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A STUDY OF EFFECTS OF FLOTATION CONDITIONS ON FLOTATION EFFICIENCY AND FIBER LOSS

by

Wiwat Walaipachara

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A STUDY OF EFFECTS OF FLOTATION CONDITIONS ON FLOTATION EFFICIENCY AND FIBER LOSS

Wiwat Walaipachara, M.S.

Western Michigan University, 1993

Three variables: (1) consistency , (2) agitation, and (3) bubble size were studied for their effects on flotation efficiency and fiber loss. Flotation was done by using a Hallimond apparatus. The floated and non-floated portions were quantified by image analysis based on number of ink particles and total area of ink. The percent fiber loss was calculated from solids' weights of both portions. The floated part was analyzed by a KAJAANI instrument for fiber length average and distribution.

The results showed that flotation efficiency increased with agitation but decreased with increasing consistency. Fiber loss increased with consistency but decreased with increasing agitation. Bubble size showed less effect than consistency and agitation. However, increasing bubble size reduced flotation efficiency and fiber loss. Average fiber length in the floated part was longer than the original pulp, indicating that fractionation occurred during the flotation. Increasing consistency reduced average fiber length in the floated part.

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Wiwat Walaipachara

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CHAPTER I

INTRODUCTION

Flotation deinking is a new segment of the paper industry. The first flotation deinking cells and plant technology were designed on the basis of the equipment used in the mineral flotation industry. Flotation is a macro-process composed of a very large number of individual microprocesses taking place simultaneously and successively in time and space. In the flotation cells the ink is actually removed from the system. The removal of ink in flotation deinking consists of these processes: (a) the detachment of ink from fibers, (b) the dispersion of ink particles, (c) the flotation of ink, and (d) the removal of the froth.

Many researches have been published on the variables which influence the efficiency of ink removal from flotation cells. Most of the studies emphasize the mechanism of attachment of ink particles to air bubbles and attempt to maximize the attachment by chemical and hydrodynamic approaches. Unfortunately, all constituents in flotation cells are subjected to the same environment. Thus, any approach to maximize ink removal inevitably affects the fiber loss from the cells. This project studies the parameters which control the amount and size of fibers entrained with air bubbles in order to optimize total efficiency of the flotation process (high ink removal efficiency and low fiber loss).

CHAPTER II

LITERATURE REVIEW

Deinking technology is one of the essentials for effective utilization of waste paper as a fiber source. The processes during flotation consist of the detachment of ink particles from the fibers, the agglomeration of detached ink particles by surfactants, and the attachment between ink particles and air bubbles. The flotation process can be classified into two domains*(1)*: The domain of hydrodynamics and the domain of chemical regime (Table 1).

Table 1

Two Domains of Flotation Processes *(1)*

Hydrodynamics	Chemical Regime
* Fluid Mechanics	* Hydrophobization of Ink
* Turbulence Generation	* Agglomeration of Ink
* Suspension-Air Interaction	* Formation of Froth
* Air Bubbles Buoyancy	* Stabilization of Froth
* Froth Removal	

For successful flotation to take place in any system, several criteria must be fulfilled*(2,3,4)*. First, the particles must collide with the air bubbles. This step is governed by hydrodynamic forces in such a way that small particles tend to follow the stream lines around the bubbles rather than actually colliding with them. Next, the collision must lead to rupture of the thin liquid film between the particle surfaces and the air in the bubbles. For this to happen, the particle and bubble must not repel each other due to colloidal forces. Also, the thin liquid film must not have a too high elasticity caused by adsorption of surfactants, and the particle surface must be sufficiently hydrophobic to attach to the bubble. When the bubble with attached particle rises through the liquid, both the gravity force and the viscose drag tend to pull the aggregate apart. For large and heavy particles, this will be the critical factor and success of the flotation will depend on the forces keeping the aggregate together.

When the ink particles have floated to the surface of the pulp, they should form a foam layer of suitable stability that can be transported away and then collapsed at will*(5)*.

Hydrodynamics

In all types of flotation deinking cells, more or less the same interaction process should occur between floatable particles and air bubbles in a highly turbulent field. The microprocesses in flotation deinking cells are the same as in classical mineral flotation cells. Important additional complicating features of deinking flotation are the presence of fibrous material of low density and printing ink particles of small size and low density. The three essential microprocesses of particle/bubble interaction are*(6)*: (1) particle collision in the hydrodynamic field of the bubble (probability of collision), (2) destabilization of the thin liquid film between particle and bubble (probability of adhesion), and (3) stabilization of aggregate against external stress forces (probability of aggregate stability).

