_b. Rearranging Equation 6.1:

$$S_b = \frac{6}{100\tau_a''}\varepsilon_g \qquad 6.2$$

The parameter τ_a'' must be a function of the superficial liquid velocity, the rheology (viscosity and density of the liquid), and bubble load. From Figure 6.8 we can see that the parameter τ_a'' was independent of J_T (the superficial liquid rate) for these tests. If the system had any significant fluctuation in rheology, a non-linear relationship between gas holdup and bubble surface area flux would be expected. In this case, a linear relationship was obtained, with constant τ_α^o. This suggests a constant rheology or may just be an artifact of taking water as the liquid to estimate bubble size using the drift flux analysis. To have considered a constant rheology (water) may explain the absence of a better correlation between the bubble surface area flux and flotation rate constant.

Substituting Equation 2.19 in Equation 6.2 and rearranging:

$$\varepsilon_g = 100\tau_\alpha^o\left(\frac{J_g}{d_b}\right) \qquad 6.3$$

This relationship is demonstrated in Figure 6.9. Taking the slope of the plot in Figure 6.8, we have that τ_α^o is about 11 ms. Therefore, the bubble diameter can now be estimated directly from Equation 6.3.

CHAPTER 7: CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

Some criteria to design the gas holdup probe were established:

- The electrode width is a critical parameter in a conductivity flow cell design. An electrode width equal to a quarter of the cell diameter is recommended.
- The lowest possible cell constant is recommended. Cells with low cell constant behave closer to ideality (less deviation from geometrical cell constant).
- A simple relationship for three electrode cells was verified, which relates the geometrical cell constant to the gap between electrodes.
- A new syphon cell design, having a conical bottom with a small orifice, was presented.
- The syphon cell diameter was increased (7.5 cm) from the original design to allow a larger diameter orifice, which decreases the chance of plugging.

- An equation that relates the velocity inside the syphon cell (cylindrical part) to the gas holdup and the orifice diameter was presented. The fluid velocity inside the cell must be lower than the terminal velocity of the rising bubbles to ensure a free-bubble environment inside the syphon cell.

The new design of the gas holdup probe was tested 17 days at INCO Matte Separation Plant (Copper Cliff, Ontario). The syphon cell did not plug. The gas holdup probe was able to detect changes in gas holdup upon changes in air flow rate. Flotation performance (recovery) did not change with air flow rate, probably due to uncontrolled changes in froth depth.

Tests carried out in waste paper de-inking at BOWATER (Gatineau, Quebec) showed the gas holdup values obtained by the probe agreed with those obtained from pressure measurements. This indicates that a bubble-free environment was obtained inside the syphon cell.

Tests carried out using sparger surface areas showed that the noise associated to the gas holdup signal could be related to the bubble diameter. This noise may be used to diagnose sparger operation.

Gas holdup is an important variable in flotation, but alone does not define flotation performance. The relationship between the gas holdup and the collection zone rate constant showed some degree of correlation. Chemistry and rheology of the feed are other factors to be considered. Bubble surface area flux also showed little correlation with the collection zone rate constant.

The dispersion in the S_b data might be related to the assumption made to calculate the bubble diameter using the drift flux analysis.

From a conceptual analysis, the bubble surface area flux would be a function of the gas holdup and a parameter τ_α^o. This parameter is defined as the time it takes a bubble surface area, moving through a vessel, to cover a distance equal to the bubble diameter. This parameter seems to be constant for a system with constant rheology. A linear relationship between gas holdup and bubble surface area flux is predicted. This linear relationship was verified in Chapter 6.

7.2 Future Work

The potential use of this sensor in the diagnostic of sparger operation may justify further exploratory research in that direction. Trying to relate changes in the noise of the gas holdup signal to changes in bubble diameter is one approach.

An exhaustive analysis of the gas holdup relation to the bubble surface area flux is recommended. Mineral systems may have smaller changes in rheology than those we suspect occurred for waste paper de-inking.

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APPENDIX A

Table A.1. Conductivity and conductance values obtained for two 3-electrode cells. Data obtained by Francisco Tavera [4]

D = 10.1 cm L = 10 cm w = 2.55 cm		D = 7.6 cm L = 10 cm w = 1.9 cm	
k (mS/cm)	K (mS)	k (mS/cm)	K (mS)
0.769	9.64	0.279	2.54
1.287	15.76	0.858	6.34
2.1	24.72	1.72	12.18
3.13	35.42	2.85	19.70
4.18	45.80	4.14	28.16
5.84	61.20	5.34	35.32
6.79	69.80	6.83	44.40
8.2	81.40	7.94	50.60

Table A.2. Cell constant values (measured and geometrical) for 4 cell diameters (3-electrode cells). Data obtained by Francisco Tavera [4]

D (cm)	10.1		[illegible]			6.5			5.1		
L (cm)	10		10			10			10		
W (cm)	2.55		1.9			1.6			1.25		
k	Cell Constant		k	Cell Constant		k	Cell Constant		k	Cell Constant	
mS/cm	Meas.	Geom.	mS/cm	Meas.	Geom.	mS/cm	Meas.	Geom.	mS/cm	Meas.	Geom.
0 769	12 54	10.61	0.28	9.10	6.57	0.65	5.08	4.72	0.50	3.62	3.27
1 287	12 25	10.61	0.86	7.39	6.57	1.42	5.14	4.72	1.02	3.60	3.27
2 1	11 77	10.61	1.72	7.08	6.57	1.95	5.08	4.72	1.67	3.56	3.27
3 13	11 32	10.61	2.85	6.91	6.57	2.58	4.97	4.72	3.04	3.46	3.27
4 18	10 96	10.61	4.14	6.80	6.57	3.37	4.92	4.72	4.35	3.38	3.27
5 84	10 48	10.61	5.34	6.61	6.57	4.46	4.84	4.72	5.65	3.35	3.27
6 79	10 28	10.61	6.83	6.50	6.57	5.65	4.76	4.72	6.88	3.29	3.27
8 2	9 93	10.61	[illegible]	[illegible]	[illegible]	[illegible]	4.67	4.72	7.95	3.27	3.27

Table A.3. Cell constants (measured and geometrical) for three electrode width (3-electrode cells). D = 7.5 cm; L = 10 cm. Data obtained by Francisco Tavera [4]

W (cm)	1.9		1.0			0.5		
k	Cell Constant		k	Cell Constant		k	Cell Constant	
mS/cm	Meas.	Geom.	mS/cm	Meas.	Geom.	mS/cm	Meas.	Geom.
0.28	9.10	6.57	0.55	7.23	7.56	0.86	6.51	8.25
0.86	7.39	6.57	1.03	7.00	7.56	1.27	6.39	8.25
1.72	7.08	6.57	1.99	6.74	7.56	2.32	5.99	8.25
2.85	6.91	6.57	3.07	6.44	7.56	3.22	5.79	8.25
4.14	6.80	6.57	4.13	6.30	7.56	4.40	5.47	8.25
5.34	6.61	6.57	5.39	6.15	7.56	5.45	5.30	8.25
6.83	6.50	6.57	6.64	5.99	7.56	6.61	4.98	8.25
7.94	6.37	6.57	7.60	5.87	7.56	8.07	4.95	8.25

Table A.4.a. Liquid velocity inside the syphon cell as function of gas holdup and H (as defined in Figure 3.5). Data for different d_h.

14 mm			16 mm			18 mm		
H (cm)	Eg (%)	VA (cm/s)	H (cm)	Eg (%)	VA (cm/s)	H (cm)	Eg (%)	VA (cm/s)
2.6	5.2	2.20	3.0	6.0	3.09	2.5	5.0	3.56
4.1	8.2	2.87	3.4	6.8	3.29	3.6	7.2	4.20
5.6	11.2	3.30	5.4	10.8	4.36	4.0	8.0	4.47
7.4	14.8	3.84	5.8	11.6	4.44	6.2	12.4	5.67
11.1	22.2	4.71	9.7	19.4	5.79	6.7	13.4	5.94
11.1	22.2	4.75	11.0	22.0	6.21	8.7	17.4	6.70
15.5	31.0	5.59	14.7	29.4	7.28	8.9	17.8	6.82
19.9	39.8	6.30	16.3	32.6	7.60	11.8	23.6	7.96
			19.0	38.0	8.31	12.2	24.4	8.11
						14.5	29.0	8.85
						15.1	30.2	9.10
						17.3	34.6	9.75
						18.1	36.2	10.00

Table A.4.b. Continuation fron Table A.4.a.

20 mm			22mm		
H (cm)	Eg (%)	VA (cm/s)	H (cm)	Eg (%)	VA (cm/s)
1.9	3.8	3.85	1.6	3.2	4.50
2.3	4.6	4.56	2.7	5.4	4.91
4.6	9.2	5.87	4.0	8	6.50
6.7	13.4	7.32	4.9	9.8	7.33
8.5	17.0	8.36	4.9	9.8	7.29
9.0	18.0	8.66	6.6	13.2	8.68
11.0	22.0	9.54	7.8	15.6	9.51
12.6	25.2	10.33	8.1	16.2	9.52
14.8	29.6	11.21	9.3	18.6	10.33
15.8	31.6	11.69	10.1	20.2	10.99
15.9	31.8	11.61	10.3	20.6	11.03
16.3	32.6	11.81	11.1	22.2	11.44
17.1	34.2	11.94	11.9	23.8	11.86

APPENDIX B

Module INITIAL

Variable definition

```
Option Explicit

Dim dia$
Dim hor$
Dim filn$
Dim d As Long
Dim b As Integer
Dim i As Integer
Dim dummy As Integer
Dim InputMode As Integer        ' best AI mode, modified by Get_LDD_Info
Dim StopEventType As Integer    ' manual (single) or automatic (continuous)
Dim TriggerSource As String     ' trigger source
Dim AI_Channel As Integer       ' A/D channel
Dim vbdataarray1() As Single    ' VB array to store voltage values
Dim SampleRate As Long          ' sample rate in Hz
Dim SampleTime As Single        ' calculated display time interval for graph
Dim numsamples As Integer       ' number of samples
Dim NumGraphPoints As Integer   ' number of points to graph
Dim UpdatingGraph As Integer    ' flag to indicate data is being processed
```

Sub Form_Load ()

```
'initialize program variables
   InitGlobalVars
'activating readings
   b = 1
'setting open cell: relays 1 and 2
   d = 3
'open file that contains parameters
   Open "c:\holdup\kparam ini" For Random As #1 Len = 6
'loading conductivity meter parameters (3 ranges)
   Get #1, 1, ar1
   Get #1, 2, br1
   Get #1, 3, cr1
   Get #1, 4, ar2
   Get #1, 5, br2
   Get #1, 6, cr2
   Get #1, 7, ar3
   Get #1, 8, br3
```

```
   Get #1, 9, cr3
'defining active conductivity meter range
   Get #1, 22, r
'loading open cell parameters
   Get #1, 10, ao1
   Get #1, 11, bo1
   Get #1, 12, co1
'loading syphon cell parameters
   Get #1, 13, as1
   Get #1, 14, bs1
   Get #1, 15, cs1
   Close #1
'setting relays related to the conductivity meter
   If r = 1 Then a = 0
   If r = 2 Then a = 40960
   If r = 3 Then a = 61440
'setting control status
   editexesr.Enabled = False              'start disable
   command2.Enabled = False               'sensor disable
   command3.Enabled = False               'conductivity meter disable
   command5.Enabled = False               'end disable
   command1.Enabled = True                'stop enable
'setting date and time
   dia$ = Date$
   hor$ = Time$
'defining name of data file
   filn$ = "c:\data\" + Mid$(dia$, 9, 2) + Left$(dia$, 2) + Mid$(dia$, 4, 2) + ".dat"
'displaying date and time on INITIAL from
   fecha.Caption = dia$
   hora.Caption = Time$
'closing relays
   rel.DOScalar = d + a
   rel.ArmState = 1                       'running relay control

End Sub

Sub InitGlobalVars ()

'initialize variables
        'AI_Channel = 0
        'SampleRate = 10000
        'numsamples = 1500
        StopEventType = DL_TCEVENT

End Sub
```

```
Sub rel_ProcessDone (WarningCode As Integer)
'routine associated to relay control

    rel.ArmState = 2                        'stopping relay control
    Call waiting(8)                         'calling delay routine
    das8                                    'calling A/C converter routine
End Sub

Sub waiting (s As Integer)
'delay routine

Dim ax As Integer
Dim ttt$
Dim tnew$
Dim tne
Dim told

         ax = 0
        told = 0
30       ttt$ = Time$
         tnew$ = Mid$(ttt$, 8, 1)
         tne = Asc(tnew$)
        If told = 0 Then told = tne
        If tne = told GoTo 30
        ax = ax + 1
        told = tne
        If ax < s GoTo 30

End Sub

Sub das8 ()
'A/C converter routine

ReDim vbdataarray1(1500)
Dim j As Integer
Dim in As Integer
'defining number of samples and sampling rate (Hz)
    numsamples = 1500
    SampleRate = 10000
'initializing A/C converter board
     init_device sr_ai
'defining A/C converter parameters
     sr_ai.Req_op = dl_device
     sr_ai.Req_device = 0
     sr_ai.Req_subsystem = dl_ai
     sr_ai.Req_mode = dl_polled
'starting A/C converter
```

```
      sr_ai.Req_op = dl_start
      sr_ai.Refresh
' Call procedure to start data acquisition
GetAnalogBuffer sr_ai, InputMode, AI_Channel, numsamples, SampleRate,
StopEventType
'Filling the output array
      dummy = VBArrayBufferConvert(sr_ai, 0, 0, numsamples, vbdataarray1(0),
      DL_tsingle, 0, 0)

End Sub
```

Sub SR_AI_ServiceDone (task As Integer, device As Integer, subsystem As Integer, mode As Integer)

```
'routine associated to A/C converter control

      If (d = 3) Then                          'identifying cell
'calculating the average voltage measured for the open cell
         aux = 0
         For i = 1 To 1500
           aux = aux + vbdataarray1(i)
         Next i
         vo = aux / 1500
'calculating open cell conductance
         aux = conductance(r, vo)
         vo1 = vo
'calculating open cell conductivity
         ko = ao1 + bo1 * aux + co1 * aux * aux
'displaying open cell conductivity
         advalue1.Text = Format(Str$(ko), "#.##")
         advalue1.Refresh
         advalue1.ArmState = 1                'running open cell label control

      Else
'calculating the average voltage measured for the syphon cell
         aux = 0
         For i = 1 To 1500
           aux = aux + vbdataarray1(i)
         Next i
         vs = aux / 1500
'calculating syphon cell conductance
         aux = conductance(r, vs)
         vs1 = vs
'calculating open cell conductivity
         ks = as1 + bs1 * aux + cs1 * aux * aux
'displaying open cell conductivity
```

```
        advalue2.Text = Format(Str$(ks), "#.##")
        advalue2.Refresh
        advalue2.ArmState = 1          'running syphon cell label control
End If

End Sub
```

Function conductance (r As Integer, aux As Single) As Single

```
  If r = 1 Then conductance = ar1 + br1 * aux + cr1 * aux * aux
  If r = 2 Then conductance = ar2 + br2 * aux + cr2 * aux * aux
  If r = 3 Then conductance = ar3 + br3 * aux + cr3 * aux * aux

End Function
```

Sub ADVALUE1_ProcessDone (WarningCode As Integer)

```
'routine associated to open cell label control

  advalue1.ArmState = 2             'stopping label control
  d = 12                            ' setting syphon cell: relays 3 and 4
  relay (a + d)                     ' calling relay routine

End Sub
```

Sub relay (m As Long)

```
'relay routine

'closing relays
  form1.rel.DOScalar = m            'setting relays
  form1.rel.Refresh
  form1.rel.ArmState = 1            'running relay control
End Sub
```

Sub ADVALUE2_ProcessDone (WarningCode As Integer)

```
'routine associated to syphon cell label control

  advalue2.ArmState = 2             'stopping label control
  d = 3                             'setting open cell relays: 1 and 2
  graph1.ArmState = 1               'running conductivity graph control

End Sub
```

Sub Graph1_ProcessDone (WarningCode As Integer)

```
'routine associated to conductivity graph control

Dim aux1 As Currency
Dim aux2n As Single
```

```
Dim aux3n As Single
        graph1.ArmState = 2              'stopping conductivity graph control
        aux2n = Val(advalue1.Text)
        If aux2n < .01 Then aux2n = .001
        aux3n = Val(advalue2.Text)
        If aux3n < .01 Then aux3n = .001
'calculating ratio γ
        aux1 = (aux2n) / (aux3n)
'calculating gas holdup
        aux1 = (1 - aux1) / (1 + .5 * aux1)
        eg = aux1 * 100
        holdup.Text = Str$(eg)           'displaying gas holdup value
        holdup.Refresh
        holdup.ArmState = 1              'running gas holdup label control

End Sub
```

Sub holdup_ProcessDone (WarningCode As Integer)

```
'routine associated to gas holdup label control

        holdup.ArmState = 2              'stopping gas holdup label control
        GRAPH2.ArmState = 1              'running gas holdup graph control

End Sub
```

Sub graph2_ProcessDone (WarningCode As Integer)

```
'routine associated to gas holdup graph control

  GRAPH2.ArmState = 2           'stopping gas holdup graph control
'open file to save data
         Open filn$ For Append As #1
  Print #1, hor$, Format(vo1, "#.###"), Format(vs1, "#.###")
  Close #1
'determining if click on stop
  If b = 0 Then
         'stopping data acquisition
              b = 1
              d = 3                           'setting open cell: relays 1 and 2
              editexesr.Enabled = True        'start enable
              command2.Enabled = True         'sensor enable
              command3.Enabled = True         'conductivity meter enable
              command5.Enabled = True         'end enable
              editexesr.SetFocus
              GoTo 100                        'stop data acquisition
  End If
  Start                                       'calling routine start
```

```
100 End Sub

Sub start ()
'routine start

'defining date and time
        hor$ = Time$
        dia$ = Date$
'defininig name of data file
        filn$ = "c:\data\" + Mid$(dia$, 9, 2) + Left$(dia$, 2) + Mid$(dia$, 4, 2) +
        ".dat"
'displaying data and time
        fecha.Caption = dia$
hora.Caption = Time$
relay (a + d)                          'calling relay routine

End Sub
```

```
'if a control (button) is enable can induce an event (click)

Sub Command1_Click ()
'routine executed after click on stop button

        b = 0
        command1.Enabled = False            'stop button disable

End Sub

Sub Command2_Click ()
'routine executed after click on conductivity meter button

        form1.Enabled = False               'initial form disable
        form3.Show                          'Go to conductivity meter module

End Sub

Sub Command3_Click ()
'routine executed after click on sensor button

        form1.Enabled = False               'initial form disable
        form2.Show                          'Go to sensor module

End Sub
```

Sub editexesr_click ()

```
'routine executed after click on start button

    editexesr.Enabled = False             'start button disable
    command2.Enabled = False              'sensor disable
    command3.Enabled = False              'conductivity meter disable
    command5.Enabled = False              'end button disable
    command1.Enabled = True               'stop button enable
    command1.SetFocus
    start                                 'calling start routine

End Sub
```

Sub Command5_Click ()

```
'routine executed after click on end button

        End                               'end of program

End Sub
```

Module General

```
'Copyright 1994 DriverLINX/VB Source Code Example Library

Option Explicit

Dim i As Integer
Dim dummy As Integer
Global aux As Single
Dim Sample() As Single
Dim NumSamples As Integer
Dim numChannels As Integer

' Conductivity meter parameters
        Global r As Integer
' Range 0.1
        Global ar1 As Single
        Global br1 As Single
        Global cr1 As Single
' Range 1.0
        Global ar2 As Single
        Global br2 As Single
        Global cr2 As Single
' Range 10
        Global ar3 As Single
        Global br3 As Single
```

```
        Global cr3 As Single

' Siphon cell parameters
        Global as1 As Single
        Global bs1 As Single
        Global cs1 As Single
' Open cell parameters
        Global ao1 As Single
        Global bo1 As Single
        Global co1 As Single

Global ko As Single
Global ks As Single
Global eg As Single
Global vo As Single
Global vs As Single

Global a As Long

Global vo1 As Single
Global vs1 As Single

Sub GetAnalogBuffer (SR As Control, Mode As Integer, Channel As Integer,
NumSamples As Integer, SampleRate As Long, StopEventType As Integer)

  ' Specify timing event
  SR.Evt_Tim_type = DL_RATEEVENT
  SR.Evt_Tim_rateChannel = DL_DEFAULTTIMER
  SR.Evt_Tim_rateMode = DL_RATEGEN
  SR.Evt_Tim_rateClock = DL_INTERNAL1

  '1/sample rate in Hz
  SR.Evt_Tim_ratePeriod = DLSecs2Tics(SR, SR.Evt_Tim_rateChannel, (1 /
SampleRate))

  ' Specify start event
  SR.Evt_Str_type = DL_COMMAND
  '  SR.Evt_Str_type = DL_AIEVENT
  '  SR.Evt_Str_aiChannel = 0
  '  SR.Evt_Str_aiGainCode = DLGain2Code(SR, -1)
  '  SR.Evt_Str_aiUpperThreshold = 1000
  '  SR.Evt_Str_aiLowerThreshold = 900
  '  SR.Evt_Str_aiSlope = True

  ' Specify stop event
  SR.Evt_Stp_type = StopEventType
```

```
 ' Specify number and size of buffers
 SR.Sel_buf_N = 1
 SR.Sel_buf_size = DLSamples2Bytes(SR, Channel, NumSamples)
 SR.Sel_buf_notify = True

 ' Specify data format and channels to acquire
 SR.Sel_chan_format = DL_tNATIVE
 SR.Sel_chan_N = 2
 SR.Sel_chan_start = 0
 SR.Sel_chan_startGainCode = DLGain2Code(SR, 1) ' unipolar, unity gain
 SR.Sel_chan_stop = Channel
 SR.Sel_chan_stopGainCode = DLGain2Code(SR, 1) ' unipolar, unity gain

 ' Initiate the Service Request
  SR.SR_execute = 1
 ' Display a result message
End Sub
```