Probability of Particle Collision

Not all particles which move in the bubble projection path (R_B) can collide with the bubble (Fig.1). Only those within a streaming tube of limiting collision radius (R_C) can collide. Therefore, the general collision probability is defined by the ratio of R_C and R_B *(6)*:

$$P_c = (R_C/R_B)^2 \quad (1)$$

For ink particles the inertial forces do not play any role because of their small size. Hence, the collision probability of such particles is much lower than of larger particles, i.e. fines, fibers. Small particles follow fluid streamlines without deviations and therefore they have

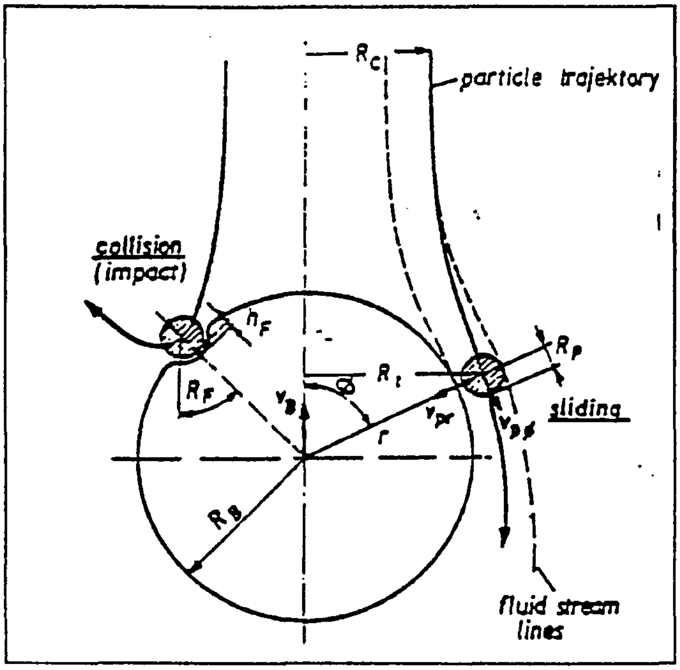


Figure 1. Schematic Representation of Particle Interaction With Gas Bubbles*(6)*.

little chance to reach a bubble surface.

Duchin and Rulev*(7)* gave the following relationships for collision probability P_c:

1. In the Stokes flow regime (Reynolds number of bubble << 1), where the small particle moves through a fluid of low viscosity, with completely rigid bubbles due to the adsorption of surfactants and without particle sedimentation

$$P_{cst} = 3R_P^2/2R_B^2 \qquad (2)$$

2. In the potential flow regime (Reynolds number of bubble >> 500), where the flow is irrotational and friction cannot develop, without adsorption of surfactants on the bubble surface

$$P_{cPot} = 3R_P/R_B \qquad (3)$$

where

R_P = radius of particle

R_B = radius of air bubble

The probability of collision is higher the larger the particle size and the smaller the air bubble size. In order to adhere as many particles as possible to air bubbles, it can be hypothesized that the effectiveness is increased with very small bubbles. According to investigations by Isler*(8)*, air bubbles smaller than 0.1 mm. in diameter tend to adhere to fibers, but on the other hand only bubbles larger than about 0.3 mm. diameter have sufficient buoyancy to pass through the elastic network formed by the fibers in the suspension. As the ink particle size decreases, the frequency of collision decreases because small particles follow the fluid streamlines and therefore the flotation efficiency decreases*(9,10)*.

Probability of Particle Adhesion

When a particle approaches a bubble within a small distance, two types of interaction may occur in the vicinity of the latter:*(11,12)*

1. impact (collision) processes of large and heavy particles in which the bubble surface is strongly deformed.

2. sliding of fines and light particles along the surface with a weak surface deformation.

Whether the particle can be attached or not depends critically on the duration of contact time in relation to the film drainage time until rupture. The most important value for calculating the probability of adhesion is the critical thickness of film rupture. It is well known that the physicochemical properties of thin liquid films between particles depend on interparticle forces and on the degree of hydrophobicity of particles*(13,14)*. Model experiments which have been carried out on wetting films between small captive bubbles and smooth polished plates have clearly shown that hydrophilic solids, such as quartz, retain an elastic water layer which protects the particles from the bubbles, whereas hydrophobic solids show a sudden collapse of the aqueous film at a certain critical thickness.

Probability of Aggregate Stability

If the attachment between the particle and bubble is stronger than the sum of all stress forces which act on the aggregate, i.e., force of gravity, static buoyancy force, and additional detaching force (represented as the product of the particle mass and the acceleration in the external field of flow), then this aggregate remains stable on its long way from the place where it is formed to the froth layer. The probability of aggregate stability can be calculated from*(6)*:

$$P_{stab} = 1 - \exp(-(F_{cam}-F_{det})/F_{det}) \qquad (4)$$

where

F_{cam} = maximum capillary force

$= -2 \pi R_p \sigma \sin \omega \sin(\omega + \theta)$

and $\omega = 180° - \theta/2$

θ = contact angle

σ = surface tension

F_{det} = detachment force

It can be seen that with a detachment force much smaller than capillary force, the probability of aggregate stability is near one. Only when F_{det} is in the order of F_{cam}, the probability of stability decreases suddenly.

Chemical Regime

The equipment and chemicals used in a given deinking process are determined by the types of ink in the waste paper. For flotation to be effective, the size of ink particles must be maintained within an optimum range, 30-60 µm.*(16)*. Smaller particles are too small to ensure collisions with air bubbles. Larger particles are often too heavy to be levitated by the air bubbles.

The chemical additives commonly used for flotation deinking are presented in Table 2*(16)*.

Table 2

Chemical Additives for Flotation Deinking*(16)*

Chemical	Dosage(%)	Function
Sodium hydroxide	1-2	increases pH causes fiber swelling, saponifies, dissolves resins
Sodium silicate	2-4	buffers pH, stabilizes peroxide, sequestrant of metal ions
Surfactant	0.5-0.75	promote wetting, added with fatty acids to facilitate ink removal
Fatty acid	0.7-1	collector for ink particles
Calcium ions	0.2-0.6	precipitate fatty acids to form soaps necessary for ink collection
Chelating agents	0.1-0.3	bind metal ions which can cause peroxide degradation and brightness reversion
Hydrogen peroxide	1-3	reverses alkali-darkening of groundwood containing furnishes, increases brightness by bleaching

Sodium Hydroxide

Sodium hydroxide (NaOH) also referred to as caustic soda, is used to adjust the pH to the alkaline region and to saponify or hydrolyze (or do both) ink resins*(17)*. The alkaline environment swells fibers and causes loosening of ink-fiber bonds. At the pH conventionally used for pulping 9.5-11, the fibers take up water and become more flexible. The addition of caustic soda to groundwood-containing furnishes will cause the pulp to yellow and darken. This is a phenomenon often referred to as "alkali darkening". Andrew*(18)* showed that the color rapidly increases as the pH rises above 5.5.

Sodium Silicate

Sodium silicate (Na_3SiO_3), or water glass, is commonly used as a 41.6 °Baume solution of sodium metasilicate which contains approximately equal amounts of SiO_2 and Na_2O*(17)*. The silicate component is actually a blend of many complex polymeric silicate anions. Silicate is believed to function by forming a colloidal structure with the heavy metal ions, but the specific action has not been determined*(19-22)*. Silicate is often referred to as a peroxide stabilizer. Ali*(21)* and Ferguson*(23)* have reported that silicate aids in deinking through an ink dispersant action to prevent the ink from redepositing on the fiber surface. The sodium silicate solution also is a source of alkalinity, derived from free hydroxyl groups, as well as a pH buffering agent which operates around pH 11.3*(24)*. The fact that silicate is a source of alkalinity and will affect the pH must be kept in mind when adjusting the pulper chemistry. Increasing the silicate will increase the pH, and this may call for a reduction in sodium hydroxide.

Surfactants

Surfactants comprise many chemical types and are selected depending on their properties and performance. Surfactants have two principle components, hydrophilic and hydrophobic. When the surfactant is introduced into the pulper, or prior to flotation, the hydrophilic end remains in water while the hydrophobic portion bonds to ink particles. Surfactants are ionic (usually anionic) or non-ionic. The molecules may be linear or branched, saturated or unsaturated, and usually contain 12-20 carbon atoms.

Three factors influence the amount of adsorption of the surfactant at the liquid-solid interface*(25)*: (1) the type of group(charge, polar or non-polar), (2) the structure(ionic or non-ionic, chain length, chain structure), and (3) the nature of liquid.

One method of characterizing surfactants is by their HLB value, the ratio of weight percentages of hydrophilic to hydrophobic groups in the structure. Turai and Williams*(26)* have done some of the early work on the role that HLB has on deinking efficiency. In their work, they found a relationship between the brightness from deinking news and the HLB value as shown in Table 3*(26)*.

Table 3

Effect of HLB Value on Deinking Newsprint*(26)*

HLB value	Use	Newsprint Deinking Brightness
4-6	water-in-oil emulsifier	47
7-9	wetting agent	48
8-18	oil-in-water emulsifier	49
13-15	detergent	50
15-18	solubilizing agent	51

In deinking, the usual types of surfactants are ethoxylated alkyl phenols, ethoxylated fatty acids, or ethoxylated linear alcohols with values in the range of 8 to 12. Berger*(27)* studied the effect of HLB value on surfactants in flotation deinking and concluded that the HLB value range best suited for flotation deinking was 12 - 14.5.

Borchardt*(28)* used multiple correlation analysis to study and predict the properties of surfactants, alcohol ethoxylates, which may be related to deinking effectiveness of surfactant use. He found that a single surfactant property cannot be considered alone when developing improved deinking surfactants. For highly linear alcohol ethoxylates, increasing the hydrophobe carbon number will reduce the cmc and decrease foaming. Decreasing the ethoxy group chain length will slightly decrease the cmc, decrease interfacial tension against mineral oil and decrease foaming. He proposed that all of these factors should improve surfactant performance in most deinking processes using primarily mineral-oil-based inks.

Collecting Agents

Collecting agents are used to increase the attachment of the ink particles to air bubbles. Collectors can be made from naturally occurring materials, such as fatty acid soaps; synthesis such as Eo/Po (ethylene oxide/propylene oxide copolymers); and blends such as ethoxylated fatty acids*(29)*. Fatty acid soaps are more commonly used in Europe than in North America, although several Canadian and U.S. mills are using soaps successfully. For ink removal to occur, the ink particles must come into contact with the collector chemicals which, in turn, must come into contact with the air bubbles so that the ink agglomerates can be removed. When a fatty acid is used, it must be converted into its sodium salt(soap) before it can be of any use in the flotation process*(30)*. In order for these collectors to work, a minimum water hardness is necessary. To achieve this, mills often add calcium salts. Raitio*(30)* proposed that collectors are precipitated with calcium ion on the surface of the much larger ink particles, producing an encapsulated hydrophobic particle, which is thus pushed away as far as possible from contact with water. Additionally, the encapsulation of ink particles destabilizes the dispersion produced in the pulper and the ink particles tend to come together in agglomerates. These macro-ink particles will have a much enhanced rate of collision with the air bubbles. This leads to adsorption of hydrophobic pigment particles to the air bubbles present in the flotation cells.