Sub init_device (SR As Control)

```
'initialize device and service request control
SR.Req_subsystem = DL_device
SR.Req_mode = DL_other
SR.Req_op = DL_INITIALIZE

SR.Refresh

End Sub
```

APPENDIX C

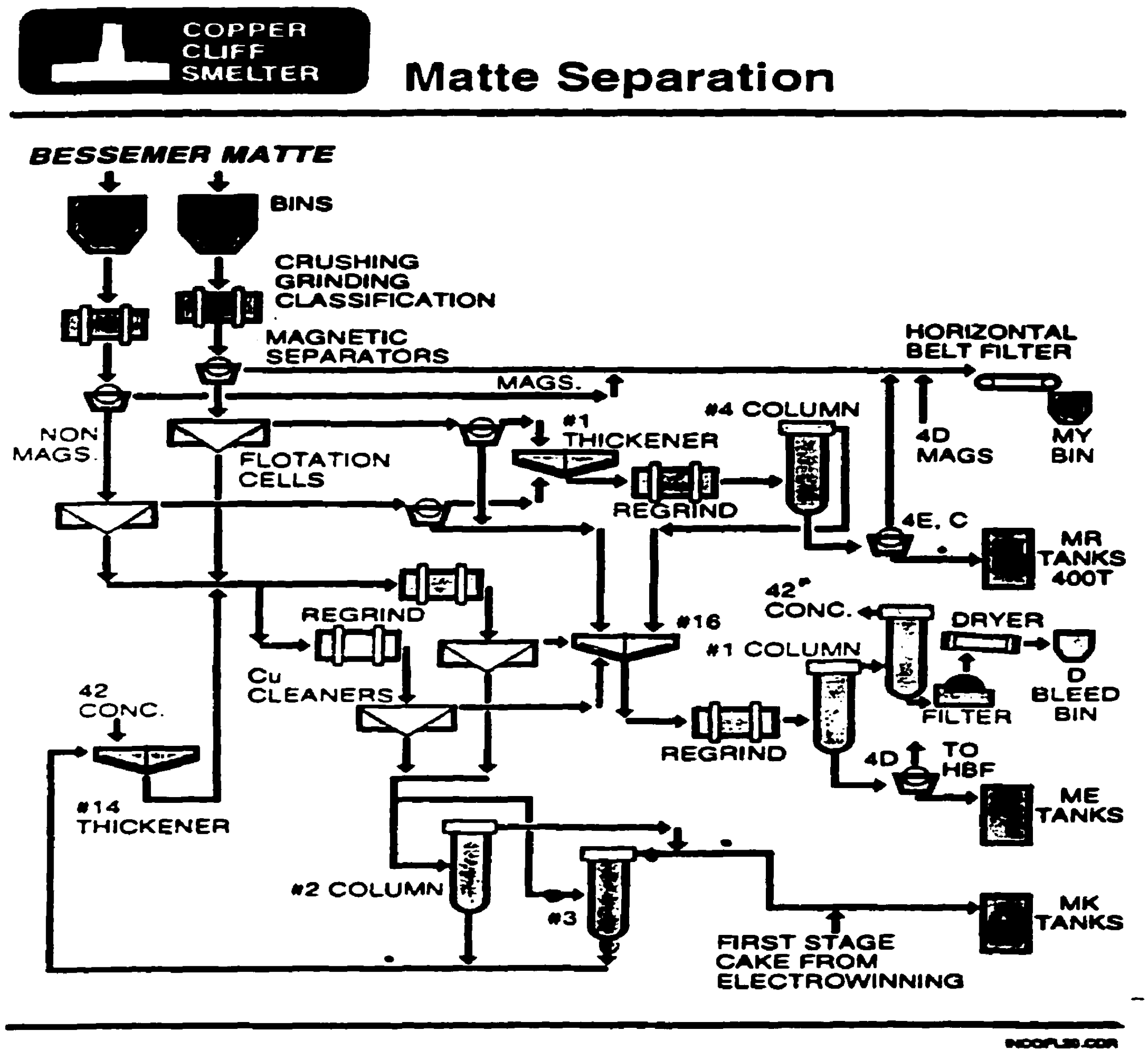

Figure C.1. INCO Matte Separation Plant

Table C.1. Calibration data, conductivity meter for INCO tests.

R (Ohm)	K (mS)	Survey (Volts)								
		1	2	3	4	5	6	7	8	Average
1000	**1.0**	2.069	2.071	2.069	2.068	2.070	2.069	2.067	2.068	**2.069**
201	**5.0**	2.817	2.816	2.820	2.815	2.820	2.817	2.819	2.815	**2.817**
111	**9.0**	3.573	3.572	3.573	3.574	3.575	3.573	3.571	3.575	**3.573**
77	**13.0**	4.298	4.296	4.297	4.296	4.301	4.299	4.302	4.304	**4.299**
59	**16.9**	5.015	5.008	5.014	5.012	5.018	5.016	5.020	5.022	**5.016**
48	**20.8**	5.695	5.694	5.696	5.697	5.706	5.706	5.708	5,707	**5.701**
40	**25.0**	6.402	6.402	6.402	6.400	6.416	6.417	6.420	6.420	**6.410**
34	**29.4**	7.157	7.157	7.162	7.160	7.178	7.175	7.182	7.181	**7.169**
30	**33.3**	7.811	7.809	7.812	7.808	7.835	7.832	7.836	7.838	**7.823**
27	**37.0**	8.387	8.387	8.390	8.385	8.416	8.416	8.423	8.420	**8.403**
25	**40.0**	8.880	8.877	8.880	8.879	8.915	8.911	8.919	8.918	**8.897**

Table C.2. Calibration data, open cell of sensor 1 for INCO tests.

k (mS/cm)	Survey (mS)					
	1	2	3	4	5	Average
0.37	4.20	4.20	4.20	4.20	4.20	**4.20**
0.62	6.05	6.05	6.05	6.05	6.05	**6.05**
0.80	7.39	7.39	7.39	7.40	7.40	**7.39**
1.08	9.55	9.55	9.55	9.56	9.55	**9.55**
1.48	12.47	12.48	12.49	12.48	12.49	**12.48**
1.86	15.16	15.16	15.16	15.16	15.16	**15.16**
2.26	17.93	17.93	17.93	17.93	17.93	**17.93**
2.74	21.11	21.11	21.12	21.12	21.12	**21.12**
3.12	23.81	23.81	23.84	23.85	23.85	**23.83**

Table C.3. Calibration data, syphon cell of sensor 1 for INCO tests.

k (mS/cm)	Survey (mS)					
	1	2	3	4	5	Average
0.37	4.22	4.22	4.22	4.22	4.22	**4.22**
0.62	6.09	6.09	6.09	6.09	6.10	**6.09**
0.80	7.45	7.45	7.44	7.45	7.45	**7.45**
1.08	9.65	9.65	9.65	9.65	9.65	**9.65**
1.48	12.58	12.58	12.58	12.58	12.58	**12.58**
1.86	15.35	15.35	15.35	15.35	15.35	**15.35**
2.26	18.21	18.21	18.21	18.21	18.21	**18.21**
2.74	21.50	21.50	21.50	21.50	21.50	**21.50**
3.12	24.28	24.28	24.28	24.29	24.29	**24.28**

Table C.4. Calibration data. open cell of sensor 2 for INCO tests.

k (mS/cm)	Survey (mS)					
	1	2	3	4	5	Average
4.21	4.21	4.21	4.21	4.21	4.21	0.37
6.07	6.08	6.08	6.08	6.08	6.08	0.62
7.47	7.47	7.47	7.47	7.47	7.47	0.80
9.70	9.70	9.70	9.70	9.70	9.70	1.08
12.70	12.71	12.71	12.72	12.72	12.71	1.48
15.55	15.56	15.56	15.56	15.56	15.56	1.86
18.50	18.51	18.51	18.52	18.52	18.51	2.26
21.93	21.93	21.94	21.94	21.95	21.94	2.74
24.87	24.87	24.89	24.89	24.89	24.88	3.12

Table C.5. Calibration data. syphon cell of sensor 2 for INCO tests.

k (mS/cm)	Survey (mS)					
	1	2	3	4	5	Average
4.33	4.33	4.33	4.33	4.33	4.33	0.37
6.29	6.29	6.29	6.29	6.29	6.29	0.62
7.73	7.73	7.73	7.73	7.73	7.73	0.80
10.05	10.05	10.05	10.05	10.05	10.05	1.08
13.16	13.17	13.17	13.17	13.17	13.17	1.48
16.13	16.14	16.14	16.14	16.14	16.14	1.86
19.20	19.20	19.20	19.20	19.20	19.20	2.26
22.73	22.73	22.73	22.73	22.73	22.73	2.74
25.73	25.74	25.74	25.74	25.74	25.74	3.12

Table C.6. Calibration data. conductivity meter for BOWATER tests.

R (Ohm)	K (mS)	Survey (Volts)								
		1	2	3	4	5	6	7	8	Average
1000	1.00	1.963	1.956	1.950	1.955	1.958	1.964	1.958	1.958	1.958
201	4.98	2.809	2.806	2.793	2.789	2.793	2.796	2.791	2.796	2.797
111	9.01	3.633	3.629	3.632	3.630	3.636	3.640	3.634	3.637	3.634
77	12.99	4.453	4.444	4.459	4.439	4.436	4.444	4.440	4.444	4.445
59	16.95	5.231	5.241	5.242	5.239	5.230	5.234	5.235	5.235	5.236
48	20.83	5.987	6.015	5.975	6.002	6.010	5.998	5.993	6.002	5.998
40	25.00	6.788	6.790	6.782	6.791	6.785	6.789	6.789	6.794	6.789
34	29.41	7.630	7.635	7.639	7.670	7.624	7.635	7.637	7.638	7.639
30	33.33	8.354	8.366	8.358	8.366	8.351	8.372	8.349	8.368	8.361
27	37.04	8.982	9.012	8.991	9.011	9.000	9.002	8.989	9.005	8.999
25	40.00	9.487	9.494	9.488	9.492	9.482	9.494	9.489	9.495	9.490

Table C.7. Calibration data, open cell for BOWATER tests.

k (mS/cm)	Survey (mS)								
	1	2	3	4	5	6	7	8	Average
0.63	6.24	6.24	6.24	6.24	6.24	6.24	6.24	6.24	**6.24**
1.25	10.63	10.63	10.63	10.63	10.63	10.63	10.63	10.64	**10.63**
1.81	14.49	14.49	14.49	14.49	14.49	14.50	14.50	14.50	**14.49**
2.44	18.86	18.87	18.87	18.87	18.86	18.87	18.87	18.87	**18.87**
3.24	24.09	24.09	24.09	24.10	24.10	24.11	24.11	24.11	**24.10**
3.97	29.24	29.24	29.24	29.25	29.25	29.26	29.27	29.27	**29.25**
4.72	34.25	34.25	34.26	34.26	34.26	34.28	34.27	34.28	**34.26**
5.50	39.30	39.30	39.30	39.30	39.31	39.32	39.33	39.33	**39.31**

Table C.8. Calibration data, syphon cell for BOWATER tests

k (mS/cm)	Survey (mS)								
	1	2	3	4	5	6	7	8	Average
0.63	6.27	6.27	6.28	6.28	6.28	6.28	6.28	6.28	**6.28**
1.25	10.67	10.67	10.67	10.67	10.68	10.68	10.68	10.68	**10.68**
1.81	14.51	14.51	14.51	14.51	14.51	14.51	14.51	14.51	**14.51**
2.44	18.82	18.83	18.83	18.83	18.83	18.83	18.83	18.83	**18.83**
3.24	23.91	23.91	23.92	23.92	23.92	23.93	23.92	23.93	**23.92**
3.97	28.93	28.93	28.94	28.93	28.93	28.94	28.94	28.94	**28.94**
4.72	33.73	33.72	33.72	33.72	33.72	33.72	33.72	33.72	**33.72**
5.50	38.56	38.56	38.56	38.55	38.56	38.56	38.56	38.56	**38.56**

APPENDIX D

Table D.1. INCO Matte Separation Plant column 2. Gas holdup data collected March 13 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)
18:09:15	0.83	0.975	10.26
18:24:16	0.81	0.954	10.49
18:39:16	0.79	0.94	11.00
18:54:16	0.79	0.93	10.84
19:09:17	0.77	0.92	11.30
19:24:17	0.76	0.92	11.87
19:39:17	0.77	0.92	11.27
19:54:18	0.78	0.92	10.34
20:09:20	0.79	0.92	9.80
20:24:21	0.81	0.93	8.60
20:39:21	0.82	0.94	8.98
20:54:21	0.83	0.95	9.24
21:09:21	0.83	0.97	9.73
21:24:22	0.85	0.99	9.34
21:39:24	0.88	1.01	8.91
21:54:25	0.89	1.03	8.96
22:09:25	0.92	1.04	8.52
22:24:27	0.92	1.06	8.94
22:39:27	0.93	1.07	9.09
22:54:27	0.94	1.07	8.76
23:09:27	0.94	1.07	8.71
23:24:27	0.94	1.07	8.50
23:39:27	0.93	1.06	8.88

Table D.2. INCO Matte Separation Plant column 2. Gas holdup data collected March 14 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:27	0.92	1.049	8.48	12:23:32	0.91	1.02	7.56
0:22:27	0.91	1.040	8.47	12:38:33	0.90	1.01	7.76
0:37:27	0.90	1.03	8.63	12:53:35	0.89	1.01	8.01
0:52:28	0.90	1.02	8:50	13:08:36	0.89	1.00	7.59
1:07:29	0.89	1.02	8.49	13:23:37	0.89	1.00	7.95
1:22:29	0.89	1.01	8.25	13:38:38	0.89	0.99	7.52
1:37:31	0.88	1.00	8.52	13:53:40	0.88	0.99	7.50
1:52:32	0.88	1.00	8.48	14:08:46	0.88	0.99	7.74
2:07:32	0.88	1.00	8.36	14:23:47	0.88	0.99	7.64
2:22:32	0.88	0.99	7.91	14:38:50	0.89	1.00	7.61
2:37:33	0.88	1.00	8.27	14:53:52	0.89	1.00	7.53
2:52:35	0.88	1.00	7.75	15:08:54	0.90	1.01	7.63
3:07:35	0.88	0.99	7.62	15:23:55	0.91	1.02	7.74
3:22:36	0.89	0.99	7.02	15:38:55	0.91	1.02	7.51
3:37:36	0.88	0.99	7.50	15:53:57	0.91	1.02	7.81
3:52:37	0.88	0.99	7.79	16:09:02	0.91	1.03	8.08
4:07:37	0.88	0.99	7.83	16:24:04	0.91	1.03	7.85
4:22:37	0.89	1.00	7.40	16:39:05	0.92	1.03	7.52
4:37:38	0.89	1.00	7.57	16:54:05	0.92	1.03	7.57
4:52:41	0.89	1.00	7.85	17:09:07	0.92	1.03	7.52
5:07:41	0.89	1.00	7.57	17:24:07	0.92	1.03	7.59
5:22:41	0.89	1.00	7.47	17:39:08	0.93	1.04	7.64
5:37:41	0.90	1.00	7.23	17:54:08	0.94	1.06	7.71
5:52:41	0.89	1.00	7.76	18:09:11	0.95	1.07	7.88
6:07:41	0.89	1.00	7.72	18:24:15	0.96	1.09	7.83
6:22:45	0.88	0.99	7.45	18:39:18	0.98	1.10	7.57
6:37:47	0.89	0.99	7.16	18:54:18	0.98	1.11	7.81
6:52:47	0.89	0.99	7.52	19:09:18	0.99	1.12	7.85
7:07:48	0.88	1.00	7.83	19:24:20	1.00	1.13	8.08
7:22:49	0.89	1.00	7.75	19:39:21	1.01	1.13	7.63
7:37:49	0.90	1.01	7.73	19:54:24	1.00	1.13	7.76
7:52:54	0.92	1.03	7.61	20:09:29	1.00	1.13	7.82
8:08:00	0.93	1.04	7.70	20:24:30	0.99	1.12	7.93
8:23:03	0.93	1.05	7.78	20:39:30	0.98	1.11	7.63
8:38:05	0.94	1.06	7.80	20:54:30	0.97	1.10	8.05
8:53:05	0.95	1.06	7.42	21:09:31	0.97	1.09	7.56
9:08:06	0.95	1.07	7.77	21:24:31	0.96	1.08	7.96
9:23:06	0.95	1.07	7.61	21:39:32	0.95	1.07	7.62
9:38:08	0.95	1.07	7.72	21:54:34	0.94	1.07	7.89
9:53:13	0.95	1.07	7.65	22:09:36	0.94	1.06	7.85
10:08:17	0.95	1.06	7.52	22:24:37	0.94	1.05	7.38
10:23:18	0.94	1.06	7.91	22:39:37	0.93	1.05	7.80
10:38:22	0.93	1.05	7.85	22:54:37	0.93	1.04	7.59
10:53:23	0.93	1.04	7.54	23:09:37	0.92	1.03	7.75
11:08:24	0.92	1.03	7.72	23:24:37	0.91	1.02	7.86
11:23:25	0.92	1.03	7.71	23:39:38	0.89	1.01	8.13
11:38:25	0.91	1.03	7.95				
11:53:26	0.91	1.02	7.61				
12:08:30	0.91	1.02	7.55				

Table D.3. INCO Matte Separation Plant column 2. Gas holdup data collected March 15 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:42	0.89	1.000	7.61	12:24:05	0.93	1.01	5.52
0:22:45	0.89	0.999	7.77	12:39:07	0.91	1.00	5.83
0:37:47	0.88	0.99	7.71	12:54:07	0.90	0.98	5.82
0:52:48	0.88	0.99	7.78	13:09:08	0.89	0.97	5.77
1:07:49	0.88	0.99	7.79	13:24:09	0.88	0.97	6.14
1:22:50	0.87	0.99	8.18	13:39:10	0.87	0.96	6.16
1:37:51	0.87	0.99	8.13	13:54:11	0.87	0.95	6.30
1:52:52	0.88	0.99	7.98	14:09:12	0.81	0.94	9.46
2:07:54	0.88	0.99	7.96	14:24:15	0.81	0.93	9.30
2:22:58	0.87	0.99	8.22	14:39:17	0.80	0.93	9.80
2:37:59	0.87	0.99	8.62	14:54:19	0.80	0.93	9.92
2:52:59	0.87	0.99	8.72	15:09:20	0.79	0.93	10.36
3:08:01	0.88	0.99	8.04	15:24:20	0.81	0.93	9.42
3:23:02	0.87	0.99	8.41	15:39:20	0.81	0.94	9.79
3:38:02	0.87	0.99	8.69	15:54:23	0.82	0.95	9.43
3:53:04	0.87	0.99	8.47	16:09:24	0.83	0.96	9.51
4:08:06	0.87	0.99	8.76	16:24:28	0.86	0.99	8.75
4:23:08	0.86	0.98	8.64	16:39:31	0.89	1.01	8.35
4:38:10	0.86	0.98	8.66	16:54:32	0.91	1.03	8.26
4:53:12	0.85	0.97	8.78	17:09:32	0.93	1.06	8.42
5:08:12	0.86	0.97	7.66	17:24:32	0.95	1.08	8.15
5:23:14	0.86	0.97	7.64	17:39:33	0.96	1.10	8.92
5:38:16	0.85	0.95	7.64	17:54:36	0.98	1.11	8.30
5:53:17	0.84	0.94	7.22	18:09:37	0.97	1.12	8.97
6:08:20	0.84	0.93	6.70	18:24:41	0.97	1.12	9.09
6:23:23	0.82	0.92	7.12	18:39:44	0.97	1.11	8.51
6:38:23	0.82	0.91	6.61	18:54:44	0.97	1.10	8.61
6:53:24	0.81	0.91	7.24	19:09:44	0.96	1.10	8.81
7:08:25	0.82	0.90	6.39	19:24:45	0.95	1.09	8.60
7:23:27	0.82	0.90	6.37	19:39:46	0.96	1.08	7.97
7:38:27	0.81	0.90	6.80	19:54:51	0.96	1.08	7.37
7:53:30	0.81	0.89	5.97	20:09:57	0.96	1.07	6.75
8:08:33	0.80	0.89	6.71	20:25:00	0.95	1.06	7.12
8:23:36	0.81	0.89	6.41	20:40:01	0.95	1.06	6.97
8:38:37	0.81	0.89	6.44	20:55:02	0.94	1.05	6.97
8:53:37	0.81	0.90	6.53	21:10:03	0.94	1.05	7.51
9:08:38	0.82	0.91	6.67	21:25:03	0.93	1.04	7.19
9:23:38	0.83	0.91	6.19	21:40:04	0.93	1.04	7.22
9:38:39	0.83	0.92	6.49	21:55:05	0.93	1.04	7.23
9:53:44	0.85	0.94	6.11	22:10:07	0.92	1.03	7.48
10:08:50	0.88	0.97	6.36	22:25:09	0.91	1.02	7.43
10:23:54	0.91	1.00	5.97	22:40:13	0.91	1.02	7.60
10:38:55	0.93	1.02	6.02	22:55:30	0.91	1.02	7.55
10:53:55	0.94	1.03	6.11	23:10:32	0.91	1.02	7.55
11:08:56	0.95	1.04	5.93	23:25:33	0.91	1.02	7.70
11:23:57	0.96	1.05	5.98	23:40:35	0.91	1.02	7.65
11:38:57	0.95	1.04	5.79				
11:53:59	0.95	1.04	5.92				
12:09:02	0.93	1.02	5.99				

Table D.4. INCO Matte Separation Plant column 2. Gas holdup data collected March 16 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:35	0.91	1.017	7.20	17:14:37	0.70	0.79	7.53
0:22:37	0.90	1.017	7.81	17:29:37	0.72	0.80	7.12
0:37:37	0.91	1.02	7.25	17:44:37	0.73	0.82	6.99
0:52:37	0.92	1.02	6.74	17:59:37	0.75	0.83	6.72
1:07:38	0.91	1.01	6.72	18:14:37	0.77	0.86	7.27
1:22:39	0.92	1.01	6.41	18:29:37	0.79	0.89	7.12
1:37:41	0.89	1.01	7.88	18:44:37	0.82	0.92	6.99
1:52:41	0.89	1.00	7.46	18:59:37	0.85	0.94	6.79
2:07:41	0.89	1.00	7.90	19:14:37	0.85	0.95	7.31
2:22:42	0.89	1.00	7.69	19:29:37	0.86	0.96	7.46
2:37:43	0.88	0.99	7.60	19:44:37	0.88	0.98	7.51
2:52:43	0.88	0.99	7.65	19:59:37	0.89	0.99	7.42
3:07:45	0.88	0.98	7.37	20:14:37	0.90	1.00	7.09
3:22:46	0.87	0.98	7.58	20:29:37	0.91	1.01	7.03
3:37:46	0.88	0.98	7.60	20:44:37	0.91	1.01	7.11
3:52:47	0.88	1.00	7.97	20:59:37	0.90	1.01	7.27
4:07:47	0.90	1.02	7.64	21:14:37	0.90	1.00	7.23
4:22:49	0.92	1.03	7.68	21:29:37	0.91	1.00	6.32
4:37:49	0.93	1.05	7.81	21:44:37	0.92	1.00	5.24
4:52:49	0.95	1.07	7.59	21:59:37	0.91	0.99	5.94
5:07:50	0.96	1.09	7.99	22:14:37	0.90	0.98	5.97
5:22:53	0.98	1.10	7.86	22:29:37	0.89	0.97	5.62
5:37:53	0.99	1.12	7.61	22:44:37	0.88	0.96	5.55
5:52:53	1.00	1.12	7.47	22:59:37	0.87	0.95	5.79
6:07:53	1.01	1.14	7.83	23:14:37	0.87	0.94	4.95
6:22:54	1.01	1.15	8.20	23:29:37	0.86	0.94	5.31
6:37:55	1.03	1.16	7.96	23:44:37	0.86	0.93	5.00
6:52:56	1.03	1.17	8.16	23:59:37	0.46	0.50	2.75
7:07:57	1.04	1.17	7.94				
7:22:58	1.04	1.17	7.70				
7:37:59	1.03	1.16	7.73				
7:53:00	1.02	1.15	7.52				
8:08:00	1.02	1.13	6.74				
8:23:01	1.00	1.11	7.03				
8:38:02	0.98	1.09	7.04				
8:53:02	0.96	1.07	7.18				
9:08:03	0.94	1.05	7.19				
9:23:04	0.92	1.03	7.16				
9:38:05	0.90	1.01	7.16				
9:53:05	0.89	0.99	7.16				
10:08:05	0.87	0.97	7.23				
10:23:06	0.86	0.96	7.25				
10:38:06	0.85	0.95	7.05				
15:44:14	0.75	0.84	7.12				
15:59:34	0.73	0.82	7.45				
16:14:37	0.72	0.80	7.69				
16:29:37	0.70	0.79	7.64				
16:44:37	0.70	0.78	7.55				
16:59:37	0.70	0.78	7.07				

Table D.5. INCO Matte Separation Plant column 2. Gas holdup data collected March 17 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:37	0.86	0.930	5.45	12:33:59	0.89	0.99	6.60
0:22:37	0.86	0.928	5.16	12:48:59	0.90	1.00	6.59
0:37:37	0.86	0.93	5.21	13:03:59	0.90	1.01	7.08
0:52:37	0.86	0.93	5.40	13:18:59	0.91	1.02	6.98
1:07:37	0.86	0.93	5.30	13:33:59	0.93	1.02	6.68
1:22:37	0.86	0.93	4.85	13:48:59	0.93	1.03	7.14
1:37:37	0.86	0.93	5.00	14:03:59	0.93	1.04	7.11
1:52:37	0.86	0.93	5.09	14:18:59	0.95	1.06	7.38
2:07:37	0.86	0.93	5.10	14:33:59	0.99	1.11	7.42
2:22:37	0.86	0.93	5.50	14:49:00	1.03	1.15	7.23
2:37:37	0.86	0.93	5.09	15:04:00	1.05	1.18	7.60
2:52:37	0.87	0.94	5.19	15:19:00	1.04	1.17	7.61
3:07:37	0.88	0.95	4.57	15:34:01	1.02	1.15	7.69
3:22:37	0.89	0.95	4.25	15:49:02	1.01	1.14	7.93
3:37:37	0.89	0.96	4.64	16:04:02	1.00	1.13	7.66
3:52:37	0.90	0.96	4.21	16:19:02	1.00	1.12	7.75
4:07:39	0.90	0.97	4.95	16:34:03	1.00	1.12	7.11
4:22:43	0.89	0.97	5.95	16:49:03	1.00	1.12	7.62
4:37:46	0.89	0.97	5.56	17:04:03	1.00	1.12	7.64
4:52:47	0.89	0.97	5.56	17:19:03	1.00	1.13	7.85
5:07:48	0.89	0.97	5.51	17:34:03	1.00	1.13	7.68
5:22:50	0.89	0.97	5.70	17:49:03	1.01	1.13	7.64
5:37:51	0.90	0.98	5.76	18:04:03	1.01	1.13	7.37
5:52:51	0.90	0.98	5.64	18:19:03	1.02	1.14	7.42
6:07:52	0.90	0.98	5.79	18:34:03	1.03	1.15	7.72
6:22:52	0.90	0.98	5.93	18:49:04	1.05	1.17	7.18
6:37:56	0.90	0.98	5.69	19:04:05	1.05	1.18	7.68
6:52:58	0.90	0.98	5.90	19:19:05	1.07	1.20	7.54
7:08:00	0.90	0.99	6.44	19:34:06	1.08	1.21	7.80
7:23:01	0.90	0.99	6.11	19:49:06	1.09	1.22	7.74
7:38:02	0.90	0.99	6.35	20:04:06	1.10	1.23	7.61
7:53:02	0.90	0.99	5.92	20:19:06	1.10	1.24	7.41
8:08:04	0.91	0.99	6.08	20:34:06	1.11	1.24	7.36
8:23:05	0.91	1.00	6.19	20:49:06	1.11	1.25	7.63
8:38:05	0.91	1.00	6.10	21:04:07	1.11	1.25	7.72
8:53:07	0.91	1.00	6.38	21:19:07	1.11	1.25	7.57
9:08:08	0.91	1.00	6.09	21:34:07	1.12	1.25	7.21
9:23:10	0.91	1.00	5.8[illegible]	21:49:07	1.11	1.24	7.21
9:38:12	0.91	0.99	5.77	22:04:09	1.10	1.24	7.46
9:56:57	0.90	0.99	6.[illegible]	22:19:12	1.10	1.23	7.42
10:12.20	0.90	0.98	5.55	22:34:15	1.09	1.22	7.31
10:27:39	0.90	0.98	5.79	22:49:17	1.09	1.22	7.41
10:42:43	0.90	0.98	5.62	23:04:22	1.08	1.21	7.87
11:01:59	0.89	0.97	5.54	23:19:28	1.08	1.21	7.63
11:17:28	0.89	0.98	5.95	23:34:33	1.08	1.21	7.10
11:32:59	0.89	0.98	5.85	23:49:38	1.07	1.20	7.49
11:48:32	0.88	0.97	6.81				
12:03:56	0.88	0.98	6.79				
12:18:59	0.88	0.98	6.71				

Table D.6. INCO Matte Separation Plant column 2. Gas holdup data collected March 18 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:39	1.07	1.196	7.56	12:25:08	0.95	1.06	7.03
0:22:40	1.07	1.190	7.04	12:40:09	0.95	1.06	7.00
0:37:42	1.06	1.19	7.30	12:55:14	0.95	1.05	6.56
0:52:46	1.06	1.18	6.94	13:10:16	0.94	1.04	7.06
1:07:49	1.06	1.18	6.94	13:25:19	0.93	1.03	6.54
1:22:51	1.04	1.17	7.41	13:40:22	0.92	1.02	6.73
1:37:57	1.04	1.17	7.42	13:55:23	0.92	1.01	6.56
1:53:02	1.04	1.16	7.10	14:10:25	0.91	1.00	6.30
2:08:06	1.03	1.15	7.28	14:25:30	0.91	1.00	6.33
2:23:09	1.03	1.15	7.22	14:40:32	0.90	0.99	6.37
2:38:14	1.03	1.14	6.86	14:55:36	0.90	0.99	6.19
2:53:17	1.02	1.14	7.06	15:10:39	0.91	1.00	6.43
3:08:18	1.03	1.14	6.75	15:25:42	0.90	1.00	6.71
3:23:21	1.03	1.14	6.77	15:40:44	0.91	1.00	6.05
3:38:23	1.02	1.14	7.16	15:55:49	0.91	1.00	6.60
3:53:26	1.01	1.13	7.58	16:10:49	0.91	1.00	6.59
4:08:27	1.01	1.13	7.37	16:25:53	0.91	1.01	6.93
4:23:29	1.01	1.12	6.82	16:40:55	0.91	1.01	6.60
4:38:31	1.00	1.12	7.58	16:55:59	0.91	1.01	6.55
4:53:36	1.00	1.12	7.49	17:11:02	0.92	1.01	6.17
5:08:38	1.00	1.12	7.48	17:26:05	0.91	1.01	6.64
5:23:41	1.02	1.13	6.91	17:41:07	0.92	1.01	6.12
5:38:46	1.01	1.14	7.54	17:56:12	0.91	1.01	6.50
5:53:51	1.02	1.14	7.40	18:11:17	0.92	1.01	6.36
6:08:54	1.02	1.14	7.06	18:26:20	0.92	1.01	6.22
6:23:57	1.02	1.15	7.47	18:41:24	0.91	1.01	6.83
6:39:00	1.03	1.15	6.93	18:56:27	0.91	1.01	6.59
6:54:02	1.03	1.15	7.23	19:11:31	0.91	1.01	6.64
7:09:02	1.02	1.14	7.02	19:26:33	0.90	1.00	6.61
7:24:07	1.01	1.13	7.33	19:41:36	0.90	1.00	6.66
7:39:10	1.01	1.12	6.88	19:56:41	0.90	0.99	6.35
7:54:14	1.01	1.11	6.35	20:11:43	0.90	0.99	6.28
8:09:16	0.99	1.10	6.69	20:26:49	0.89	0.98	6.52
8:24:21	0.98	1.08	6.49	20:41:51	0.88	0.97	6.63
8:39:23	0.96	1.06	6.60	20:56:54	0.88	0.96	6.19
8:54:24	0.95	1.05	6.48	21:11:56	0.87	0.96	6.26
9:09:27	0.94	1.04	6.43	21:26:59	0.87	0.96	6.41
9:24:29	0.93	1.03	6.48	21:42:02	0.87	0.96	6.60
9:39:35	0.92	1.02	6.48	21:57:07	0.87	0.96	6.23
9:54:40	0.93	1.02	6.25	22:12:09	0.87	0.96	6.13
10:09:42	0.92	1.02	6.43	22:27:15	0.87	0.95	6.16
10:24:47	0.93	1.03	6.80	22:42:16	0.87	0.96	6.46
10:39:49	0.93	1.03	6.85	22:57:19	0.87	0.96	6.70
10:54:50	0.95	1.05	6.45	23:12:22	0.88	0.96	6.15
11:09:53	0.95	1.05	6.34	23:27:25	0.88	0.97	6.42
11:24:55	0.95	1.06	6.73	23:42:28	0.87	0.96	6.62
11:40:01	0.96	1.06	6.56				
11:55:04	0.96	1.06	6.58				
12:10:06	0.95	1.06	6.98				

Table D.7. INCO Matte Separation Plant column 2. Gas holdup data collected March 19 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:37	0.87	0.960	6.36	12:30:18	0.92	1.02	6.50
0:22:39	0.87	0.963	6.93	12:45:25	0.94	1.03	6.39
0:37:41	0.87	0.96	6.66	13:00:29	0.94	1.04	6.76
0:52:43	0.86	0.95	6.46	13:15:32	0.94	1.04	6.44
1:07:48	0.86	0.95	6.60	13:30:33	0.94	1.04	6.94
1:22:51	0.85	0.94	6.69	13:45:34	0.93	1.05	7.95
1:37:53	0.85	0.94	6.80	14:00:37	0.92	1.05	8.25
1:52:56	0.85	0.94	6.75	14:15:38	0.93	1.05	8.24
2:08:00	0.85	0.94	6.45	14:30:39	0.95	1.06	6.70
2:23:05	0.85	0.94	6.62	14:45:43	0.95	1.05	6.46
2:38:10	0.85	0.94	6.65	15:00:46	0.94	1.05	6.92
2:53:15	0.85	0.94	6.60	15:15:51	0.95	1.05	6.70
3:08:18	0.84	0.94	6.92	15:30:54	0.94	1.05	6.86
3:23:23	0.85	0.94	6.61	15:45:59	0.94	1.04	6.61
3:38:28	0.85	0.93	6.34	16:00:59	0.94	1.04	6.58
3:53:28	0.84	0.93	6.62	16:15:59	0.93	1.04	6.82
4:08:29	0.84	0.93	6.93	16:31:02	0.93	1.03	6.83
4:23:34	0.83	0.93	7.29	16:46:07	0.93	1.03	6.76
4:38:39	0.84	0.93	6.89	17:01:13	0.92	1.02	6.67
4:53:45	0.83	0.92	6.76	17:16:15	0.92	1.02	6.95
5:08:47	0.84	0.92	6.16	17:31:17	0.92	1.01	6.30
5:23:49	0.84	0.93	6.94	17:46:21	0.91	1.01	6.54
5:38:54	0.84	0.92	6.32	18:01:22	0.92	1.01	6.41
5:53:58	0.83	0.92	6.39	18:16:23	0.92	1.01	6.45
6:09:00	0.82	0.92	6.98	18:31:25	0.91	1.01	6.55
6:24:03	0.82	0.91	6.60	18:46:30	0.91	1.01	6.20
6:39:05	0.82	0.91	6.97	19:01:36	0.91	1.00	6.24
6:54:08	0.82	0.91	7.05	19:16:39	0.90	1.00	6.91
7:09:10	0.83	0.91	5.93	19:31:40	0.89	0.99	6.63
7:24:12	0.82	0.91	6.87	19:46:45	0.89	0.99	6.68
7:39:16	0.81	0.91	7.36	20:01:45	0.89	0.99	6.64
7:54:19	0.82	0.91	7.05	20:16:47	0.89	0.99	6.37
8:09:21	0.89	0.91	2.24	20:31:49	0.89	0.98	6.40
8:24:27	0.81	0.90	7.19	20:46:53	0.89	0.98	6.41
8:39:28	0.80	0.90	7.25	21:01:55	0.89	0.98	6.40
8:54:33	0.80	0.89	6.77	21:17:01	0.89	0.98	6.58
9:09:36	0.80	0.89	6.66	21:32:06	0.90	0.99	6.49
9:24:38	0.81	0.89	6.51	21:47:11	0.89	0.99	6.52
9:39:42	0.80	0.88	6.86	22:02:11	0.89	0.98	6.34
9:54:44	0.80	0.89	6.63	22:17:12	0.89	0.98	6.46
10:09:46	0.80	0.88	6.48	22:32:15	0.89	0.98	6.52
10:24:46	0.80	0.88	6.66	22:47:19	0.87	0.97	6.82
10:39:51	0.81	0.90	6.57	23:02:21	0.88	0.97	6.53
10:54:53	0.83	0.91	6.44	23:17:27	0.87	0.97	6.82
11:09:55	0.83	0.93	6.94	23:32:29	0.88	0.96	6.23
11:25:01	0.85	0.94	6.52	23:47:33	0.87	0.97	6.69
11:40:04	0.87	0.96	6.70				
11:55:16	0.88	0.98	6.75				
12:15:01	0.91	1.00	6.38				

Table D.8. INCO Matte Separation Plant column 2. Gas holdup data collected March 20 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:35	0.88	0.967	6.55	12:24:29	1.05	1.15	6.28
0:22:37	0.88	0.969	6.35	12:40:54	1.04	1.13	5.85
0:37:39	0.87	0.96	6.57	12:56:18	1.03	1.13	6.03
0:52:44	0.87	0.96	6.40	13:11:23	1.04	1.15	6.20
1:07:49	0.87	0.96	6.30	13:26:25	1.07	1.17	5.88
1:22:54	0.87	0.96	6.55	13:41:25	1.10	1.20	6.13
1:37:56	0.86	0.96	6.97	13:56:26	1.12	1.23	5.79
1:52:59	0.87	0.95	6.17	14:11:29	1.13	1.24	6.00
2:08:00	0.86	0.95	6.28	14:26:29	1.14	1.24	5.67
2:23:01	0.86	0.95	6.87	14:41:29	1.15	1.26	5.94
2:38:02	0.85	0.94	6.82	14:56:31	1.15	1.27	6.33
2:53:07	0.85	0.94	6.90	15:11:32	1.15	1.28	6.72
3:08:09	0.85	0.93	6.29	15:26:35	1.15	1.28	7.25
3:23:11	0.84	0.93	6.46	15:41:37	1.16	1.29	7.17
3:38:13	0.84	0.93	6.31	15:56:38	1.15	1.29	7.33
3:53:15	0.84	0.93	6.41	16:11:39	1.15	1.28	6.87
4:08:16	0.84	0.93	6.32	16:26:42	1.15	1.27	6.83
4:23:16	0.84	0.92	6.23	16:41:46	1.16	1.27	5.84
4:38:18	0.84	0.92	6.28	16:56:47	1.15	1.26	6.03
4:53:20	0.83	0.92	6.43	17:11:47	1.14	1.25	5.99
5:08:26	0.83	0.92	6.39	17:26:49	1.14	1.25	5.87
5:23:28	0.83	0.92	6.47	17:41:51	1.13	1.24	5.83
5:38:29	0.83	0.91	6.23	17:56:53	1.13	1.24	5.98
5:53:30	0.84	0.92	6.41	18:11:56	1.13	1.23	5.80
6:08:30	0.85	0.94	6.54	18:26:57	1.13	1.23	5.84
6:23:31	0.88	0.97	6.39	18:41:57	1.13	1.23	5.76
6:38:33	0.90	1.00	6.82	18:56:59	1.13	1.23	5.80
6:53:37	0.93	1.03	6.53	19:12:00	1.12	1.23	5.88
7:08:39	0.96	1.06	6.35	19:27:02	1.12	1.23	5.96
7:23:41	0.99	1.10	6.57	19:42:03	1.12	1.23	5.99
7:38:46	1.04	1.13	5.78	19:57:03	1.12	1.22	5.49
7:53:47	1.05	1.16	6.36	20:12:05	1.12	1.22	5.62
8:08:48	1.07	1.19	6.74	20:27:07	1.11	1.22	5.93
8:23:51	1.10	1.21	6.16	20:42:08	1.12	1.22	5.71
8:38:55	1.12	1.23	6.40	20:57:11	1.10	1.21	6.01
8:53:56	1.14	1.26	6.39	21:12:12	1.11	1.21	5.71
9:08:59	1.15	1.27	6.31	21:27:12	1.10	1.21	6.09
9:24:04	1.17	1.27	5.51	21:42:14	1.10	1.21	6.02
9:39:05	1.17	1.27	5.61	21:57:16	1.10	1.21	6.14
9:54:08	1.16	1.27	5.63	22:12:16	1.10	1.21	5.95
10:09:09	1.16	1.26	5.25	22:27:21	1.10	1.20	5.83
10:24:09	1.17	1.26	5.00	22:42:23	1.10	1.20	5.84
10:39:11	1.15	1.25	5.13	22:57:24	1.09	1.20	6.07
10:54:13	1.15	1.24	5.01	23:12:24	1.09	1.20	6.00
11:09:16	1.15	1.22	4.34	23:27:24	1.09	1.19	5.73
11:24:20	1.14	1.21	4.42	23:42:25	1.09	1.19	5.88
11:39:22	1.12	1.20	4.53				
11:54:25	1.10	1.19	5.23				
12:09:27	1.08	1.17	5.33				