Chelants

DTPA (diethelenetriaminepentaacetic acid) is the most commonly used chelant, although, EDTA (ethelenediaminetetraacetic acid) is also used. The role of chelants is to form soluble complexes with heavy metal ions*(22,24)*. The complexes prevent these ions from decomposing hydrogen peroxide or causing brightness reversion. The amount of chelant that is necessary is directly dependent on the amount of heavy metal ions in the pulper. The metal ions can be sourced from the waste paper or from the mill water.

DTPA will chelate metals in the following order of priority*(24)*:

$Ni^{++}>Cu^{++}>Co^{++}>Fe^{++}>Mn^{++}>Pb^{++}>Zn^{++}>Fe^{+++}>Ca^{++}>Mg^{++}>Al^{+++}$

Some deinking mills have found that their metal concentrations are low enough to preclude the use of chelant.

Hydrogen Peroxide

Hydrogen peroxide (H_2O_2) is used to decolorize the chromophores generated by the alkaline pH in a groundwood containing furnish*(17)*. The ink and contraries load present in the pulper reduce the bleaching efficiency of the peroxide. The peroxide reaction with the caustic soda is shown as following .

$$H_2O_2 + NaOH <=========> HOO^- + Na^+ + H_2O$$

where

pH = 10.0-11.5

temperature = 40-80 °C

The perhydroxyl anion (HOO^-) is the active bleaching agent*(31)*. To get the best use of the peroxide, it is important to maximize the amount the perhydroxyl anion. The options available are: raising the pH by increasing the caustic level, raising the temperature, reducing the competing side reactions, and increasing the amount of peroxide. The competing reactions are those that can decompose peroxide such as those caused by heavy metal ions. The peroxide decomposition products and conditions have been identified as contributing to the loss of brightness in wood-containing virgin pulp*(18,32)*. It is reasonable to expect a similar effect with recycled pulp. The decomposition of peroxide can be reduced by addition of stabilizing agents such as chelants and sodium silicate.

Models of Flotation Deinking Process

The mechanism of flotation deinking is not clearly understood. Many models have been proposed to explain the process. Larsson, Stenius and Odberg*(33)* proposed that when the calcium soap is precipitated, it forms a layer of small particles around the ink particles. This gives the ink particle the surface properties of the calcium soap. In the presence of excess calcium, the particles become hydrophobic and acquire a low zeta potential. They can then more easily attach to air bubbles.

According to Ortner*(34)*, soap molecules react with calcium or magnesium ions present in the water in order to act as a collectors and to connect air bubbles and ink particles. Bechstein*(35)* assumed that first fatty acids have to precipitate as hydrophobic calcium soap particles.

Air bubbles and ink particles are attached to these particles. Putz, Schaffrath and Gottsching*(1)* presented a flotation deinking model based on the adsorption of surfac-tants at the ink particle surface and at the air bubbles and water. In their model, the adsorption of the surfactant on hydrophobic ink particle surface is independent from its ionogenity. However, ions of the opposite charge are required if ionic surfactants are used to achieve the approach between air bubbles and ink particles with a rupture of the hydrate cover and an attachment between the flotation components. The charge of the surfactant has a significant influence on the adsorption of surfactant molecules at the particle surface of hydrophilic ink particles with the result of their hydrophobation. For the approach and the linkage between particles and air bubbles, the surfactant charge is of minor importance*(1)*.

Foam

Foam phenomena are surface-active phenomena. A foam consists of bubbles of gas dispersed in a liquid in a ratio such that the mixture's bulk density approaches that of the gas rather than a liquid*(36)*. Foams cannot be produced from pure liquids. Some type of surface activity must be induced to make liquids foam.

Surface activity is a change in surface energy and the surface tension of the liquid, caused either by changes in the liquid's physical and chemical conditions or by the addition of a surface-active agent (surfactant). A surface-energy change may decrease (usually) or increase the surface tension of the liquid. A decrease in surface tension favors foaming.

Foams are thermodynamically unstable since their collapse is accompanied by a decrease in total free-energy*(37)*. However, certain foams will persist for long periods while others break immediately after they are formed. Foams collapse as the result of drainage of liquid in the bubble walls until the portion of the film reaches a thickness of about 50-150 Å, where the random motion of molecules is sufficient to cause the sudden breakdown of the film. Several factors which influence the rate of drainage follow: *(38,39)*

1. High viscosity of the liquid in the bubble walls will reduce the rate of thinning. It will tend to dissipate shock, thus increasing the persistence of the film.