Table D.9. INCO Matte Separation Plant column 2. Gas holdup data collected March 21 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:28	1.08	1.180	5.58	12:23:27	1.09	1.19	5.42
0:22:28	1.08	1.180	5.82	12:38:28	1.08	1.18	5.59
0:37:28	1.08	1.17	5.37	12:53:31	1.07	1.17	5.63
0:52:30	1.07	1.17	5.83	13:08:32	1.07	1.16	5.71
1:07:31	1.06	1.17	6.12	13:23:33	1.07	1.16	5.25
1:22:33	1.06	1.16	5.72	13:38:35	1.06	1.15	5.44
1:37:33	1.07	1.16	5.51	13:53:35	1.06	1.15	5.34
1:52:35	1.06	1.16	5.80	14:08:36	1.05	1.14	5.45
2:07:38	1.07	1.16	5.66	14:23:39	1.05	1.14	5.54
2:22:40	1.07	1.17	5.59	14:38:40	1.04	1.13	5.29
2:37:40	1.08	1.17	5.34	14:53:41	1.04	1.14	5.55
2:52:41	1.08	1.18	5.87	15:08:44	1.05	1.14	5.69
3:07:42	1.08	1.17	5.47	15:23:44	1.05	1.14	5.57
3:22:44	1.07	1.17	5.68	15:38:45	1.05	1.14	5.32
3:37:45	1.07	1.16	5.29	15:53:48	1.05	1.14	5.62
3:52:45	1.06	1.15	5.64	16:08:48	1.05	1.13	5.11
4:07:45	1.05	1.14	5.69	16:23:51	1.05	1.13	5.00
4:22:47	1.04	1.13	5.44	16:38:53	1.03	1.13	5.80
4:37:47	1.03	1.12	5.65	16:53:57	1.03	1.12	5.84
4:52:48	1.03	1.12	5.76	17:08:57	1.03	1.12	5.72
5:07:49	1.02	1.12	5.73	17:23:58	1.03	1.12	5.52
5:22:51	1.02	1.11	5.77	17:38:58	1.04	1.14	5.84
5:37:52	1.01	1.10	5.81	17:54:00	1.08	1.18	5.65
5:52:52	1.01	1.10	5.82	18:09:00	1.14	1.24	5.28
6:07:52	1.00	1.10	6.08	18:24:00	1.18	1.29	5.71
6:22:53	1.01	1.10	5.53	18:39:00	1.22	1.33	5.94
6:37:53	1.01	1.10	5.69	18:54:02	1.25	1.37	6.00
6:52:57	1.02	1.12	6.10	19:09:03	1.29	1.42	6.08
7:08:00	1.06	1.16	5.41	19:24:05	1.33	1.45	5.84
7:23:01	1.10	1.20	5.84	19:39:05	1.34	1.47	5.93
7:38:02	1.14	1.24	5.85	19:54:07	1.34	1.47	5.95
7:53:04	1.18	1.28	5.56	20:09:10	1.34	1.46	5.67
8:08:04	1.21	1.31	5.21	20:24:12	1.33	1.44	5.64
8:23:05	1.23	1.34	5.80	20:39:12	1.30	1.42	5.93
8:38:06	1.24	1.36	5.99	20:54:13	1.27	1.39	6.04
8:53:06	1.26	1.38	5.82	21:09:14	1.25	1.37	6.21
9:08:10	1.27	1.38	5.82	21:24:16	1.23	1.35	5.97
9:23:12	1.27	1.38	5.54	21:39:17	1.22	1.33	5.95
9:38:14	1.26	1.38	5.64	21:54:17	1.20	1.31	6.06
9:53:15	1.25	1.36	5.44	22:09:17	1.18	1.30	6.20
10:08:16	1.23	1.34	5.80	22:24:18	1.18	1.29	6.00
10:23:16	1.21	1.32	5.65	22:39:18	1.17	1.28	5.69
10:38:18	1.19	1.29	5.72	22:54:20	1.16	1.27	5.96
10:53:19	1.17	1.27	5.60	23:09:21	1.15	1.26	6.09
11:08:19	1.16	1.25	5.35	23:24:23	1.15	1.25	5.74
11:23:21	1.14	1.24	5.64	23:39:29	1.14	1.24	5.48
11:38:21	1.13	1.22	5.37				
11:53:23	1.11	1.21	5.50				
12:08:26	1.10	1.20	5.68				

Table D.10. INCO Matte Separation Plant column 2. Gas holdup data collected March 22 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:30	1.13	1.229	5.43	12:23:42	0.95	1.02	5.17
0:22:30	1.13	1.220	5.08	12:38:43	0.94	1.02	5.46
0:37:33	1.12	1.21	5.46	12:53:43	0.94	1.02	5.51
0:52:33	1.11	1.21	5.40	13:08:44	0.94	1.02	5.47
1:07:34	1.10	1.20	5.30	13:23:44	0.94	1.01	5.22
1:22:36	1.10	1.19	5.26	13:38:46	0.93	1.01	5.42
1:37:38	1.09	1.18	5.31	13:53:47	0.93	1.01	5.52
1:52:40	1.08	1.17	5.35	14:08:47	0.92	1.00	5.28
2:07:43	1.07	1.16	5.36	14:23:49	0.92	1.00	5.46
2:22:43	1.06	1.15	5.33	14:38:49	0.92	1.01	6.08
2:37:46	1.05	1.14	5.21	14:53:49	0.93	1.01	5.70
2:52:49	1.04	1.13	5.21	15:08:52	0.93	1.01	5.70
3:07:51	1.04	1.12	5.24	15:23:53	0.93	1.01	5.83
3:22:51	1.03	1.12	5.44	15:38:54	0.93	1.02	6.16
3:37:51	1.02	1.11	5.32	15:53:58	0.93	1.02	6.02
3:52:51	1.02	1.10	5.06	16:08:59	0.93	1.02	6.04
4:07:51	1.01	1.10	5.31	16:24:00	0.95	1.04	5.99
4:22:52	1.01	1.09	5.10	16:39:01	0.98	1.07	5.94
4:37:53	1.01	1.09	4.98	16:54:03	1.02	1.11	5.72
4:52:54	1.01	1.09	5.08	17:09:03	1.04	1.15	6.48
5:07:55	1.00	1.08	5.02	17:24:04	1.06	1.17	6.53
5:22:57	0.99	1.08	5.50	17:39:04	1.08	1.18	6.07
5:37:58	0.99	1.08	5.45	17:54:07	1.08	1.19	6.17
5:52:58	1.01	1.09	5.47	18:09:11	1.07	1.18	6.13
6:07:58	1.03	1.12	5.32	18:24:12	1.07	1.17	6.03
6:22:59	1.06	1.14	5.10	18:39:13	1.05	1.16	5.98
6:38:00	1.08	1.17	5.36	18:54:16	1.05	1.14	5.45
6:53:03	1.11	1.19	4.78	19:09:18	1.03	1.12	5.90
7:08:05	1.12	1.22	5.18	19:24:21	1.01	1.11	6.01
7:23:07	1.13	1.23	5.46	19:39:25	1.00	1.10	6.12
7:38:12	1.14	1.24	5.55	19:54:28	0.99	1.09	5.93
7:53:13	1.14	1.23	5.23	20:09:29	0.98	1.08	6.22
8:08:13	1.13	1.22	5.12	20:24:29	0.97	1.06	6.07
8:23:15	1.11	1.20	5.27	20:39:31	0.96	1.05	6.10
8:38:17	1.10	1.18	5.16	20:54:33	0.95	1.04	6.16
8:53:19	1.08	1.17	5.24	21:09:35	0.94	1.03	6.01
9:08:21	1.06	1.15	5.00	21:24:37	0.93	1.02	6.03
9:23:21	1.05	1.13	4.95	21:39:37	0.92	1.01	6.08
9:38:21	1.03	1.12	4.99	21:54:38	0.91	1.00	6.09
9:53:24	1.02	1.10	5.18	22:09:42	0.91	1.00	5.91
10:08:25	1.01	1.09	4.95	22:24:44	0.91	0.99	5.73
10:23:26	0.99	1.07	5.05	22:39:44	0.90	0.98	5.77
10:38:27	0.98	1.06	5.10	22:54:45	0.90	0.98	5.74
10:53:30	0.98	1.05	5.06	23:09:46	0.89	0.97	6.01
11:08:33	0.97	1.04	4.97	23:24:49	0.89	0.97	5.90
11:23:34	0.97	1.04	4.69	23:39:49	0.88	0.96	5.96
11:38:39	0.96	1.03	4.81				
11:53:40	0.95	1.03	5.00				
12:08:40	0.95	1.03	5.23				

Table D.11. INCO Matte Separation Plant column 2. Gas holdup data collected March 23 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:49	0.88	0.950	4.84	12:26:07	0.03	0.02	0.00
0:22:50	0.87	0.948	5.29	12:41:08	0.03	0.02	0.00
0:37:50	0.86	0.94	5.64	12:56:24	0.03	0.02	0.00
0:52:50	0.86	0.94	5.55	13:11:50	0.03	0.02	0.00
1:07:52	0.87	0.94	4.80	13:27:17	0.03	0.02	0.00
1:22:54	0.87	0.93	4.28	13:42:45	0.03	0.02	0.00
1:37:59	0.87	0.93	4.70	13:58:14	0.03	0.02	0.00
1:53:01	0.87	0.93	4.55	14:13:42	0.03	0.02	0.00
2:08:01	0.87	0.93	4.50	14:29:09	0.03	0.02	0.00
2:23:02	0.86	0.92	4.29	14:44:36	0.03	0.02	0.00
2:38:03	0.85	0.92	5.23	15:00:09	0.03	0.02	0.00
2:53:03	0.83	0.91	5.81	15:15:37	0.03	0.02	0.00
3:08:05	0.82	0.90	5.81	15:31:07	0.03	0.02	0.00
3:23:05	0.81	0.89	5.91	15:46:16	0.03	0.02	0.00
3:38:06	0.80	0.88	6.62	16:01:19	0.03	0.02	0.00
3:53:08	0.82	0.88	4.48	16:16:23	0.03	0.02	0.00
4:08:08	0.87	0.89	2.09	16:31:23	0.03	0.02	0.00
4:23:09	0.37	0.33	0.95	16:46:25	0.03	0.02	0.00
4:38:10	0.04	0.04	0.00	17:01:28	0.03	0.02	0.00
4:53:10	0.04	0.03	0.00	17:16:30	0.03	0.02	0.00
5:08:12	0.03	0.02	0.00	17:31:31	0.03	0.02	0.00
5:23:15	0.03	0.02	0.00	17:46:33	0.03	0.02	0.00
5:38:16	0.03	0.02	0.00	18:01:33	0.03	0.02	0.00
5:53:19	0.03	0.02	0.00	18:16:34	0.03	0.02	0.00
6:08:20	0.03	0.02	0.00	18:31:35	0.03	0.02	0.00
6:23:20	0.03	0.02	0.00	18:46:37	0.03	0.02	0.00
6:38:21	0.03	0.02	0.00	19:01:39	0.03	0.02	0.00
6:53:23	0.03	0.02	0.00	19:16:42	0.03	0.02	0.00
7:08:23	0.03	0.02	0.00	19:31:44	0.03	0.02	0.00
7:23:25	0.03	0.02	0.00	19:46:48	0.03	0.02	0.00
7:38:25	0.03	0.02	0.00	20:01:52	0.03	0.02	0.00
7:53:27	0.03	0.02	0.00	20:16:53	0.03	0.02	0.00
8:08:31	0.03	0.02	0.00	20:31:53	0.03	0.02	0.00
8:23:32	0.03	0.02	0.00	20:46:53	0.03	0.02	0.00
8:38:32	0.03	0.02	0.00	21:01:57	0.03	0.02	0.00
8:53:34	0.03	0.02	0.00	21:16:57	0.03	0.02	0.00
9:08:36	0.03	0.02	0.00	21:31:58	0.03	0.02	0.00
9:23:37	0.03	0.02	0.00	21:46:58	0.03	0.02	0.00
9:38:40	0.03	0.02	0.00	22:02:01	0.03	0.02	0.00
9:53:41	0.03	0.02	0.00	22:17:04	0.03	0.02	0.00
10:08:42	0.03	0.02	0.00	22:32:07	0.03	0.02	0.00
10:23:43	0.03	0.02	0.00	22:47:07	0.03	0.02	0.00
10:38:45	0.03	0.02	0.00	23:02:10	0.03	0.02	0.00
10:53:46	0.03	0.02	0.00	23:17:12	0.03	0.02	0.00
11:08:47	0.03	0.02	0.00	23:32:14	0.03	0.02	0.00
11:25:46	0.03	0.02	0.00	23:47:15	0.03	0.02	0.00
11:40:59	0.03	0.02	0.00				
11:56:04	0.03	0.02	0.00				
12:11:06	0.03	0.02	0.00				

Table D.12. INCO Matte Separation Plant column 2. Gas holdup data collected March 24 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:17	0.03	0.020	0.00	12:25:41	0.55	0.58	3.53
0:22:17	0.05	0.051	8.20	12:40:41	0.54	0.57	3.25
0:37:18	0.09	0.09	2.44	12:55:41	0.54	0.57	3.25
0:52:23	0.15	0.14	0.28	13:10:41	0.54	0.57	3.44
1:07:26	0.38	0.30	0.69	13:25:41	0.54	0.56	2.66
1:22:26	0.56	0.58	2.32	13:40:41	0.54	0.56	2.66
1:37:27	0.56	0.59	4.35	13:55:41	0.54	0.56	2.66
1:52:28	0.56	0.61	5.09	14:10:41	0.54	0.56	2.96
2:07:30	0.56	0.61	5.25	14:25:41	0.54	0.57	3.09
2:22:33	0.56	0.60	4.11	14:40:41	0.56	0.58	2.49
2:37:36	0.55	0.58	4.04	14:55:41	0.56	0.58	3.02
2:52:36	0.53	0.57	4.37	15:10:41	0.56	0.59	3.14
3:07:39	0.52	0.56	4.31	15:25:41	0.57	0.60	3.25
3:22:41	0.51	0.55	4.42	15:40:41	0.58	0.60	2.55
3:37:43	0.50	0.53	4.26	15:55:41	0.58	0.61	2.89
3:52:45	0.49	0.52	3.92	16:10:41	0.59	0.61	1.92
4:07:45	0.48	0.51	4.16	16:25:41	0.60	0.62	2.25
4:22:46	0.48	0.51	4.55	16:40:41	0.60	0.63	2.65
4:37:48	0.48	0.51	4.09	16:55:41	0.60	0.63	2.79
4:52:49	0.49	0.52	4.11	17:10:41	0.61	0.64	3.33
5:07:49	0.50	0.53	4.53	17:25:41	0.61	0.64	3.68
5:22:51	0.52	0.55	3.82	17:40:41	0.61	0.64	3.17
5:37:52	0.53	0.57	4.15	17:55:41	0.61	0.65	3.77
5:52:53	0.55	0.59	4.25	18:10:41	0.62	0.66	3.50
6:07:56	0.57	0.60	3.76	18:25:41	0.64	0.67	3.76
6:22:57	0.58	0.61	4.13	18:40:41	0.65	0.69	3.74
6:37:58	0.59	0.62	3.43	18:55:41	0.67	0.71	3.39
6:53:00	0.60	0.63	3.45	19:10:41	0.68	0.72	3.89
7:08:02	0.60	0.63	3.23	19:25:41	0.70	0.74	3.69
7:23:03	0.60	0.63	2.79	19:40:41	0.71	0.75	3.51
7:38:05	0.60	0.63	3.16	19:55:41	0.69	0.75	5.07
7:53:05	0.59	0.62	3.57	20:10:41	0.66	0.73	6.54
8:08:07	0.59	0.62	3.08	20:25:41	0.65	0.71	6.02
8:23:10	0.58	0.61	3.34	20:40:41	0.65	0.71	5.90
8:38:12	0.57	0.61	3.94	20:55:41	0.65	0.70	5.15
8:53:12	0.57	0.60	3.30	21:10:41	0.64	0.70	5.30
9:08:13	0.57	0.60	3.55	21:25:41	0.64	0.69	4.68
9:23:15	0.56	0.59	3.05	21:40:41	0.64	0.68	4.32
9:38:17	0.56	0.59	3.06	21:55:41	0.64	0.68	4.14
9:53:18	0.55	0.59	4.39	22:10:41	0.64	0.68	3.73
10:08:18	0.55	0.58	4.04	22:25:41	0.65	0.68	2.52
10:23:20	0.55	0.58	3.20	22:40:41	0.65	0.68	2.92
10:38:23	0.55	0.58	3.27	22:55:41	0.65	0.68	3.39
10:53:26	0.56	0.58	3.09	23:10:41	0.65	0.68	3.46
11:08:26	0.55	0.58	3.41	23:25:41	0.64	0.68	4.14
11:23:29	0.56	0.58	2.93	23:40:41	0.64	0.68	4.14
11:40:33	0.55	0.58	3.42				
11:55:41	0.55	0.58	3.27				
12:10:41	0.55	0.58	3.27				

Table D.13. INCO Matte Separation Plant column 2. Gas holdup data collected March 25 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:41	0.63	0.670	3.86	12:24:50	0.77	0.84	5.49
0:22:41	0.63	0.670	4.13	12:39:51	0.77	0.84	5.32
0:37:41	0.62	0.67	4.69	12:54:52	0.78	0.84	4.99
0:52:41	0.62	0.67	4.89	13:09:55	0.79	0.85	4.90
1:07:41	0.62	0.67	4.96	13:24:57	0.78	0.85	5.32
1:22:41	0.62	0.67	5.17	13:39:59	0.78	0.85	5.26
1:37:41	0.62	0.67	5.03	13:55:04	0.79	0.85	5.18
1:52:41	0.62	0.67	5.24	14:10:08	0.79	0.86	5.20
2:07:41	0.63	0.67	4.55	14:25:10	0.80	0.87	5.19
2:22:41	0.62	0.67	4.75	14:40:12	0.80	0.87	5.28
2:37:41	0.63	0.67	4.41	14:55:15	0.81	0.88	5.18
2:52:41	0.63	0.67	4.41	15:10:21	0.82	0.88	5.07
3:07:41	0.62	0.67	4.96	15:25:21	0.82	0.89	5.23
3:22:41	0.62	0.67	5.10	15:40:22	0.82	0.89	5.02
3:37:41	0.62	0.67	4.82	15:55:26	0.83	0.89	4.34
3:52:41	0.62	0.68	5.72	16:10:29	0.83	0.89	4.81
4:07:41	0.62	0.68	5.58	16:25:31	0.82	0.89	5.07
4:22:41	0.63	0.68	5.30	16:40:33	0.83	0.89	4.91
4:37:41	0.63	0.68	5.28	16:55:35	0.83	0.89	4.55
4:52:41	0.64	0.70	5.69	17:10:38	0.83	0.90	4.83
5:07:41	0.67	0.73	5.45	17:25:40	0.84	0.90	4.75
5:22:41	0.68	0.74	5.72	17:40:43	0.84	0.91	5.06
5:37:41	0.69	0.75	5.79	17:55:43	0.85	0.91	4.80
5:52:41	0.69	0.76	5.91	18:10:45	0.84	0.92	5.64
6:07:41	0.70	0.77	5.72	18:25:48	0.85	0.92	5.41
6:22:41	0.71	0.78	5.95	18:40:53	0.85	0.92	5.41
6:37:41	0.73	0.79	4.63	18:55:55	0.85	0.93	5.61
6:52:41	0.75	0.80	4.61	19:10:57	0.86	0.93	5.50
7:07:41	0.75	0.81	4.78	19:25:57	0.86	0.93	5.48
7:22:41	0.76	0.81	4.49	19:40:58	0.87	0.94	5.38
7:37:41	0.76	0.81	4.60	19:56:00	0.88	0.96	5.29
7:52:41	0.75	0.81	5.01	20:11:05	0.89	0.97	5.71
8:07:41	0.74	0.80	5.05	20:26:09	0.90	0.97	5.44
8:22:41	0.74	0.80	5.30	20:41:10	0.89	0.98	5.94
8:37:41	0.74	0.79	4.82	20:56:11	0.88	0.97	6.31
8:52:41	0.73	0.79	5.32	21:11:14	0.89	0.97	5.98
9:07:41	0.73	0.78	4.81	21:26:19	0.90	0.98	5.62
9:22:41	0.72	0.78	5.03	21:41:24	0.91	0.99	5.91
9:37:41	0.71	0.77	4.91	21:56:26	0.90	0.99	6.06
9:52:41	0.71	0.76	4.79	22:11:31	0.90	0.99	6.30
10:07:41	0.70	0.76	5.04	22:26:33	0.90	0.99	6.23
10:22:41	0.70	0.76	4.98	22:41:34	0.90	0.98	6.06
10:37:41	0.70	0.75	4.85	22:56:35	0.89	0.98	6.65
10:52:41	0.70	0.75	4.55	23:11:40	0.88	0.97	6.24
11:07:41	0.70	0.76	4.81	23:26:42	0.88	0.97	6.53
11:24:20	0.73	0.78	4.44	23:41:47	0.88	0.98	6.97
11:39:42	0.75	0.81	4.86				
11:54:47	0.77	0.83	4.62				
12:09:49	0.77	0.84	5.44				

Table D.14. INCO Matte Separation Plant column 2. Gas holdup data collected March 26 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:53	0.88	0.981	7.18	12:25:21	1.03	1.14	6.61
0:22:55	0.88	0.987	7.37	12:40:23	1.03	1.14	6.99
0:37:57	0.88	0.99	7.18	12:55:23	1.03	1.15	7.10
0:52:57	0.89	0.99	7.01	13:10:25	1.05	1.17	6.95
1:08:01	0.90	1.00	7.17	13:25:31	1.07	1.19	7.14
1:23:06	0.92	1.02	7.17	13:40:36	1.09	1.21	7.21
1:38:12	0.94	1.05	7.25	13:55:41	1.11	1.23	6.91
1:53:14	0.96	1.08	7.27	14:10:43	1.12	1.24	6.82
2:08:17	0.99	1.10	7.28	14:25:48	1.12	1.24	6.71
2:23:21	1.00	1.12	7.39	14:42:05	1.11	1.23	7.09
2:38:24	1.02	1.14	7.31	14:57:33	1.10	1.23	6.91
2:53:26	1.03	1.16	7.80	15:12:51	1.10	1.22	6.76
3:08:27	1.05	1.18	7.73	15:27:56	1.08	1.21	7.16
3:23:30	1.07	1.20	7.40	15:42:59	1.09	1.20	6.54
3:38:35	1.12	1.22	5.42	15:58:01	1.08	1.20	6.91
3:53:37	1.13	1.23	5.69	16:13:04	1.06	1.19	7.43
4:08:39	1.14	1.24	5.39	16:28:04	1.06	1.19	7.26
4:23:44	1.17	1.28	5.48	16:43:07	1.06	1.18	7.18
4:38:46	1.16	1.26	5.56	16:58:10	1.06	1.18	7.27
4:53:49	1.14	1.23	5.48	17:13:12	1.05	1.18	7.50
5:08:50	1.12	1.22	5.48	17:28:14	1.05	1.18	7.42
5:23:56	1.11	1.21	5.37	17:43:19	1.06	1.18	7.06
5:39:01	1.10	1.20	5.50	17:58:21	1.06	1.18	7.18
5:54:06	1.09	1.19	5.85	18:13:26	1.07	1.18	6.84
6:09:08	1.08	1.17	5.69	18:28:26	1.08	1.20	7.00
6:24:10	1.06	1.17	6.25	18:43:31	1.10	1.22	6.57
6:39:13	1.05	1.16	6.57	18:58:33	1.12	1.24	6.42
6:54:15	1.04	1.15	6.86	19:13:34	1.13	1.25	6.93
7:09:16	1.04	1.15	6.83	19:28:35	1.15	1.27	6.40
7:24:18	1.03	1.14	6.87	19:43:39	1.15	1.28	7.18
7:39:22	1.03	1.14	6.65	19:58:44	1.16	1.29	6.77
7:54:25	1.03	1.14	6.61	20:13:46	1.17	1.29	6.78
8:09:28	1.03	1.14	6.82	20:28:48	1.18	1.30	6.54
8:24:30	1.02	1.13	6.62	20:43:53	1.17	1.29	6.64
8:39:32	1.02	1.13	6.32	20:58:56	1.18	1.29	5.64
8:54:34	1.01	1.12	7.07	21:13:58	1.18	1.28	5.46
9:09:36	1.01	1.11	6.06	21:29:01	1.17	1.27	5.44
9:24:42	1.01	1.11	6.45	21:44:05	1.16	1.26	5.12
9:39:44	1.00	1.10	6.23	21:59:07	1.13	1.24	6.11
9:54:47	1.00	1.10	6.29	22:14:10	1.14	1.24	5.90
10:09:51	1.00	1.10	6.42	22:29:14	1.13	1.23	5.61
10:24:53	1.00	1.10	6.55	22:44:17	1.15	1.24	5.07
10:39:55	0.99	1.10	6.77	22:59:19	1.16	1.26	5.73
10:54:57	0.99	1.10	6.90	23:14:19	1.16	1.27	6.12
11:10:02	0.99	1.10	6.87	23:29:22	1.15	1.26	5.94
11:25:08	1.00	1.12	6.88	23:44:28	1.14	1.25	5.92
11:40:13	1.02	1.13	6.44				
11:55:15	1.02	1.14	6.84				
12:10:17	1.03	1.14	6.65				

Table D.15. INCO Matte Separation Plant column 2. Gas holdup data collected March 27 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:32	1.12	1.219	5.51	12:27:01	1.09	1.19	5.49
0:22:35	1.10	1.203	5.66	12:42:03	1.12	1.21	5.19
0:37:37	1.09	1.18	5.52	12:57:04	1.14	1.23	5.36
0:52:40	1.08	1.17	5.29	13:12:07	1.15	1.25	5.27
1:07:41	1.06	1.15	5.55	13:27:12	1.15	1.25	5.25
1:22:43	1.04	1.14	5.74	13:42:17	1.15	1.26	5.75
1:37:49	1.03	1.13	6.10	13:57:19	1.16	1.25	5.35
1:52:52	1.02	1.12	5.94	14:12:24	1.15	1.24	5.43
2:07:53	1.01	1.11	6.15	14:27:27	1.13	1.23	5.71
2:22:58	1.01	1.11	6.37	14:42:32	1.12	1.22	5.55
2:38:02	1.01	1.10	5.95	14:57:33	1.11	1.20	5.24
2:53:02	1.00	1.10	5.95	15:12:36	1.09	1.18	5.56
3:08:06	1.00	1.10	5.99	15:27:40	1.08	1.17	5.51
3:23:06	1.01	1.10	5.60	15:42:43	1.07	1.16	5.46
3:38:12	1.01	1.11	5.99	15:57:48	1.07	1.17	5.75
3:53:13	1.01	1.10	5.99	16:12:50	1.08	1.18	5.79
4:08:15	1.01	1.10	5.86	16:27:53	1.10	1.19	5.29
4:23:20	1.00	1.10	5.95	16:42:55	1.11	1.21	5.51
4:38:20	1.00	1.10	5.99	16:57:57	1.07	1.21	7.79
4:53:21	1.00	1.10	6.13	17:12:58	1.04	1.19	8.82
5:08:24	1.01	1.10	5.94	17:28:01	1.04	1.19	8.79
5:23:29	1.02	1.12	6.11	17:43:06	1.06	1.20	7.95
5:38:34	1.03	1.13	6.06	17:58:08	1.06	1.20	7.99
5:53:38	1.05	1.15	6.13	18:13:11	1.05	1.19	8.46
6:08:42	1.07	1.17	5.72	18:28:16	1.04	1.18	8.56
6:23:46	1.09	1.19	5.90	18:43:16	1.04	1.17	7.81
6:38:48	1.11	1.21	5.83	18:58:18	1.03	1.17	8.10
6:53:48	1.13	1.23	5.78	19:13:22	1.03	1.16	8.10
7:08:50	1.15	1.26	5.94	19:28:27	1.03	1.17	8.12
7:23:55	1.17	1.27	5.50	19:43:32	1.03	1.16	7.89
7:39:00	1.18	1.28	5.57	19:58:34	1.01	1.15	8.49
7:54:02	1.17	1.28	5.79	20:13:37	1.00	1.13	8.21
8:09:05	1.16	1.27	5.76	20:28:39	1.01	1.13	7.60
8:24:08	1.15	1.26	5.78	20:43:42	1.00	1.12	7.81
8:39:10	1.14	1.24	5.89	20:58:45	0.98	1.12	8.37
8:54:11	1.13	1.22	5.33	21:13:46	0.99	1.11	7.86
9:09:13	1.11	1.21	5.75	21:28:50	0.99	1.11	7.78
9:24:18	1.11	1.20	5.10	21:43:55	0.98	1.11	7.88
9:39:23	1.10	1.19	5.38	21:59:00	0.98	1.10	7.86
9:54:28	1.08	1.18	5.94	22:14:03	0.98	1.10	7.85
10:09:31	1.07	1.17	5.70	22:29:05	0.97	1.09	7.92
10:24:34	1.07	1.17	5.60	22:44:10	0.96	1.09	8.14
10:39:36	1.06	1.16	5.90	22:59:11	0.95	1.08	8.45
10:54:37	1.05	1.14	5.92	23:14:12	0.95	1.08	8.28
11:11:06	1.04	1.14	5.75	23:29:16	0.95	1.07	8.09
11:26:33	1.04	1.13	5.46	23:44:22	0.95	1.07	8.08
11:41:49	1.05	1.14	5.34				
11:56:53	1.06	1.15	5.76				
12:11:59	1.07	1.17	5.52				

Table D.16. INCO Matte Separation Plant column 2. Gas holdup data collected March 28 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:24	0.94	1.062	7.78	12:24:55	0.93	1.05	7.60
0:22:28	0.93	1.057	8.18	12:39:58	0.93	1.05	7.74
0:37:31	0.93	1.05	8.20	12:55:02	0.93	1.05	7.64
0:52:32	0.92	1.05	8.34	13:10:05	0.93	1.04	7.36
1:07:34	0.91	1.04	8.67	13:25:06	0.91	1.03	8.17
1:22:36	0.91	1.04	8.88	13:40:09	0.91	1.02	7.68
1:37:42	0.91	1.03	8.44	13:55:14	0.90	1.02	8.17
1:52:44	0.90	1.03	8.60	14:10:19	0.90	1.01	7.49
2:07:49	0.90	1.02	8.36	14:25:21	0.90	1.01	7.49
2:22:51	0.90	1.02	8.36	14:40:27	0.89	1.01	8.02
2:37:54	0.90	1.02	8.41	14:55:28	0.89	1.01	7.92
2:52:55	0.90	1.02	7.98	15:10:29	0.89	1.01	7.92
3:07:57	0.90	1.02	8.21	15:25:30	0.89	1.01	7.96
3:23:02	0.89	1.01	8.30	15:40:32	0.90	1.01	8.16
3:38:08	0.90	1.01	7.91	15:55:37	0.91	1.02	7.60
3:53:13	0.89	1.01	8.29	16:10:41	0.90	1.03	8.36
4:08:15	0.89	1.01	8.30	16:25:44	0.92	1.03	7.83
4:23:17	0.89	1.01	8.11	16:40:47	0.92	1.04	7.91
4:38:23	0.89	1.01	8.20	16:55:49	0.92	1.04	7.95
4:53:24	0.89	1.02	8.72	17:10:50	0.93	1.05	7.77
5:08:27	0.89	1.02	8.83	17:25:53	0.92	1.05	8.30
5:23:28	0.89	1.02	8.61	17:40:58	0.92	1.05	8.57
5:38:34	0.90	1.01	7.80	17:56:03	0.93	1.05	8.35
5:53:39	0.89	1.01	8.06	18:11:09	0.94	1.08	8.85
6:08:42	0.89	1.01	8.31	18:26:11	0.97	1.11	8.80
6:23:45	0.89	1.00	7.47	18:41:16	1.01	1.14	8.04
6:38:49	0.89	1.00	7.61	18:56:18	1.03	1.17	8.67
6:53:51	0.88	1.00	8.21	19:11:23	1.05	1.20	8.61
7:08:53	0.88	0.99	7.69	19:26:25	1.08	1.22	8.43
7:23:54	0.87	0.99	8.13	19:41:26	1.09	1.24	8.50
7:38:57	0.87	0.99	8.07	19:56:26	1.10	1.25	8.43
7:54:00	0.86	0.98	8.41	20:11:29	1.09	1.24	8.21
8:09:03	0.86	0.98	8.39	20:26:33	1.10	1.24	7.85
8:24:06	0.86	0.97	8.01	20:41:36	1.09	1.23	7.91
8:39:08	0.85	0.97	8.45	20:56:40	1.08	1.22	7.74
8:54:09	0.85	0.97	8.48	21:11:43	1.07	1.21	7.73
9:09:12	0.85	0.96	8.08	21:26:45	1.06	1.20	7.73
9:24:15	0.85	0.96	7.90	21:41:50	1.05	1.18	7.64
9:39:20	0.86	0.97	8.24	21:56:52	1.03	1.17	8.32
9:54:25	0.88	0.99	7.82	22:11:57	1.02	1.16	8.25
10:09:27	0.88	1.00	8.49	22:26:57	1.02	1.15	8.23
10:24:32	0.89	1.02	8.29	22:42:02	1.00	1.14	8.49
10:39:34	0.90	1.03	8.47	22:57:06	1.00	1.13	8.25
10:54:35	0.91	1.03	8.29	23:12:09	0.99	1.13	8.32
11:09:35	0.91	1.04	8.42	23:27:14	1.00	1.13	7.68
11:24:38	0.92	1.04	8.44	23:42:14	1.00	1.13	7.72
11:39:43	0.93	1.05	8.11				
11:54:48	0.92	1.05	8.39				
12:09:51	0.93	1.05	8.20				

Table D.17. INCO Matte Separation Plant column 2. Gas holdup data collected March 29 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)		k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:20	1.00	1.129	7.77	12:25:03	0.84	0.95	8.25
0:22:23	0.99	1.120	7.84	12:40:07	0.85	0.96	8.19
0:37:26	0.99	1.11	7.68	12:55:08	0.85	0.96	8.14
0:52:31	0.98	1.10	8.04	13:10:13	0.85	0.96	8.03
1:07:34	0.97	1.09	8.16	13:25:13	0.85	0.97	8.31
1:22:37	0.96	1.08	8.15	13:40:15	0.85	0.97	8.36
1:37:40	0.95	1.08	7.90	13:55:20	0.85	0.96	8.09
1:52:43	0.94	1.07	8.32	14:10:23	0.85	0.96	7.99
2:07:46	0.94	1.06	8.03	14:25:27	0.85	0.97	8.29
2:22:50	0.93	1.05	7.96	14:40:29	0.86	0.97	7.96
2:37:52	0.93	1.05	7.92	14:55:31	0.86	0.98	8.32
2:52:54	0.93	1.05	7.79	15:10:33	0.87	0.98	7.95
3:08:00	0.93	1.04	7.70	15:25:38	0.88	0.99	7.79
3:23:03	0.92	1.04	7.88	15:40:40	0.87	0.99	8.34
3:38:07	0.91	1.03	8.27	15:55:46	0.89	1.00	7.69
3:53:09	0.90	1.02	8.02	16:10:51	0.90	1.01	7.58
4:08:14	0.90	1.01	7.94	16:25:53	0.91	1.02	7.67
4:23:16	0.89	1.00	8.21	16:40:58	0.91	1.02	7.79
4:38:18	0.88	0.99	7.90	16:56:00	0.91	1.03	8.10
4:53:20	0.87	0.99	8.30	17:11:06	0.91	1.03	8.04
5:08:26	0.87	0.98	7.97	17:26:09	0.92	1.04	8.06
5:23:29	0.86	0.98	8.40	17:41:10	0.92	1.05	8.37
5:38:33	0.86	0.97	7.86	17:56:15	0.93	1.05	8.07
5:53:35	0.85	0.97	8.13	18:11:18	0.93	1.06	8.49
6:08:40	0.84	0.96	8.39	18:26:22	0.95	1.08	8.08
6:23:42	0.84	0.96	8.13	18:41:24	0.96	1.09	7.88
6:38:45	0.84	0.95	7.83	18:56:26	0.96	1.09	8.31
6:53:46	0.85	0.95	7.41	19:11:28	0.97	1.10	8.12
7:08:52	0.85	0.96	8.11	19:26:31	0.98	1.11	7.90
7:23:55	0.86	0.97	8.22	19:41:32	0.99	1.12	8.04
7:38:59	0.87	0.98	8.23	19:56:35	0.99	1.12	8.31
7:54:04	0.88	0.99	8.03	20:11:40	1.00	1.12	7.62
8:09:09	0.89	1.00	7.86	20:26:42	1.00	1.13	7.77
8:24:12	0.89	1.01	8.04	20:41:45	1.00	1.14	8.18
8:39:15	0.90	1.02	8.17	20:56:49	1.01	1.14	8.07
8:54:19	0.90	1.02	8.24	21:11:51	1.02	1.14	7.79
9:09:19	0.90	1.02	8.54	21:26:57	1.02	1.15	7.95
9:24:23	0.90	1.02	8.46	21:41:58	1.03	1.16	7.93
9:39:28	0.90	1.02	8.37	21:57:01	1.03	1.17	8.05
9:54:32	0.88	1.01	8.87	22:12:04	1.04	1.17	7.94
10:09:35	0.87	1.00	8.64	22:27:07	1.04	1.18	7.96
10:24:38	0.87	0.99	8.41	22:42:10	1.05	1.19	7.71
10:39:43	0.86	0.97	8.47	22:57:12	1.06	1.20	8.38
10:54:45	0.84	0.96	9.14	23:12:15	1.07	1.22	8.34
11:09:49	0.83	0.96	8.98	23:27:16	1.08	1.23	8.22
11:24:50	0.83	0.95	8.62	23:42:18	1.08	1.22	8.14
11:39:51	0.83	0.95	8.95				
11:54:57	0.83	0.95	8.64				
12:10:02	0.84	0.95	8.13				

Table D.18. INCO Matte Separation Plant column 2. Gas holdup data collected March 30 (1998) using sensor 2.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)
0:07:27	1.07	1.220	8.51
0:22:29	1.08	1.223	8.06
0:37:31	1.08	1.23	8.36
0:52:34	1.09	1.23	8.15
1:07:37	1.09	1.24	8.45
1:22:38	1.11	1.25	8.06
1:37:41	1.12	1.28	8.57
1:52:45	1.17	1.33	8.26
2:07:49	1.21	1.39	8.60
2:22:52	1.29	1.46	7.71
2:37:55	1.35	1.52	7.79
2:52:59	1.39	1.57	8.16
3:08:01	1.43	1.61	7.86
3:23:04	1.47	1.65	7.68
3:38:05	1.49	1.68	8.21
3:53:11	1.52	1.72	8.08
4:08:16	1.54	1.75	8.07
4:23:17	1.56	1.77	8.33
4:38:20	1.57	1.78	8.28
4:53:25	1.57	1.78	7.96
5:08:27	1.56	1.76	8.02
5:23:29	1.55	1.74	7.76
5:38:29	1.53	1.71	7.46
5:53:34	1.49	1.68	7.88
6:08:35	1.45	1.65	8.15
6:23:38	1.44	1.62	7.67
6:38:43	1.40	1.59	8.31
6:53:43	1.39	1.57	7.99
7:08:44	1.38	1.56	7.93
7:23:46	1.37	1.54	7.96
7:38:51	1.35	1.53	8.05
7:53:56	1.35	1.52	7.88
8:09:01	1.33	1.50	7.83
8:21:04	1.32	1.49	8.00
8:39:06	1.31	1.48	7.88
8:54:11	1.31	1.47	7.60
9:20:14	1.30	1.46	7.83
9:35:14	1.07	1.20	7.64

Table D.19.a. INCO Matte Separation Plant column 3. Gas holdup data collected March 31 (1998) using sensor 1.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)	Gamma
10:02:42	1.12	1.24	6.23	0.91
10:07:42	1.14	1.25	6.26	0.91
10:12:42	1.16	1.27	5.74	0.92
10:17:42	1.18	1.28	5.77	0.92
10:22:42	1.18	1.29	5.94	0.91
10:27:42	1.19	1.31	5.89	0.91
10:32:42	1.21	1.32	6.02	0.91
10:37:42	1.22	1.34	5.85	0.91
10:42:42	1.23	1.35	6.00	0.91
10:47:42	1.24	1.36	5.95	0.91
10:52:42	1.26	1.38	5.89	0.91
10:57:42	1.26	1.38	6.06	0.91
11:11:37	1.28	1.40	5.98	0.91
11:16:40	1.29	1.41	5.74	0.92
11:21:54	1.29	1.41	5.94	0.91
11:27:01	1.28	1.41	6.34	0.91
11:32:02	1.29	1.41	5.94	0.91
11:37:02	1.30	1.41	5.34	0.92
11:42:02	1.29	1.41	5.75	0.92
11:47:02	1.29	1.41	5.95	0.91
11:52:02	1.28	1.40	6.07	0.91
11:57:02	1.29	1.40	5.66	0.92
12:02:02	1.27	1.40	6.29	0.91
12:07:02	1.27	1.40	6.29	0.91
12:12:02	1.27	1.39	6.32	0.91
12:17:02	1.26	1.39	6.23	0.91
12:22:02	1.27	1.38	5.55	0.92
12:27:02	1.27	1.38	5.46	0.92
12:32:02	1.25	1.37	6.20	0.91
12:37:02	1.25	1.37	5.91	0.91
12:42:02	1.23	1.36	6.38	0.91
12:47:02	1.24	1.35	5.88	0.91
12:52:02	1.23	1.35	6.12	0.91
12:57:02	1.22	1.34	5.95	0.91
13:02:02	1.21	1.33	6.20	0.91
13:07:02	1.19	1.32	6.68	0.90
13:12:02	1.23	1.32	4.67	0.93
13:17:02	1.20	1.31	5.78	0.92
13:22:02	1.18	1.30	6.57	0.90
13:27:02	1.18	1.29	5.75	0.92
13:32:02	1.16	1.28	6.65	0.90
13:37:02	1.14	1.28	7.48	0.89
13:42:02	1.15	1.27	6.28	0.91
13:47:02	1.14	1.26	6.44	0.91
13:52:02	1.13	1.25	6.70	0.90
13:57:02	1.13	1.25	6.39	0.91
14:02:02	1.12	1.24	6.67	0.90
14:07:02	1.12	1.24	6.46	0.91
14:12:02	1.11	1.23	6.84	0.90