2. High viscosity of surface film will act as a viscous drag on neighboring molecules, reducing the rate of drainage.

3. Low permeability of surface-film will constitute a barrier to air diffusion thus tending to preserve the foam with correspondingly slow liquid drainage.

4. Electrostatic repulsion between similarly charged film surfaces reduces the rate of drainage.

Often, foams are more stable when mineralized by near-colloidal or colloidal-size particles. Such foams are undesirable in flotation because of their reduced drainage, which results in entrainment of hydrophilic solids*(39)*. Once the bubbles become mineralized (that is, acquire a fairly continuous coating of mineral particles), the stability of the resultant foam differs from that of a nonmineralized one. If the floated particles possess a residual charge, however slight, the foam is much more stable than one without mineral. The interlayer existing between the two gas phases in the mineralized froth is a composite one, solid-liquid-solid, with two symmetrical overlapping electrical double layers, introducing a higher stability repulsion parameter, P_E. The repulsion due to the electrical double layer keeps bubbles apart from each other, hence, reduces drainage of water from lamella. If the zeta potential of the floated particles is equal (practically) to zero, the mineralized foam is less stable and sheds its load of particles fairly easily as soon as the supply of air bubbles ceases. Such foams are preferred in practice.

Flotation Studies

To optimize a flotation process, proper physical operation conditions are necessary. Some of these parameters: water hardness, pH, consistency, bubble size and quantity of air, and zeta potential of the ink particle and bubble affect the performance of a flotation cell.

Water Hardness

Water hardness is typically expressed in terms of ppm of $CaCo_3$ or by degrees German Hardness (°DH). When traditional soaps are used in flotation deinking, a minimum water hardness is necessary. To maintain this hardness, mills often add calcium salts. If the hardness drops, so does the brightness of the deinked stock. Bechstein*(40)* reported maximum flotation was achieved when all the hardness agents were flocculated and there was a slight excess of free surface active soap. Larsson*(41)* found that in the absence of calcium the ink particles did not float. However, small additions of calcium chloride improved the flotation considerably. Higher additions did not have any significant effect. Turvey*(42)* reported that the deinked stock brightness at 4°DH was about the same as values recorded at 12°DH. He also showed that as water hardness increased from 4°DH to 12°DH, stock loss increased from 3.5% to 6.5%.

pH

Raimondo*(43)* reported that large bubbles were formed at a pH value of 5. Above a pH of 11, he observed a thick dense foam and a high fiber loss. Borchardt*(44)* studied effect of process variables in laboratory deinking. He reported that an increase in pulping pH from 9.0 to 12.0 in the presence of 1.0% hydrogen peroxide did not decrease handsheet brightness. He also reported that decreasing the flotation pH from 9.0 to 5.5 resulted in a three point brightness increase. Seenivasan*(55)* studied the flotation deinking of UV-curved ink and found that pH at 7.56 gave the maximum flotation efficiency. He reported that flotation efficiency increased as the pH increased.

Consistency

A consistency range of 5-6% in the primary stock preparation generally allows for effective operation of the pulping equipment but not for the flotation step. To achieve efficient flotation, the consistency should not be above 1.0%*(45)*. Wood*(45)* mentioned that if consistency is higher than 1.0%, too many fiber are entrained with the foam and more dirt is entrained with the accepted stock. Borchardt*(44)* found in his study that handsheet brightness did not change significantly with increased pulping consistency. The results in his work indicated that decreased consistency in the flotation step resulted in increased yield loss. He proposed that this trend may be due to the design of the flotation cell which he used and may not occur in flotation cells of different design.

A concept of fractionation prior to flotation was proposed by Eul, Meier, Arnold and Berger*(46)*. Fractionation was done by screening which separated the pulp into long fiber and fine fraction. The long fiber fraction which is similar to a well- washed pulp can be further increased in brightness by subsequent hydrogen peroxide bleaching. Flotation of the fine fraction at 1% consistency was very effective for rapid ink removal and required lower energy for air mixing due to the low viscosity.

Bubble Size and Quantity of Air

The flotation process consists of three stages: collision, attachment, and separation. Air addition into a flotation cell has to be controlled to achieve maximum collision and attachment between air bubbles and ink particles. Control of air addition refers to control of air quantity and bubble size. Raimando*(43)* carried out experiments and found that the quantity of air required for efficient flotation was very small. In conventional flotation cells, air is drawn into the unit by venturi devices. The quantity of air throughput influences the size of the bubbles produced. If the air throughput is increased the bubble diameter become large and increases the risk that the individual bubbles will join together to form even larger bubbles. Szatkowski*(47)* showed that for best flotation there was an optimum bubble size for each particle size. Bently*(9)* confirmed that small bubbles were most efficient at removing small ink particles and large bubbles were most efficient at removing large ink particles. Carroll and McCool*(48)* stated that most of the ink particles are very small, hence most of the air bubbles should be very small. Pressurize deinking modules use pressurized air to produce a large number of small bubbles. In addition, dissolved air comes out of solution in the cavitation area and preferentially seeds onto ink parti-cles. They claimed that the probability of ink particle-bubble attachment is increased by this design.