Table D.19.b. Continuation from Table D.19.a.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)	Gamma
14:17:02	1.10	1.23	7.07	0.90
14:22:02	1.10	1.22	6.78	0.90
14:27:02	1.10	1.22	6.90	0.90
14:32:02	1.10	1.21	6.49	0.91
14:37:02	1.09	1.21	6.84	0.90
14:42:02	1.09	1.20	6.29	0.91
14:47:02	1.09	1.20	6.31	0.91
14:52:02	1.08	1.20	6.68	0.90
14:57:02	1.07	1.19	7.20	0.90
15:02:02	1.06	1.18	6.99	0.90
15:07:02	1.06	1.18	7.26	0.89
15:12:02	1.04	1.17	7.68	0.89
15:17:02	1.05	1.17	6.97	0.90
15:22:02	1.04	1.16	7.02	0.90
15:27:02	1.04	1.16	7.27	0.89
15:32:02	1.03	1.15	7.56	0.89
15:37:02	1.04	1.15	6.84	0.90
15:42:02	1.04	1.15	6.82	0.90
15:47:02	1.03	1.15	7.32	0.89
15:52:02	1.03	1.15	7.31	0.89
15:57:02	1.03	1.16	7.42	0.89
16:02:02	1.03	1.15	7.31	0.89
16:07:02	1.05	1.16	6.65	0.90
16:12:02	1.04	1.16	7.39	0.89
16:17:02	1.03	1.16	7.52	0.89
16:22:02	1.05	1.16	6.53	0.91
16:27:02	1.04	1.16	7.39	0.89
16:32:02	1.04	1.16	7.02	0.90
16:37:02	1.04	1.16	7.14	0.90
16:42:02	1.03	1.16	7.64	0.89
16:47:02	1.04	1.16	6.90	0.90
16:52:02	1.06	1.16	5.92	0.91
16:57:02	1.06	1.16	5.92	0.91
17:02:02	1.06	1.16	5.79	0.92
17:07:02	1.07	1.16	5.18	0.92
17:12:02	1.07	1.16	5.42	0.92
17:17:02	1.06	1.16	6.04	0.91
17:22:02	1.06	1.16	5.80	0.92
17:27:02	1.06	1.16	5.67	0.92
17:32:02	1.06	1.16	5.92	0.91
17:37:02	1.06	1.16	5.67	0.92
17:42:02	1.08	1.16	4.83	0.93
17:47:02	1.06	1.16	5.67	0.92
17:52:02	1.06	1.16	6.17	0.91
17:57:02	1.06	1.16	6.04	0.91
18:02:02	1.06	1.16	6.16	0.91
18:07:02	1.07	1.16	5.55	0.92
18:12:02	1.05	1.16	6.30	0.91
18:17:02	1.06	1.16	5.57	0.92

Table D.19.c. Continuation from Table D.19.b.

	k open (mS/cm)	k syphon (mS/cm)	Eg (%)	Gamma
18:22:02	1.06	1.15	5.72	0.92
18:27:02	1.06	1.15	5.72	0.92
18:32:02	1.06	1.15	5.48	0.92
18:37:08	1.06	1.15	5.61	0.92
18:42:08	1.06	1.15	5.36	0.92
18:47:08	1.05	1.15	6.09	0.91
18:52:08	1.05	1.15	5.85	0.91
18:57:08	1.05	1.15	6.22	0.91
19:02:08	1.05	1.15	6.09	0.91
19:07:08	1.05	1.15	5.98	0.91
19:12:08	1.04	1.15	6.47	0.91
19:17:08	1.05	1.14	5.77	0.92
19:22:08	1.05	1.14	5.41	0.92
19:27:08	1.03	1.14	6.40	0.91
19:32:08	1.04	1.14	6.27	0.91
19:37:08	1.05	1.13	5.31	0.92
19:42:08	1.04	1.13	5.57	0.92
19:47:08	1.03	1.13	5.96	0.91
19:52:08	1.03	1.13	5.83	0.92
19:57:08	1.04	1.13	5.71	0.92
20:02:08	1.03	1.13	6.07	0.91
20:07:08	1.04	1.14	5.92	0.91
20:12:08	1.04	1.14	5.79	0.92
20:17:08	1.04	1.14	5.90	0.91
20:22:08	1.05	1.14	5.41	0.92
20:27:08	1.04	1.14	5.78	0.92
20:32:08	1.06	1.14	4.91	0.93
20:37:08	1.05	1.15	5.85	0.91
20:42:08	1.04	1.15	6.46	0.91
20:47:08	1.05	1.15	6.10	0.91
20:52:08	1.05	1.15	6.09	0.91
20:57:08	1.04	1.15	6.71	0.90
21:02:08	1.05	1.15	6.22	0.91
21:07:08	1.05	1.15	5.73	0.92
21:12:08	1.05	1.15	6.10	0.91
21:17:08	1.03	1.15	7.08	0.90
21:22:08	1.04	1.15	6.59	0.90
21:27:08	1.05	1.15	6.44	0.91
21:32:08	1.05	1.16	6.18	0.91
21:37:08	1.05	1.16	6.78	0.90
21:42:08	1.05	1.16	6.65	0.90
21:47:08	1.05	1.16	6.78	0.90
21:52:08	1.06	1.16	6.16	0.91
21:57:08	1.05	1.16	6.28	0.91

Table D.20. Measured grades for INCO test.

		FEED				CONCENTRATE				TAILING			
		Cu	Ni	Co	Fe	Cu	Ni	Co	Fe	Cu	Ni	Co	Fe
3/31/98	10:30	71.84	5.99	0.11	0.29	75.10	3.17	0.055	0.21	66.27	11.52	0.21	0.48
	11:30	72.04	6.19	0.10	0.34	75.40	2.92	0.049	0.21	67.47	10.56	0.19	0.51
	12:30	70.29	6.60	0.11	0.38	75.00	3.19	0.050	0.24	66.07	11.10	0.20	0.58
	14:30	69.29	7.72	0.14	0.49	74.40	3.64	0.061	0.31	62.68	13.82	0.25	0.77
	15:30	69.20	8.03	0.15	0.47	74.40	3.63	0.062	0.29	62.61	13.97	0.25	0.74
	16:30	68.65	8.13	0.15	0.51	74.40	3.62	0.063	0.30	62.42	13.93	0.26	0.79
	18:15	70.47	6.76	0.13	0.53	74.80	3.37	0.059	0.29	64.47	12.21	0.23	0.80
	19:15	70.59	6.38	0.12	0.59	74.70	3.28	0.058	0.30	65.24	10.88	0.21	0.79
	20:15	70.12	6.91	0.13	0.56	74.80	3.18	0.055	0.32	65.71	10.15	0.19	0.81

Table D.21. Grade values used to estiMatte the weights for the mass balance adjustments

Sample	Feed				Concentrate				Tailings			
	Cu	Ni	Co	Fe	Cu	Ni	Co	Fe	Cu	Ni	Co	Fe
1	69.65	8.09	0.14	0.42	74.40	3.63	0.060	0.31	64.50	12.65	0.21	0.68
2	69.45	8.07	0.14	0.42	73.61	3.50	0.060	0.28	64.20	12.56	0.21	0.68
3	69.64	8.10	0.14	0.42	74.40	3.63	0.061	0.30	64.24	12.52	0.22	0.66
4	69.61	8.12	0.14	0.43	74.40	3.63	0.060	0.31	64.33	12.67	0.22	0.68
5	69.41	8.08	0.14	0.42	74.50	3.59	0.060	0.30	64.23	12.63	0.22	0.66
6	69.66	8.03	0.14	0.43	73.91	3.53	0.060	0.28	64.21	12.57	0.22	0.67
7	69.50	8.00	0.14	0.42	74.40	3.62	0.060	0.31	64.47	12.70	0.22	0.67
8	69.48	8.05	0.14	0.42	74.40	3.63	0.061	0.30	64.48	12.61	0.22	0.67
9	69.26	8.04	0.13	0.42	74.14	3.56	0.060	0.29	64.40	12.58	0.22	0.68
10	69.45	8.06	0.14	0.42	73.58	3.48	0.060	0.28	64.21	12.66	0.22	0.67
Average	69.51	8.06	0.14	0.42	74.17	3.58	0.06	0.30	64.33	12.62	0.22	0.67
STDEV	0.13	0.04	0.00	0.00	0.35	0.06	0.00	0.01	0.12	0.06	0.00	0.01
%STDEV	0.002	0.004	0.023	0.010	0.005	0.016	0.007	0.043	0.002	0.005	0.019	0.012
Weight	290507	51158	1932	10017	44874	3721	20385	548	266755	49303	2673	7258

Table D.22. Adjusted grades for INCO test

		FEED				CONCENTRATE				TAILING			
		Cu	Ni	Co	Fe	Cu	Ni	Co	Fe	Cu	Ni	Co	Fe
3/31/98	10:30	71.91	5.99	0.11	0.29	[illegible]	3.17	0.055	0.20	66.25	11.52	0.21	0.48
	11:30	72.04	6.18	0.11	0.34	75.40	2.94	0.049	0.21	67.47	10.58	0.18	0.51
	12:30	70.53	6.60	0.11	0.38	[illegible]	3.19	0.050	0.23	65.97	11.10	0.20	0.58
	14:30	69.39	7.73	0.14	0.49	73.95	3.62	0.061	0.30	62.64	13.81	0.25	0.77
	15:30	69.24	8.04	0.14	0.47	74.21	3.62	0.062	0.28	62.59	13.96	0.25	0.74
	16:30	68.79	8.14	0.15	0.51	73.82	3.61	0.063	0.29	62.37	13.92	0.26	0.79
	18:15	70.54	6.79	0.13	0.52	74.49	3.31	0.059	0.33	64.44	12.17	0.23	0.81
	19:15	70.63	6.42	0.12	0.56	74.55	3.20	0.058	0.38	65.23	10.83	0.21	0.82
	20:15	70.07	6.90	0.13	0.57	74.98	3.20	0.055	0.30	65.74	10.17	0.19	0.80

Table D.23. Recovery and typical deviation values for INCO test.

		Cu			Ni			Co			Fe		
3/31/98	10:30	68.84%	±	7.14%	34.99%	±	0.79%	33.72%	±	4.06%	44.71%	±	12.28%
	11:30	60.33%	±	7.18%	27.47%	±	0.68%	26.62%	±	3.55%	36.19%	±	9.92%
	12:30	59.68%	±	7.19%	27.50%	±	0.66%	25.11%	±	3.32%	34.75%	±	9.10%
	14:30	63.60%	±	7.31%	27.97%	±	0.62%	26.39%	±	3.22%	36.96%	±	8.31%
	15:30	61.38%	±	7.35%	25.79%	±	0.58%	24.61%	±	3.08%	33.59%	±	8.04%
	16:30	60.14%	±	7.36%	24.83%	±	0.56%	23.58%	±	2.99%	32.29%	±	7.62%
	18:15	64.11%	±	7.24%	29.59%	±	0.68%	28.18%	±	3.45%	38.35%	±	8.28%
	19:15	61.13%	±	7.24%	28.92%	±	0.69%	27.66%	±	3.55%	38.71%	±	8.20%
	20:15	50.18%	±	7.32%	21.74%	±	0.58%	20.21%	±	3.05%	25.00%	±	6.54%

Table D.24. Data on Air flow rate, level (froth depth) and solid percent for INCO test.

	Air flow rate (m3/hr)	Level (cm)	% Solids
10:30	170	-	40.8
11:30	170	120	45.2
12:30	170	125	42.5
12:35	192	-	-
14:30	192	120	37.7
15:30	192	190	38.2
16:30	192	190	38.6
16:35	160	-	-
18:15	160	130	38.2
19:15	160	150	43.7
20:15	160	150	38.3

Table D.25.a. Data from two sensors at different depths inside column 3. Sensor 1 at 4-meter depth and sensor 2 at 7-meter depth.

Time	Sensor 1			Sensor 2		
	k open (mS/cm)	k syphon (mS/cm)	Eg (%)	k open (mS/cm)	k syphon (mS/cm)	Eg (%)
8:02:28	1.40	1.50	4.64	1.14	1.27	7.19
8:07:28	1.39	1.50	4.92	1.11	1.27	8.65
8:12:29	1.41	1.50	4.18	1.15	1.27	6.62
8:17:29	1.40	1.50	4.45	1.14	1.27	7.29
8:22:30	1.41	1.50	4.35	1.12	1.27	7.89
8:27:30	1.40	1.50	4.36	1.12	1.26	8.03
8:32:30	1.40	1.50	4.54	1.11	1.26	8.38
8:37:30	1.39	1.50	5.10	1.11	1.26	8.51
8:42:30	1.40	1.50	4.45	1.12	1.26	7.49
8:47:30	1.40	1.50	4.46	1.10	1.25	8.31
8:52:31	1.39	1.50	5.11	1.09	1.25	8.92
8:57:31	1.41	1.49	3.92	1.09	1.25	9.15
9:02:31	1.41	1.49	3.83	1.12	1.25	7.07
9:07:32	1.39	1.49	4.67	1.11	1.25	7.79
9:12:32	1.37	1.49	5.33	1.08	1.24	8.86
9:17:32	1.39	1.49	4.50	1.10	1.24	8.06
9:22:32	1.38	1.48	4.80	1.10	1.24	7.60
9:27:33	1.39	1.48	4.33	1.09	1.24	8.21
9:32:33	1.38	1.48	4.70	0.72	0.81	13.99
9:37:33	1.38	1.48	4.52	0.04	0.03	0.00
9:42:33	1.39	1.47	3.89	0.72	0.89	10.05
9:47:33	1.37	1.47	4.64	1.36	1.47	5.04
9:52:33	1.37	1.47	4.55	1.35	1.47	5.32
9:57:34	1.37	1.47	4.56	1.35	1.46	4.97
10:02:34	1.36	1.46	4.58	1.34	1.46	5.35
10:07:35	1.36	1.46	4.68	1.34	1.46	5.44
10:12:35	1.36	1.46	4.67	1.35	1.46	5.35
10:17:35	1.36	1.46	4.58	1.35	1.46	4.96
10:22:36	1.35	1.46	5.16	1.35	1.46	4.87
10:27:36	1.36	1.46	4.87	1.35	1.46	5.06
10:32:36	1.37	1.46	4.01	1.35	1.46	5.25
10:37:36	1.35	1.45	4.69	1.35	1.46	4.97
10:42:37	1.36	1.46	4.31	1.35	1.46	5.26
10:47:37	1.35	1.46	5.35	1.34	1.45	5.19
10:52:37	1.37	1.46	4.11	1.34	1.46	5.44
10:57:37	1.37	1.46	4.20	1.34	1.46	5.46
11:02:37	1.38	1.46	3.92	1.35	1.46	4.87
11:07:37	1.37	1.46	4.29	1.36	1.46	4.59
11:12:38	1.38	1.46	3.91	1.34	1.47	5.80
11:17:38	1.37	1.47	4.45	1.36	1.47	4.75

Table D.25.b. Continuation from Table D.25.a.

Time	Sensor 1			Sensor 2		
	k open (mS/cm)	k syphon (mS/cm)	Eg (%)	k open (mS/cm)	k syphon (mS/cm)	Eg (%)
11:22:39	1.39	1.48	4.24	1.37	1.48	4.99
11:27:39	1.39	1.49	4.39	1.38	1.49	4.97
11:32:39	1.39	1.50	4.83	1.39	1.50	4.93
11:37:40	1.40	1.51	4.89	1.39	1.50	5.29
11:42:40	1.43	1.52	4.12	1.40	1.52	5.23
11:47:40	1.42	1.53	4.74	1.41	1.53	5.30
11:52:40	1.45	1.54	4.06	1.45	1.54	4.15
11:57:40	1.46	1.55	4.03	1.44	1.55	4.58
12:02:40	1.49	1.56	3.21	1.46	1.56	4.02
12:07:40	1.48	1.57	4.16	1.46	1.57	4.69
12:12:41	1.49	1.58	4.04	1.48	1.58	4.40
12:17:41	1.50	1.59	3.93	1.49	1.59	4.11
12:22:41	1.52	1.59	3.23	1.50	1.59	4.19
12:27:42	1.52	1.60	3.64	1.49	1.60	4.68
12:32:42	1.51	1.61	4.14	1.50	1.61	4.41
12:37:43	1.52	1.61	4.05	1.51	1.61	4.06
12:42:43	1.51	1.62	4.72	1.52	1.62	4.37
12:47:43	1.53	1.62	3.93	1.52	1.62	4.20
12:52:44	1.54	1.63	3.67	1.52	1.63	4.43
12:57:44	1.54	1.64	3.99	1.53	1.63	3.85
13:02:44	1.53	1.63	4.18	1.51	1.63	5.02
13:07:44	1.51	1.63	5.04	1.53	1.62	3.85
13:12:44	1.51	1.62	4.63	1.51	1.63	4.95
13:17:44	1.49	1.62	5.24	1.51	1.62	4.63
13:22:44	1.49	1.61	5.26	1.49	1.62	5.59
13:27:45	1.52	1.63	4.69	1.50	1.63	5.21
13:32:45	1.51	1.62	4.80	1.51	1.62	4.63
13:37:45	1.47	1.61	5.98	1.48	1.61	5.54
13:42:46	1.49	1.60	4.71	1.47	1.60	5.40
13:47:46	1.47	1.58	4.58	1.48	1.59	4.73
13:52:47	1.46	1.57	4.87	1.47	1.58	4.50
13:57:47	1.45	1.56	4.99	1.45	1.57	5.15
14:02:47	1.42	1.55	5.85	1.44	1.56	5.09
14:07:47	1.44	1.54	4.60	1.44	1.55	5.03
14:12:47	1.42	1.54	5.34	1.43	1.54	4.70
14:17:47	1.42	1.53	5.00	1.42	1.54	5.07
14:22:48	1.42	1.53	4.93	1.41	1.53	5.28
14:27:48	1.41	1.52	5.04	1.39	1.53	6.13
14:32:48	1.40	1.52	5.14	1.40	1.52	5.22
14:37:48	1.41	1.51	4.42	1.40	1.51	5.07

Table D.25.c. Continuation from Table D.25.b.

Time	Sensor 1			Sensor 2		
	k open (mS/cm)	k syphon (mS/cm)	Eg (%)	k open (mS/cm)	k syphon (mS/cm)	Eg (%)
14:42:49	1.40	1.50	4.63	1.40	1.51	4.89
14:47:49	1.40	1.50	4.74	1.39	1.50	4.83
14:52:49	1.39	1.49	4.57	1.39	1.50	4.65
14:57:50	1.38	1.49	4.87	1.38	1.49	4.87
15:02:50	1.37	1.48	5.18	1.37	1.48	4.98
15:07:51	1.35	1.47	5.60	1.35	1.48	5.77
15:12:51	1.34	1.46	5.91	1.36	1.47	5.30
15:17:51	1.34	1.46	5.63	1.34	1.46	5.91
15:22:51	1.32	1.45	6.34	1.33	1.46	5.94
15:27:51	1.32	1.45	5.88	1.34	1.45	5.27
15:32:51	1.32	1.44	5.62	1.33	1.45	5.49
15:37:51	1.32	1.44	5.62	1.33	1.45	5.77
15:42:51	1.32	1.44	5.72	1.32	1.44	5.89
15:47:52	1.32	1.44	5.72	1.33	1.44	5.51
15:52:52	1.31	1.44	5.92	1.33	1.44	4.94
15:57:53	1.30	1.43	6.05	1.33	1.43	5.05
16:02:53	1.31	1.43	5.68	1.29	1.43	6.65
16:07:53	1.31	1.42	5.20	1.33	1.43	4.69
16:12:54	1.31	1.42	5.40	1.32	1.42	4.91
16:17:54	1.32	1.41	4.55	1.31	1.42	5.21
16:22:54	1.31	1.41	4.65	1.32	1.41	4.35
16:27:54	1.30	1.40	4.87	1.31	1.41	4.94
16:32:54	1.31	1.40	4.48	1.31	1.40	4.18
16:37:54	1.30	1.39	4.50	1.30	1.40	4.89
16:42:55	1.30	1.39	4.31	1.30	1.40	5.08
16:47:55	1.30	1.39	4.12	1.29	1.39	5.02
16:52:55	1.31	1.38	3.64	1.30	1.39	4.42
16:57:55	1.29	1.38	4.65	1.28	1.38	4.94
17:02:56	1.29	1.37	4.16	1.28	1.38	4.75
17:07:56	1.29	1.37	3.87	1.28	1.38	4.97
17:12:57	1.29	1.37	3.87	1.27	1.37	5.09
17:17:57	1.30	1.37	3.57	1.28	1.37	4.48
17:22:57	1.27	1.37	4.59	1.28	1.37	4.48
17:27:58	1.29	1.36	3.70	1.27	1.37	4.79
17:32:58	1.28	1.36	4.01	1.28	1.36	4.01
17:37:58	1.27	1.35	4.03	1.27	1.36	4.32
17:42:58	1.27	1.35	3.93	1.27	1.35	4.32
17:47:58	1.26	1.35	4.76	1.26	1.35	4.65
17:52:58	1.25	1.34	4.68	1.27	1.35	4.13
17:57:59	1.25	1.34	4.37	1.25	1.34	4.57

APPENDIX E

Table E.1. Experimental data on gas holdup: gas holdup from pressure versus gas holdup from conductivity. Every point is the average of 15 min of operation. (last 4 points correspond to jetting sparger tests). Temperature 323 K.

P_{bottom} cmH2O	P_{middle} cmH2O	E_{gP} (%)	S.D.E_{gP} (%)	kd (mS/cm)	ksl (mS/cm)	E_{gk} (%)	S.D.E_{gk} (%)
192	340	10.7	0.2	3.75	4.30	9.0	0.6
195	346	9.2	0.2	3.84	4.32	7.7	0.6
192	340	10.8	0.3	3.73	4.34	9.9	0.9
186	329	13.9	0.3	3.44	4.20	12.8	0.9
191	338	11.3	0.3	3.63	4.25	10.3	0.8
188	333	12.6	0.8	3.44	4.25	13.6	2.3
178	315	17.5	0.7	3.31	4.38	17.8	1.3
183	276	15.1	0.6	3.47	4.42	15.4	0.9
186	330	13.5	0.3	3.66	4.47	12.9	0.9
192	340	10.7	0.2	3.81	4.44	9.8	0.6
200	356	6.2	0.2	4.10	4.47	5.6	0.7
149	289	16.0	0.7	3.21	4.11	15.7	1.5
151	292	15.6	0.3	3.29	4.14	14.7	0.8
129	269	15.8	0.6	3.32	4.19	14.8	1.5
124	259	18.5	0.4	2.98	3.93	17.7	1.0
128	269	15.4	0.4	3.21	4.01	14.3	0.9
135	281	12.2	0.2	3.43	4.05	10.7	0.7
145	298	8.1	0.2	3.69	4.11	7.0	0.6
138	296	5.2	0.2	3.87	4.13	4.3	0.4
135	281	12.2	1.0	3.46	4.20	12.5	2.0
137	283	11.5	0.6	3.49	4.20	12.0	1.5
137	285	10.7	0.5	3.59	4.22	10.4	0.9
134	275	15.2	0.4	3.34	4.27	15.7	1.2
138	281	13.6	0.7	3.37	4.26	14.9	1.5
141	290	10.7	0.4	3.55	4.23	11.4	1.8
137	272	19.0	0.4	3.13	4.15	17.9	0.9
136	273	17.2	0.3	3.28	4.19	15.6	0.7
136	277	15.1	0.4	3.45	4.21	12.8	0.9
143	290	11.1	0.3	3.71	4.24	8.6	0.7
148	303	6.6	0.2	3.94	4.23	4.8	0.6
133	273	15.4	0.4	3.34	4.19	14.4	1.0
139	284	12.4	0.5	3.52	4.21	11.7	1.2
145	296	9.0	0.5	3.72	4.22	8.3	1.5
208	371	2.1	0.3	4.07	4.34	4.3	2.4
206	366	3.7	0.3	3.96	4.34	6.1	3.0
203	360	5.4	0.6	3.84	4.36	8.4	3.7
200	355	6.5	0.5	3.79	4.34	9.0	4.0

Table E.2. Test conditions for BOWATER tests

Test #	superficial velocity (cm/s)			Level	R.T.	Eg	S.D.Eg	P
	Jg	feed	accepts	(cm)	(min)	(%)	(%)	(cmH_2O)
1A-1	2.34	1.75	1.73	100	3.2	17.7	1.0	1292
1A-2	1.89	1.85	1.81	100	3.2	14.3	0.9	1302
1A-3	1.46	1.89	1.86	100	3.2	10.7	0.7	1314
1A-4	0.94	1.98	1.98	100	3.1	7.0	0.6	1331
1A-5	0.72	2.03	2.00	100	3.2	4.3	0.4	1329
1B-1	2.83	0.95	0.92	100	6.0	17.9	0.9	1238
1B-2	2.37	0.98	0.93	100	6.1	15.6	0.7	1238
1B-3	1.89	0.96	0.93	100	6.3	12.8	0.9	1240
1B-4	1.40	1.02	0.99	100	6.2	8.6	0.7	1249
1B-5	0.93	1.06	1.04	100	6.1	4.8	0.6	1259
1C-1	2.83	1.07	1.06	50	5.8	17.8	1.3	1280
1C-2	2.37	1.06	1.03	50	6.2	15.4	0.9	1263
1C-3	1.87	1.08	1.05	50	6.2	12.9	0.9	1263
1C-4	1.40	1.12	1.10	50	6.1	9.8	0.6	1299
1C-5	0.96	1.16	1.15	50	6.2	5.6	0.7	1311
2A-5sp	2.34	1.75	1.71	100	3.3	15.7	1.2	1237
2A-4sp	2.39	1.75	1.71	100	3.4	12.0	1.5	1242
2A-3sp	2.37	1.76	1.73	100	3.5	10.4	1.9	1249
2B-5sp	2.37	0.99	0.95	100	6.0	14.4	1.0	1236
2B-4sp	2.37	0.96	0.95	100	6.2	11.7	1.2	1244
2B-3sp	2.37	0.97	0.92	100	6.6	8.3	1.5	1253
3A-5sp	1.86	0.99	0.95	50	6.9	12.8	0.9	1290
3A-4sp	1.86	0.94	0.94	50	7.2	10.3	0.9	1298
3A-4sp-b	3.10	0.97	0.94	50	6.9	13.6	2.3	1293
3B-5sp	1.40	0.98	0.94	50	7.3	9.0	0.6	1299
3B-4sp	1.41	0.99	0.94	50	7.4	7.7	0.6	1303
3B-4sp-b	1.79	0.97	0.94	50	7.2	9.9	0.9	1299
4A-1	2.49	1.18	1.13	50	6.0	9.0	4.0	1311
4A-2	2.09	1.17	1.13	50	6.1	8.4	3.7	1314
4A-3	1.51	1.17	1.16	50	6.1	6.1	3.0	1319
4A-4	1.17	1.09	1.07	50	6.7	4.3	2.4	1322

Table E.3. Flotation efficiency and brightness gain for BOWATER tests.

Test #	ERIC (ppm)		Efficiency (%)	Brightness (%ISO)		
	feed	accepts		feed	accepts	gain
1A-1	1062	343	67.7	45.95	57.06	11.11
1A-2	1075	389	63.8	46.06	56.07	10.01
1A-3	975	441	54.7	47.43	55.85	8.42
1A-4	934	739	20.9	48.02	50.92	2.90
1A-5	915	927	0.0	47.96	47.62	0.00
1B-1	1224	308	74.8	42.95	56.21	13.26
1B-2	1225	311	74.6	42.71	56.51	13.80
1B-3	1308	338	74.2	42.48	55.91	13.43
1B-4	1226	476	61.2	43.60	52.97	9.37
1B-5	1146	1071	6.5	43.45	46.25	2.80
1C-1	1230	321	73.9	43.50	56.03	12.53
1C-2	1187	348	70.7	43.35	55.90	12.55
1C-3	1207	372	69.2	42.94	55.35	12.41
1C-4	1319	460	65.1	43.77	54.27	10.50
1C-5	1290	1048	18.8	42.95	45.56	2.61
2A-5sp	1011	446	55.9	44.20	52.67	8.47
2A-4sp	981	516	47.4	46.03	52.23	6.20
2A-3sp	1023	869	15.1	46.53	48.29	1.76
2B-5sp	1255	316	74.8	43.16	57.40	14.24
2B-4sp	1167	430	63.2	44.35	55.14	10.79
2B-3sp	1142	945	17.3	45.45	48.19	2.74
3A-5sp	1201	275	77.1	43.41	58.42	15.01
3A-4sp	1095	332	69.7	45.41	57.36	11.95
3A-4sp-b	1233	439	64.4	44.87	55.58	10.71
3B-5sp	1100	298	73.0	45.73	58.31	12.58
3B-4sp	945	355	62.5	47.39	57.00	9.61
3B-4sp-b	1043	352	66.2	46.23	56.66	10.43

Table E.4. Test condition for test 2B-5sp H_f = 100 cm; 5 spargers; τ = 6 min..

	Pb (cmH2O)	Pm (cmH2O)	Egp (%)	Qa (L/min)	Jg (cm/s)	Jfeed (cm/s)	Jtail (cm/s)	ko (mS/cm)	ks (mS/cm)	Egk (%)
14:58:04	134.0	274.1	15.4	276	2.37	0.97	0.98	3.29	4.19	15.5
14:58:24	134.3	274.0	15.9	276	2.37	0.97	0.98	3.36	4.19	14.1
14:58:44	134.0	273.0	16.6	276	2.37	0.97	0.98	3.34	4.18	14.4
14:59:04	132.6	273.7	14.8	276	2.37	0.97	0.98	3.28	4.19	15.6
14:59:24	132.7	273.3	15.2	276	2.37	0.97	0.98	3.45	4.19	12.4
14:59:44	133.7	273.3	15.6	276	2.37	0.97	0.98	3.39	4.19	13.7
15:00:04	133.0	272.7	15.8	276	2.37	0.97	0.98	3.39	4.19	13.6
15:00:24	131.6	271.6	16.0	276	2.37	0.97	0.98	3.33	4.19	14.7
15:00:44	131.9	272.4	15.6	276	2.37	0.97	0.98	3.36	4.18	14.1
15:01:04	132.5	272.4	15.2	276	2.37	0.97	0.98	3.31	4.19	15.1
15:01:24	133.1	272.7	15.7	276	2.37	0.97	0.98	3.30	4.19	15.2
15:01:44	132.6	272.4	15.0	276	2.37	0.97	0.98	3.37	4.19	13.9
15:02:04	131.8	272.2	15.6	276	2.37	0.97	0.98	3.25	4.19	16.1
15:02:24	132.6	272.4	15.7	276	2.37	0.97	0.98	3.33	4.19	14.7
15:02:44	132.0	271.4	15.7	276	2.37	0.97	0.98	3.41	4.19	13.2
15:03:04	132.2	272.5	15.5	276	2.37	0.97	0.98	3.32	4.18	14.7
15:03:24	131.8	271.6	16.0	276	2.37	0.97	0.98	3.34	4.19	14.6
15:03:44	131.9	272.2	15.3	276	2.37	0.97	0.98	3.40	4.18	13.3
15:04:04	130.8	271.4	15.5	276	2.37	0.97	0.98	3.39	4.18	13.5
15:04:24	131.0	271.3	15.6	276	2.37	0.97	0.92	3.35	4.20	14.4
15:04:44	131.0	271.4	15.4	276	2.37	0.97	0.92	3.28	4.19	15.6
15:05:04	130.8	271.3	15.2	276	2.37	1.14	0.92	3.33	4.19	14.7
15:05:24	130.9	272.2	14.9	276	2.37	1.01	0.92	3.31	4.19	15.0
15:05:44	131.5	271.3	15.7	276	2.37	1.01	0.92	3.39	4.19	13.6
15:06:04	131.8	272.5	15.1	276	2.37	1.01	0.92	3.33	4.19	14.8
15:06:24	132.2	272.9	15.4	276	2.37	1.01	0.92	3.42	4.19	13.1
15:06:44	131.6	273.2	14.7	276	2.37	1.01	0.92	3.35	4.19	14.3
15:07:04	132.6	273.5	14.8	276	2.37	1.01	0.92	3.41	4.20	13.3
15:07:24	133.8	273.3	16.0	276	2.37	1.01	0.92	3.40	4.19	13.3
15:07:44	132.4	273.7	14.9	276	2.37	1.01	0.92	3.39	4.19	13.5
15:08:04	133.7	273.8	15.5	276	2.37	1.01	0.92	3.37	4.19	14.0
15:08:24	134.0	273.7	15.8	276	2.37	1.01	0.92	3.34	4.19	14.6
15:08:44	133.5	274.0	15.4	276	2.37	1.01	0.92	3.37	4.19	13.9
15:09:04	133.5	274.3	14.9	276	2.37	1.01	0.92	3.30	4.19	15.2
15:09:24	135.1	275.1	15.8	276	2.37	1.01	0.92	3.35	4.19	14.2
15:09:44	134.6	275.2	15.3	277	2.37	1.01	0.92	3.34	4.18	14.5
15:10:04	134.8	275.1	15.2	276	2.37	1.01	0.92	3.38	4.18	13.7
15:10:24	135.1	275.7	15.1	277	2.37	1.01	0.92	3.28	4.19	15.7
15:10:44	135.7	275.7	15.5	277	2.37	1.01	0.92	3.32	4.19	14.9
15:11:04	134.9	276.0	15.3	277	2.37	1.01	0.92	3.42	4.19	13.0
15:11:24	135.4	276.8	14.8	276	2.37	1.01	0.92	3.31	4.19	15.0
15:11:44	135.2	275.7	15.7	277	2.37	0.92	0.92	3.36	4.19	14.2
15:12:04	134.8	274.9	15.6	277	2.37	0.92	0.92	3.27	4.19	15.7
15:12:24	134.8	274.9	15.6	276	2.37	0.92	0.92	3.37	4.19	13.9
15:12:44	133.0	274.8	14.8	[illegible]	[illegible]	0.92	0.92	3.18	4.19	17.6

Table E.5. Test condition for test 2B-4sp H_f = 100 cm; 4 spargers; τ = 6 min..

	Pb (cmH2O)	Pm (cmH2O)	Egp (%)	Qa (L/min)	Jg (cm/s)	Jfeed (cm/s)	Jtail (cm/s)	ko (mS/cm)	ks (mS/cm)	Egk (%)
15:28:04	138.8	283.3	12.3	276	2.37	0.97	0.92	3.51	4.21	11.7
15:28:24	139.2	283.8	12.8	276	2.37	0.97	0.92	3.59	4.20	10.2
15:28:44	138.1	283.5	12.4	276	2.37	0.97	0.92	3.55	4.20	10.8
15:29:04	139.0	283.7	12.6	276	2.37	0.97	0.92	3.46	4.20	12.6
15:29:24	138.9	284.1	12.4	276	2.37	0.97	0.92	3.48	4.21	12.3
15:29:44	137.8	283.8	12.0	276	2.37	0.97	0.92	3.32	4.21	15.1
15:30:04	138.8	284.4	12.2	276	2.37	0.97	0.92	3.48	4.20	12.1
15:30:24	139.0	281.9	13.9	276	2.37	0.97	0.92	3.53	4.21	11.3
15:30:44	138.1	283.2	12.4	276	2.37	0.97	0.92	3.50	4.21	11.9
15:31:04	138.1	282.7	12.6	276	2.37	0.97	0.92	3.50	4.21	12.0
15:31:24	138.5	282.9	13.2	276	2.37	0.97	0.92	3.57	4.21	10.7
15:31:44	137.3	283.3	12.4	276	2.37	0.97	0.92	3.41	4.21	13.6
15:32:04	138.4	282.9	12.6	276	2.37	0.97	0.92	3.55	4.22	11.1
15:32:24	138.4	281.9	13.3	276	2.37	0.97	0.92	3.56	4.21	10.9
15:32:44	138.5	283.0	12.9	276	2.37	0.97	0.92	3.50	4.21	12.0
15:33:04	137.5	283.5	12.4	276	2.37	0.97	0.92	3.58	4.21	10.6
15:33:24	138.6	284.8	11.5	276	2.37	1.02	0.92	3.53	4.21	11.4
15:33:44	137.9	282.7	12.8	276	2.37	1.02	0.92	3.49	4.22	12.2
15:34:04	139.3	284.9	12.1	276	2.37	1.02	0.92	3.49	4.21	12.0
15:34:24	138.9	286.0	11.8	276	2.37	1.02	0.92	3.63	4.20	9.5
15:34:44	140.7	285.4	12.8	276	2.37	0.87	0.92	3.46	4.22	12.7
15:35:04	139.6	286.5	11.7	276	2.37	0.98	0.97	3.55	4.22	11.1
15:35:24	139.8	287.3	11.7	276	2.37	0.85	0.97	3.59	4.21	10.3
15:35:44	139.9	286.2	11.6	276	2.37	0.95	0.97	3.51	4.21	11.8
15:36:04	139.8	284.8	12.7	276	2.37	0.95	0.97	3.46	4.21	12.6
15:36:24	140.7	285.7	12.4	276	2.37	0.95	0.97	3.59	4.22	10.5
15:36:44	138.8	285.4	12.0	276	2.37	0.95	0.97	3.44	4.22	13.0
15:37:04	140.1	285.9	11.8	276	2.37	0.95	0.97	3.52	4.22	11.6
15:37:24	139.8	285.1	12.9	276	2.37	0.95	0.97	3.48	4.21	12.1
15:37:44	139.1	286.0	12.4	276	2.37	0.94	0.97	3.57	4.22	10.7
15:38:04	140.4	286.5	12.0	276	2.37	0.94	0.97	3.61	4.21	10.0
15:38:24	138.9	284.6	12.2	276	2.37	0.92	0.97	3.51	4.21	11.8
15:38:44	137.6	283.7	12.4	276	2.37	0.92	0.97	3.45	4.21	12.8
15:39:04	138.5	283.3	12.7	276	2.37	0.92	0.97	3.56	4.22	11.0
15:39:24	138.4	284.6	11.9	276	2.37	0.92	0.97	3.52	4.22	11.7
15:39:44	137.0	283.3	11.6	276	2.37	0.92	0.97	3.32	4.22	15.4
15:40:04	136.4	282.7	12.3	276	2.37	0.92	0.97	3.45	4.22	12.9
15:40:24	136.7	282.7	12.3	276	2.37	0.92	0.97	3.49	4.21	12.1
15:40:44	136.4	282.2	11.9	276	2.37	0.92	0.97	3.59	4.21	10.3
15:41:04	138.2	282.4	12.9	276	2.37	0.98	0.97	3.56	4.21	10.8
15:41:24	137.1	281.7	12.8	276	2.37	0.98	0.97	3.57	4.20	10.5
15:41:44	138.0	283.0	12.6	276	2.37	0.98	0.97	3.50	4.21	11.9
15:42:04	137.0	282.2	12.7	276	2.37	0.98	0.97	3.55	4.21	11.1
15:42:24	136.5	281.7	12.9	276	2.37	0.98	0.97	3.50	4.21	11.9
15:42:44	138.6	284.4	11.7	276	2.37	0.98	0.97	3.61	4.21	10.0

Table E.6. Test condition for test 2B-3sp H_f = 100 cm: 3 spargers: τ = 6 min..