Zeta Potential

It is well know that colloidal particles carry a net charge. The sign and magnitude of the charge on both bubbles and particles would have important effects on the flotation rate. The net charge on a particle can be expressed as zeta potential. Larsson*(41)* found that newsprint ink particles had a high negative zeta potential. Collins and Jameson*(48)* floated spherical latex particles and varied the charge by addition of sodium sulphate. The results lead to an conclusion for a single species system that the flotation rate would be maximum when the charge or zeta potential of the particles and bubbles was zero. With a system containing mixed species, it would be undesirable to create conditions of zero charge for material to be floated, because conditions may then favor heterocoagulation of materials in the system. Fukui and Yuu*(49)* floated polystyrene latices by hydrogen bubbles in an electrolysis vessel. The results showed that the rate of flotation strongly depended on the charge on both particles and bubbles. The rate decreased suddenly as the product of zeta potential of particle and bubble is above a certain value, depending on the effective Hamaker constant.

The phenomena which take place in the froth layer probably have little effect on the yield of the "values", i.e. ink, because there is little evidence to suggest that there is a substantial return of values from the froth to the slurry by rupture and disengagement from the bubbles in the froth. However, the effects have a very large effect on the grade, i.e. on the mass fraction of values in the concentrate. Watson and Grainger-Allen*(50,51)* who constructed an apparatus in which the froth could be separated from the slurry after the desired flotation time, analyzed the froth and reported that mass fraction of the values in the solid recovered from the froth was from two to four times that in the feed.

Cutting and Devinish*(52)* constructed a cell in which the froth could be divided into four slices. The contents of each slice were removed by suction for analysis. The results, using hematite as the recoverable mineral, showed that there was a very strong effect of sample height above the level of the slurry in the cell. Near the base of the froth, the mass ratio of values to pulp was approximately 2.5, whereas at the top of the froth, it was 4.3. In the feed, the ratio was 0.11. Increasing the air flow rate increased the wetness of the froth, and there were also small changes in mass ratio of the hematite in each slice. The implication here is that if in a conventional flotation cell, the froth residence time could be controlled so that only the top layers of the froth was skimmed off, the mass ratio of values would be much improved. The improvement is clearly due to the drainage of water and pulp into the lower layer and back into the slurry.

Flint*(53)* suggested that the apparent flotation rate may be controlled by froth phenomena. The overall performance of the cell will suffer if the surface zone in the froth does not allow the froth sufficient drainage time, or if there are factors inherent in the nature of the particles themselves which prevent a froth from draining.

CHAPTER III

STATEMENT OF PROBLEM AND OBJECTIVES OF THIS STUDY

In flotation deinking cells, ink particles are removed from the pulp by attachment to air bubbles and floated to the surface, where the froth is skimmed. A number of parameters, e.g. pH, chemical addition, consistency, etc., have to be adjusted to achieve maximum ink removal. The rising air bubbles do not only attach to ink particles but also entrain fibers into the froth region which results in fiber loss. Since fibers, ink and air bubbles are introduced to a flotation cell at the same time, any endeavor to change the conditions in the flotation process in order to achieve maximum ink removal inevitably affects fiber in the system and in turn affects the yield of the process. The total performance of a flotation process concerns not only its efficiency of removing ink but also the fiber yield of the process. This experiment is designed to study the effect of flotation variables on the amount of fibers which are entrained with air bubbles. The objectives of this experimental study are: (a) to identify parameters that control the amount of fiber entrained with air bubbles, (b) to demonstrate quantitatively how these parameters affect the amount of fiber entrained with air bubbles, and (c) to identify the optimum levels of these parameters which result in high ink removal efficiency and low entrained fiber.

Since flotation deinking is becoming increasingly important, it should be better understood. The results from this project will explain how key parameters affect the amount of fiber loss and this knowledge might be applied to the mill deinking process to optimize total efficiency of a flotation cell.

CHAPTER IV

EXPERIMENTAL DESIGN

This experiment was designed to study the influence of control variables in the flotation process on ink removal efficiency and the quantity of entrained fiber. Most research studies have emphasized the effects of flotation conditions on ink removal efficiency, but very few mentioned fiber loss. In order to select the variables and define the proper range of each variable, a preliminary exploration of variables expected to affect both the deinking efficiency and fiber loss was done. The results from the exploratory experiments were used to design the parameters for subsequent experiments for optimization of the variables.

Phase I: Preliminary Experiments

The objective of this phase was to select a surfactant and to determine the variables and their range.

To select a surfactant for this study, three commercial surfactants; Pluronic L-10, Nonatell MT 1120 and Nonatell MT 1087, were evaluated. The MT 1087 was selected following the procedures described in CHAPTER V.

Table 4 shows the variables and levels of each variable which were used in this phase. The experiments were done by varying one variable while the others were kept constant at medium level. Three variables which had the largest effects on flotation efficiency and fiber loss were selected for further study in phase II.