	Pb (cmH2O)	Pm (cmH2O)	Egp (%)	Qa (L/min)	Jg (cm/s)	Jfeed (cm/s)	Jtail (cm/s)	ko (mS/cm)	ks (mS/cm)	Egk (%)
16:08:04	143.1	293.3	8.9	275	2.37	0.99	0.92	3.66	4.23	9.3
16:08:24	142.4	292.7	9.2	276	2.37	0.99	0.92	3.70	4.23	8.7
16:08:44	143.2	293.0	9.9	276	2.37	0.99	0.92	3.78	4.22	7.2
16:09:04	142.5	293.0	9.7	276	2.37	0.99	0.92	3.80	4.23	6.9
16:09:24	142.9	294.3	8.4	276.	2.37	0.99	0.92	3.66	4.22	9.4
16:09:44	143.2	294.1	9.2	276	2.37	0.99	0.92	3.81	4.23	6.8
16:10:04	143.3	293.2	9.5	276	2.37	0.99	0.92	3.79	4.22	7.1
16:10:24	142.6	294.1	8.7	276	2.37	1.01	0.92	3.62	4.23	10.1
16:10:44	144.8	294.4	9.4	276	2.37	1.01	0.92	3.68	4.22	9.0
16:11:04	145.2	294.8	9.9	276	2.37	1.02	0.92	3.84	4.23	6.3
16:11:24	145.4	295.7	9.4	276	2.37	1.02	0.92	3.79	4.23	7.1
16:11:44	145.4	296.7	8.7	276	2.37	1.02	0.92	3.61	4.23	10.2
16:12:04	145.6	295.7	9.2	276	2.37	1.02	0.92	3.61	4.22	10.2
16:12:24	146.5	296.0	9.6	276	2.37	1.02	0.92	3.77	4.22	7.4
16:12:44	145.2	297.6	8.3	277	2.37	0.97	0.92	3.68	4.23	9.0
16:13:04	145.3	296.7	8.8	276	2.37	0.97	0.92	3.72	4.22	8.1
16:13:24	146.2	296.5	9.7	277	2.37	0.97	0.92	3.63	4.23	9.9
16:13:44	145.9	296.7	9.5	277	2.37	0.93	0.92	3.71	4.23	8.5
16:14:04	145.9	297.1	9.0	276	2.37	0.93	0.92	3.72	4.22	8.1
16:14:24	146.3	296.3	9.4	276	2.37	0.93	0.92	3.71	4.23	8.6
16:14:44	145.4	297.9	8.4	276	2.37	0.93	0.92	3.84	4.22	6.2
16:15:04	145.2	298.3	8.3	276	2.37	0.93	0.92	3.83	4.23	6.5
16:15:24	146.8	297.5	8.9	276	2.37	0.93	0.92	3.73	4.22	8.1
16:15:44	146.0	297.0	9.1	274	2.37	0.93	0.92	3.64	4.22	9.6
16:16:04	145.2	297.6	8.5	274	2.37	0.93	0.92	3.84	4.23	6.2
16:16:24	145.8	296.7	9.1	276	2.37	0.93	0.92	3.52	4.23	11.8
16:16:44	144.4	296.3	9.3	276	2.37	0.92	0.92	3.71	4.22	8.4
16:17:04	145.5	296.8	8.8	277	2.37	0.92	0.92	3.68	4.22	8.8
16:17:24	145.3	296.3	8.7	277	2.37	0.92	0.92	3.68	4.22	8.9
16:17:44	144.5	296.5	8.3	277	2.37	0.92	0.92	3.78	4.22	7.1
16:18:04	144.0	295.6	9.1	276	2.37	0.92	0.92	3.75	4.23	7.8
16:18:24	144.5	296.0	8.7	276	2.37	0.92	0.92	3.82	4.22	6.5
16:18:44	144.5	295.2	9.3	276	2.37	0.92	0.92	3.83	4.22	6.5
16:19:04	144.4	295.2	9.1	276	2.37	0.92	0.92	3.65	4.23	9.7
16:19:24	142.7	294.6	8.7	276	2.37	0.92	0.92	3.82	4.22	6.5
16:19:44	144.6	295.9	8.9	275	2.37	0.92	0.92	3.49	4.22	12.2
16:20:04	142.5	294.9	7.7	276	2.37	0.99	0.92	3.66	4.23	9.4
16:20:24	143.6	295.1	8.9	277	2.37	0.98	0.92	3.69	4.22	8.6
16:20:44	143.7	294.3	9.2	277	2.37	0.98	0.92	3.79	4.22	7.0
16:21:04	145.1	295.4	9.1	277	2.37	0.98	0.92	3.78	4.22	7.3
16:21:24	144.8	295.9	9.0	277	2.37	0.98	0.92	3.72	4.22	8.2
16:21:44	143.8	296.7	8.5	277	2.37	0.98	0.92	3.82	4.22	6.5
16:22:04	145.3	296.7	8.8	276	2.37	1.02	0.92	3.75	4.22	7.8
16:22:24	144.7	296.7	8.5	276	2.37	1.02	0.92	3.60	4.22	10.3
16:22:44	145.3	297.6	8.2	276	2.37	1.02	0.92	3.66	4.22	9.3

Table E.7. Test condition for test 2A-5sp H_f = 100 cm; 5 spargers; τ = 3 min..

	Pb (cmH2O)	Pm (cmH2O)	Egp (%)	Qa (L/min)	Jg (cm/s)	Jfeed (cm/s)	Jtail (cm/s)	ko (mS/cm)	ks (mS/cm)	Egk (%)
16:15:03	134.8	274.6	15.6	276	2.34	1.73	1.67	3.26	4.30	17.5
16:15:27	134.3	274.9	15.2	276	2.34	1.73	1.73	3.32	4.30	16.5
16:15:43	134.6	274.6	15.4	276	2.34	1.79	1.73	3.36	4.30	15.7
16:15:59	134.6	274.8	15.4	276	2.34	1.79	1.73	3.28	4.31	17.4
16:16:23	134.1	274.3	15.7	276	2.34	1.69	1.69	3.37	4.30	15.5
16:16:47	133.0	274.6	14.7	276	2.34	1.76	1.69	3.31	4.29	16.4
16:17:03	133.4	274.4	15.0	276	2.34	1.76	1.69	3.28	4.30	17.1
16:17:27	133.8	273.5	15.7	276	2.34	1.76	1.69	3.37	4.30	15.5
16:17:43	134.1	274.1	15.4	276	2.34	1.74	1.75	3.38	4.30	15.4
16:18:07	133.2	273.8	15.0	276	2.34	1.74	1.75	3.38	4.29	15.2
16:18:23	134.0	274.4	15.4	276	2.34	1.74	1.75	3.30	4.29	16.7
16:18:47	132.9	273.0	15.5	276	2.34	1.74	1.75	3.37	4.28	15.3
16:19:03	133.0	273.8	14.9	276	2.34	1.74	1.75	3.43	4.29	14.4
16:19:27	133.4	273.5	15.5	277	2.34	1.74	1.68	3.26	4.29	17.5
16:19:43	134.3	273.5	15.9	277	2.34	1.74	1.71	3.34	4.29	15.8
16:20:07	133.3	274.0	15.1	276	2.34	1.74	1.71	3.39	4.29	15.0
16:20:23	134.0	274.4	15.3	276	2.34	1.80	1.71	3.34	4.29	16.0
16:20:47	133.2	273.3	14.8	276	2.34	1.74	1.71	3.30	4.29	16.7
16:21:03	133.7	274.0	15.7	276	2.34	1.74	1.71	3.38	4.28	15.0
16:21:27	133.8	273.8	15.8	276	2.34	1.74	1.71	3.32	4.28	16.2
16:21:43	133.7	273.5	15.3	276	2.34	1.74	1.71	3.31	4.28	16.4
16:22:07	133.3	274.6	14.7	276	2.34	1.74	1.71	3.24	4.28	17.7
16:22:23	134.0	274.1	15.6	276	2.34	1.74	1.71	3.48	4.28	13.3
16:22:47	133.3	273.2	15.6	276	2.34	1.74	1.71	3.31	4.28	16.4
16:23:03	133.4	274.0	15.3	276	2.34	1.74	1.71	3.32	4.27	16.1
16:23:27	134.6	274.3	15.5	276	2.34	1.74	1.71	3.41	4.26	14.2
16:23:43	133.4	274.3	15.3	276	2.34	1.74	1.71	3.41	4.27	14.5
16:24:07	134.6	275.6	14.8	276	2.34	1.74	1.71	3.35	4.26	15.2
16:24:23	132.5	274.9	14.4	276	2.34	1.74	1.71	3.26	4.26	17.1
16:24:47	133.8	274.6	15.5	276	2.34	1.74	1.71	3.46	4.26	13.4
16:25:03	134.2	274.4	15.4	275	2.34	1.74	1.65	3.26	4.27	17.1
16:25:27	133.3	274.4	14.8	275	2.34	1.74	1.69	3.37	4.26	14.9
16:25:43	133.1	274.3	15.2	275	2.34	1.74	1.69	3.24	4.26	17.3
16:26:07	134.1	275.6	14.3	276	2.34	1.74	1.69	3.26	4.27	17.1
16:26:23	133.7	274.8	14.2	276	2.34	1.74	1.69	3.33	4.26	15.8
16:26:47	134.1	276.2	14.5	276	2.34	1.74	1.79	3.39	4.25	14.5
16:27:03	134.8	275.4	15.2	276	2.34	1.74	1.73	3.35	4.24	15.0
16:27:27	134.0	274.1	15.4	276	2.34	1.74	1.73	3.30	4.26	16.2
16:27:43	134.2	274.6	15.7	276	2.34	1.74	1.73	3.35	4.25	15.1
16:28:07	134.2	275.2	15.0	276	2.34	1.74	1.73	3.36	4.25	15.1
16:28:23	134.2	275.9	14.4	276	2.34	1.74	1.70	3.40	4.25	14.4
16:28:47	133.8	275.6	14.7	276	2.34	1.77	1.70	3.41	4.26	14.3
16:29:03	135.8	276.5	14.9	276	2.34	1.77	1.70	3.46	4.26	13.3
16:29:27	133.8	275.9	14.5	276	2.34	1.77	1.70	3.34	4.25	15.3
16:29:43	135.1	275.4	15.2	276	2.34	1.77	1.70	3.39	4.24	14.4

Table E.8. Test condition for test 2A-4sp H_f = 100 cm; 4 spargers; τ = 3 min..

	Pb (cmH2O)	Pm (cmH2O)	Egp (%)	Qa (L/min)	Jg (cm/s)	Jfeed (cm/s)	Jtail (cm/s)	ko (mS/cm)	ks (mS/cm)	Egk (%)
16:48:07	137.9	280.6	13.5	276	2.39	1.77	1.73	3.39	4.28	14.9
16:48:23	137.4	279.0	14.4	276	2.39	1.75	1.73	3.30	4.28	16.5
16:48:47	136.8	280.2	13.6	276	2.39	1.75	1.73	3.22	4.29	18.1
16:49:03	137.6	280.5	13.9	276	2.39	1.75	1.73	3.43	4.28	14.2
16:49:27	137.7	280.0	14.3	276	2.39	1.75	1.73	3.39	4.27	14.8
16:49:43	136.5	280.2	13.3	276	2.39	1.75	1.73	3.41	4.27	14.5
16:50:07	135.6	281.3	12.2	276	2.39	1.75	1.73	3.46	4.27	13.6
16:50:31	138.9	281.9	13.7	276	2.39	1.79	1.73	3.47	4.28	13.4
16:50:47	136.9	280.2	14.0	276	2.39	1.74	1.73	3.43	4.27	14.0
16:51:03	138.1	279.7	14.9	276	2.39	1.74	1.73	3.26	4.27	17.1
16:51:27	138.6	280.6	14.4	276	2.39	1.74	1.71	3.28	4.27	16.8
16:51:43	138.4	281.6	13.7	276	2.39	1.74	1.71	3.35	4.27	15.4
16:52:07	135.9	281.3	12.8	276	2.39	1.74	1.71	3.20	4.27	18.3
16:52:23	138.7	282.1	12.6	276	2.39	1.74	1.71	3.25	4.26	17.1
16:52:47	137.0	280.2	13.6	276	2.39	1.74	1.71	3.38	4.27	14.9
16:53:03	135.6	279.8	14.2	276	2.39	1.74	1.71	3.44	4.27	13.7
16:53:27	137.4	281.4	13.6	276	2.39	1.75	1.71	3.47	4.26	13.2
16:53:43	138.0	279.4	15.0	276	2.39	1.75	1.71	3.46	4.25	13.3
16:54:07	137.7	281.4	13.3	276	2.39	1.75	1.71	3.32	4.26	15.9
16:54:23	137.6	281.0	13.6	276	2.39	1.75	1.71	3.39	4.26	14.5
16:54:47	137.7	279.8	14.9	276	2.39	1.75	1.71	3.40	4.26	14.4
16:55:03	138.1	280.3	14.4	276	2.39	1.75	1.71	3.40	4.27	14.5
16:55:27	136.8	281.6	12.8	276	2.39	1.74	1.71	3.41	4.25	14.1
16:55:43	138.0	281.6	13.8	276	2.39	1.74	1.71	3.32	4.25	15.8
16:56:07	137.1	280.0	14.1	276	2.39	1.74	1.71	3.33	4.25	15.6
16:56:23	137.5	280.0	14.3	276	2.39	1.74	1.71	3.51	4.26	12.5
16:56:47	137.6	280.6	13.8	276	2.39	1.74	1.71	3.39	4.25	14.4
16:57:03	137.5	280.2	14.2	276	2.39	1.75	1.71	3.43	4.26	13.8
16:57:27	137.0	281.0	13.2	276	2.39	1.75	1.71	3.32	4.26	15.8
16:57:43	137.5	282.4	12.7	276	2.39	1.75	1.71	3.18	4.24	18.3
16:58:07	138.2	281.3	13.6	276	2.39	1.75	1.71	3.42	4.24	13.8
16:58:23	137.1	281.6	13.0	276	2.39	1.75	1.71	3.40	4.25	14.3
16:58:47	137.4	281.4	13.9	276	2.39	1.75	1.71	3.42	4.26	14.0
16:59:03	137.5	281.6	13.4	276	2.39	1.75	1.71	3.33	4.25	15.6
16:59:27	137.6	281.7	12.6	277	2.39	1.75	1.71	3.34	4.25	15.3
16:59:43	136.5	280.0	13.6	277	2.39	1.75	1.71	3.50	4.25	12.4
17:00:07	138.8	281.9	13.8	277	2.39	1.81	1.71	3.49	4.25	12.7
17:00:23	138.1	283.5	11.9	277	2.39	1.76	1.71	3.45	4.24	13.2
17:00:47	138.7	282.2	13.3	277	2.39	1.76	1.71	3.22	4.25	17.5
17:01:03	139.1	280.8	14.7	276	2.39	1.58	1.71	3.33	4.26	15.7
17:01:27	137.8	280.5	13.7	276	2.39	1.76	1.71	3.40	4.25	14.4
17:01:43	136.7	282.1	12.7	276	2.39	1.76	1.71	3.43	4.25	13.8
17:02:07	138.4	281.7	13.0	276	2.39	1.76	1.71	3.37	4.25	14.9
17:02:23	138.8	280.6	14.4	276	2.39	1.76	1.71	3.34	4.25	15.5
17:02:47	137.6	282.4	13.2	276	2.39	1.76	1.71	3.41	4.25	14.1

Table E.9. Test condition for test 2A-3sp H_f = 100 cm: 3 spargers: τ = 3 min..

	Pb (cmH2O)	Pm (cmH2O)	Egp (%)	Qa (L/min)	Jg (cm/s)	Jfeed (cm/s)	Jtail (cm/s)	ko (mS/cm)	ks (mS/cm)	Egk (%)
17:22:03	141.3	288.9	11.1	276	2.37	1.73	1.73	3.47	4.23	12.9
17:22:27	140.8	288.7	11.1	277	2.37	1.78	1.73	3.56	4.24	11.3
17:22:43	141.2	289.0	10.9	276	2.37	1.78	1.73	3.60	4.23	10.4
17:23:07	141.5	288.6	11.5	277	2.37	1.78	1.73	3.47	4.23	12.9
17:23:23	141.6	288.9	11.3	276	2.37	1.73	1.73	3.41	4.23	13.8
17:23:47	141.1	289.7	10.5	277	2.37	1.78	1.73	3.63	4.23	10.1
17:24:03	140.9	289.0	11.1	277	2.37	1.78	1.73	3.40	4.24	14.1
17:24:27	141.9	290.0	10.8	276	2.37	1.73	1.73	3.55	4.23	11.4
17:24:43	141.6	289.5	10.7	276	2.37	1.73	1.73	3.51	4.24	12.1
17:25:07	141.4	289.8	10.7	276	2.37	1.73	1.71	3.47	4.24	13.0
17:25:23	142.2	288.3	12.0	276	2.37	1.73	1.71	3.38	4.24	14.5
17:25:47	142.2	289.8	11.0	276	2.37	1.76	1.71	3.40	4.24	14.1
17:26:03	141.1	289.4	10.9	276	2.37	1.76	1.71	3.48	4.24	12.7
17:26:27	141.2	289.0	11.2	276	2.37	1.76	1.71	3.53	4.25	11.9
17:26:43	141.0	289.5	10.9	276	2.37	1.76	1.71	3.44	4.24	13.4
17:27:07	142.7	290.3	11.1	276	2.37	1.76	1.71	3.61	4.24	10.5
17:27:23	142.5	290.0	10.9	276	2.37	1.76	1.71	3.55	4.25	11.6
17:27:47	141.1	289.2	10.7	276	2.37	1.76	1.71	3.27	4.24	16.5
17:28:03	141.2	289.5	11.0	276	2.37	1.76	1.71	3.55	4.24	11.4
17:28:27	141.4	289.8	10.8	276	2.37	1.76	1.71	3.61	4.24	10.5
17:28:43	142.0	290.5	10.3	276	2.37	1.76	1.77	3.59	4.23	10.6
17:29:07	141.2	291.1	10.2	276	2.37	1.76	1.77	3.34	4.23	15.1
17:29:23	140.5	289.8	10.3	276	2.37	1.76	1.77	3.58	4.24	11.0
17:29:47	141.4	290.6	10.2	277	2.37	1.76	1.77	3.58	4.24	10.9
17:30:03	141.9	289.7	10.8	276	2.37	1.76	1.70	3.64	4.23	9.7
17:30:27	141.6	290.3	10.4	276	2.37	1.76	1.76	3.72	4.24	8.5
17:30:43	141.3	289.7	10.3	276	2.37	1.76	1.76	3.63	4.23	9.9
17:31:07	141.2	290.8	10.2	276	2.37	1.76	1.76	3.62	4.23	10.2
17:31:23	141.8	289.5	10.8	276	2.37	1.76	1.76	3.65	4.23	9.6
17:31:47	140.5	289.5	10.7	276	2.37	1.76	1.76	3.58	4.23	10.8
17:32:03	141.8	291.0	9.9	276	2.37	1.76	1.76	3.64	4.24	9.8
17:32:27	141.0	289.5	10.8	276	2.37	1.76	1.76	3.51	4.23	11.9
17:32:43	141.5	290.2	10.2	275	2.37	1.76	1.76	3.68	4.23	9.0
17:33:07	141.3	289.8	10.4	275	2.37	1.76	1.76	3.60	4.22	10.3
17:33:23	141.3	288.6	11.3	275	2.37	1.76	1.76	3.65	4.22	9.5
17:33:47	141.9	289.4	11.1	276	2.37	1.76	1.76	3.58	4.23	10.8
17:34:03	142.2	290.6	10.6	275	2.37	1.76	1.76	3.57	4.23	11.0
17:34:27	140.7	289.7	10.4	276	2.37	1.76	1.76	3.60	4.23	10.5
17:34:43	141.8	290.8	10.0	276	2.37	1.78	1.69	3.43	4.22	13.4
17:35:07	140.9	289.5	10.5	276	2.37	1.76	1.69	3.43	4.23	13.5
17:35:23	141.1	291.0	9.9	276	2.37	1.75	1.69	3.69	4.22	8.9
17:35:47	141.8	289.8	10.7	276	2.37	1.75	1.76	3.67	4.23	9.3
17:36:03	141.8	290.0	11.0	276	2.37	1.75	1.69	3.63	4.22	9.8
17:36:27	141.8	290.2	10.4	276	2.37	1.75	1.69	3.68	4.23	8.9
17:36:43	141.3	289.2	10.9	276	2.37	1.75	1.69	3.59	4.22	10.5

Table E.10. Bubble size, bubble surface area flux and collection zone rate constant estimated for BOWATER tests. Bubble sizes over 0.2 cm are invalid.

Test #	Jg (323 K, P) (cm/s)	Jr (cm/s)	Eg (%)	db (323 K, P) (cm)	db (273 K, 1 atm) (cm)	kc (1/min)	Sb (323 K, P) (1/s)	Sb (273 K, 1atm) (1/s)
1A-1	2.21	1.73	17.7	0.152	0.155	0.519	87	91
1A-2	1.77	1.81	14.3	0.147	0.150	0.478	72	76
1A-3	1.36	1.86	10.7	0.146	0.150	0.384	56	59
1A-4	0.86	1.98	7.0	0.139	0.143	0.135	37	39
1A-5	0.66	2.00	4.3	0.170	0.175	-	23	25
1B-1	2.79	0.92	17.9	0.176	0.177	0.326	95	96
1B-2	2.34	0.93	15.6	0.166	0.167	0.319	85	85
1B-3	1.86	0.93	12.8	0.158	0.159	0.305	71	71
1B-4	1.37	0.99	8.6	0.167	0.168	0.231	49	50
1B-5	0.90	1.04	4.8	0.196	0.198	0.021	28	28
1C-1	2.70	1.06	17.8	0.173	0.176	0.326	94	97
1C-2	2.29	1.03	15.4	0.166	0.168	0.286	83	85
1C-3	1.81	1.05	12.9	0.153	0.155	0.274	71	73
1C-4	1.32	1.10	9.8	0.118	0.120	0.253	67	70
1C-5	0.89	1.15	5.6	0.143	0.146	0.062	38	39
2A-5sp	2.31	1.71	15.7	0.174	0.175	0.384	80	80
2A-4sp	2.35	1.71	12.0	*0.223*	*0.224*	0.300	63	64
2A-3sp	2.32	1.73	10.4	*0.252*	*0.254*	0.088	55	56
2B-5sp	2.34	0.95	14.4	0.179	0.180	0.322	79	79
2B-4sp	2.33	0.95	11.7	*0.217*	*0.218*	0.240	64	65
2B-3sp	2.31	0.92	8.3	*0.307*	*0.310*	0.053	45	46
3A-5sp	1.76	0.95	12.8	0.150	0.153	0.297	70	73
3A-4sp	1.75	0.94	10.3	0.181	0.185	0.241	58	60
3A-4sp-b	2.93	0.94	13.6	*0.239*	*0.244*	0.222	74	76
3B-5sp	1.32	0.94	9.0	0.154	0.157	0.256	51	54
3B-4sp	1.33	0.94	7.7	0.179	0.183	0.199	44	46
3B-4sp-b	1.68	0.94	9.9	0.179	0.183	0.222	56	59
4A-1	2.32	1.13	9.0	*0.286*	*0.293*	-	49	51
4A-2	1.94	1.13	8.4	*0.252*	*0.258*	-	46	49
4A-3	1.40	1.16	6.1	*0.248*	*0.254*	-	34	36
4A-4	1.08	1.07	4.3	*0.270*	*0.277*	-	24	25