Table 4

The Variables and Levels of Each Variable for Experiments in Phase I

	Levels		
Variables	Low	Medium	High
pH	8	9	10
Surfactant Concentration (%)	0.6	0.7	0.8
Consistency (%)	0.2	0.3	0.5
Air Bubble Size (μm.)	4.75	12.5	50.0
Air Flow Rate (ml/min.)	50	70	147
Agitation Rate, rpm.	550	1010	1950
Floating Time (min.)	5	10	15

Phase II: Optimization Experiments

The variables selected for phase II were consistency, agitation rate and bubble size. The selected variables were varied by three levels while the unselected variables were kept constant at suitable values. The conditions for phase

II flotation are shown in Table 5.

Table 5

Flotation Conditions for Phase II Experiments

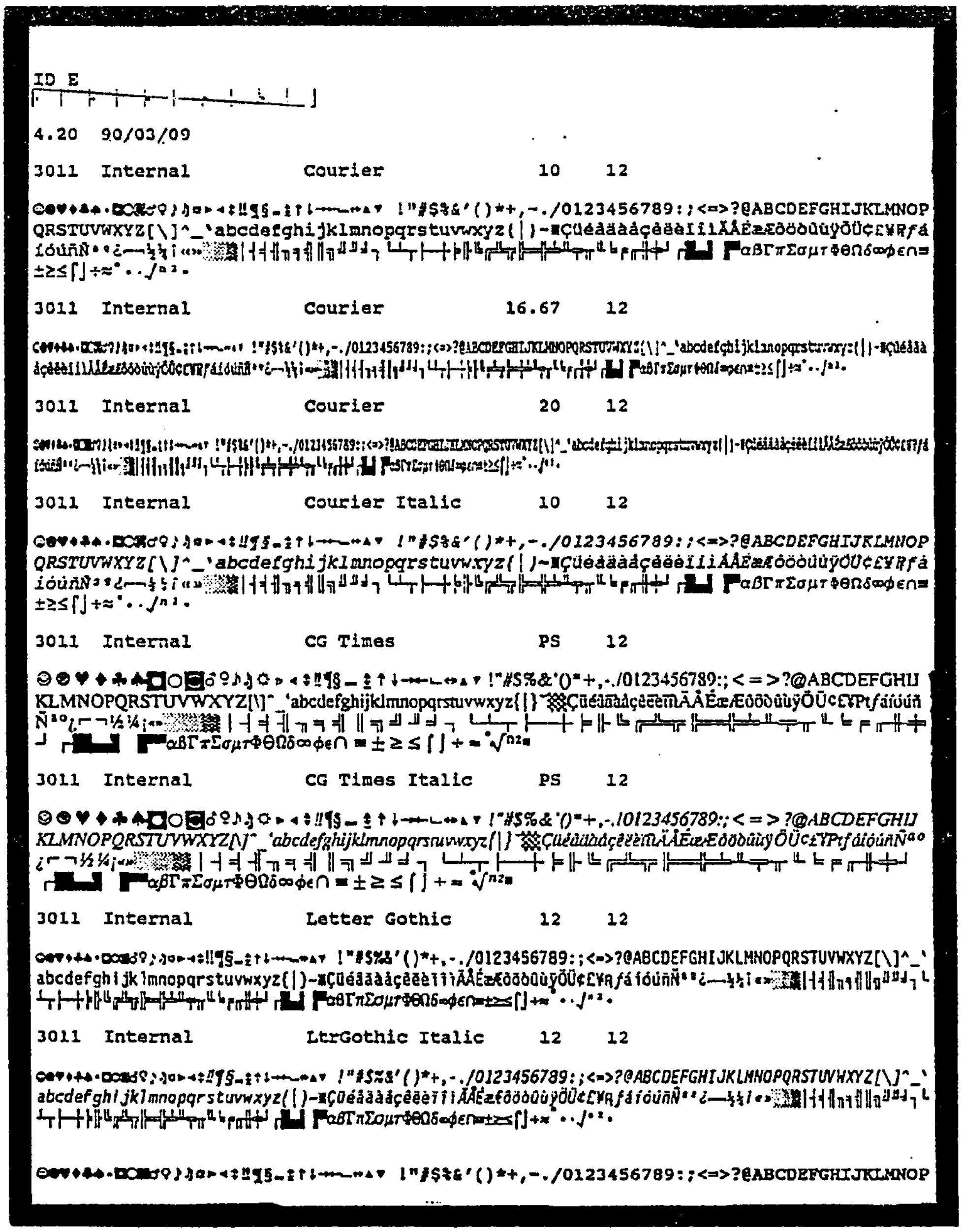
		Levels		
Variables	Constant	Low	Medium	High
Consistency (%)		0.2	0.3	0.4
Agitation Rate		#1	#3	#5
Bubble Size (µm.)		4.75	12.50	50.00
pH	9.0			
Surfactant Concentration (%)	0.7			
Air Flow Rate (ml/min.)	35			
Floating Time (min.)	10			

The experiments were completely cross-designed between the selected variables and levels. The Run Number was randomly given to each test condition as shown in Table 43 in Appendix G and experiments were done according to Run Number to reduce effects of non-random factors. Each run was conducted in triplicate to establish reproducibility and sensitivity information.

Procedure

Dispersion Preparation

The standard image with random characters shown in Figure 2 was made on typical 8.5 x 11 inches copy paper (Xerox 4200 DP 20 lb.) by a copy machine, SHARP SF9800, in the Paper and Printing Science and Engineering Department. The ingredients of the toner, SHARP SF-980NT1, were: styreneacrylate copolymer, carbon black, poly-propolyne, organic pigment, and iron oxide. It should be noted that Figure 2 shows the reduced size of the image, i.e. 80% of the actual size, in order to maintain proper size for this report. The printed sheets were one-side printed and two-side printed. Ten sheets of blank, one-side printed and two-side printed were weighed. The weights were 44.85, 45.39 and 45.93 g. for blank, one-side and two-side printed, respectively. For 50 % of one-side printed sheet mixed with 50 % of two-side printed sheet, the weight percentage of ink was calculated to be 1.78 %. These printed sheets were torn and soaked in deionized water for 24 hours before repulping. The paper was repulped in a Hamilton Beach Mixer at medium speed under standard conditions as shown in Table 6.



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ID E

4.20   90/03/09

3011   Internal          Courier                 10      12

3011   Internal          Courier                 16.67   12

3011   Internal          Courier                 20      12

3011   Internal          Courier Italic          10      12

3011   Internal          CG Times                PS      12

3011   Internal          CG Times Italic         PS      12

3011   Internal          Letter Gothic           12      12

3011   Internal          LtrGothic Italic        12      12
```

Figure 2. Standard Image.

Table 6

Standard Conditions for Repulping

Paper Composition	50 % one-side printed, 50 % two-side printed
Temperature	27 °C
pH	10
Consistency	4 %
Pulping Time	10 min.

Note : Weight of ink was 1.78 % of total dry weight of paper.

Flotation

Figure 3 shows the arrangement of equipment for flotation. The mixture which was prepared for a designed test condition was stirred by a magnetic stirrer for 30 minutes before flotation. After the conditioning time, it was poured into the Hallimond tube. The mixture was floated for the designed time with nitrogen gas. The flow rate of nitrogen gas was controlled at a specified rate.

After the dwell time, the gas control valve was closed and the floated and non-floated portions were collected for further measurement.

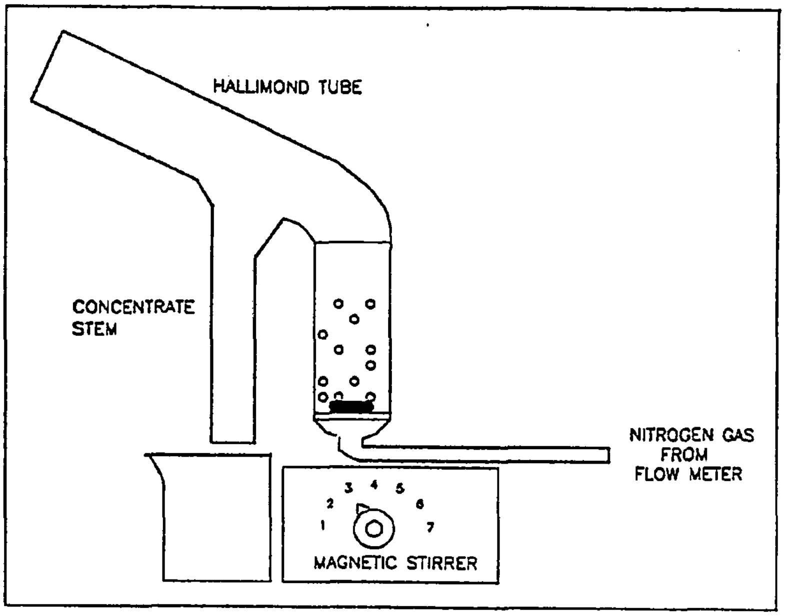

Figure 3. The Arrangement of Equipment for Flotation.

Measurement

Ink Removal Efficiency

The image analyzer was used to count the total number and total area of ink in the floated portion and non-floated portion. The preparation of sample pad for the image analyzer is described in Appendix C. The ink removal efficiency was determined in terms of percent area and percent number of ink particles to the total area and total number of ink particles as shown in equation (5).

$$\text{Efficiency (\%)} = \frac{\text{floated}}{\text{(floated + non-floated)}} \times 100 \qquad (5)$$

Fiber Loss

The floated and non-floated part were filtered and dried in an oven for 24 hrs. The dried samples were weighed to determine dry weight of the floated and non-floated solids. The weight of ink in the floated part was relatively small (less than 10 %) compared to weight of fiber, thus, ink weight was neglected and fiber loss was calculated according to equation (6).

$$\text{Fiber loss } (\%) = \frac{\text{weight of floated}}{\text{weight of (floated +non-floated)}} \times 100 \qquad (6)$$

Fiber Length Distribution

The floated part was sampled and analyzed with a KAJAANI fiber analyzer for fiber length distribution and average fiber length. The arithmetic average fiber length was used in this study.

CHAPTER V

RESULTS AND DISCUSSION

The experiments were designed and conducted in two phases, phase I and phase II. Phase I was designed to explore the effects of seven flotation variables on flotation efficiency and the yield from flotation. The results from phase I study were used for selecting three variables for further study in phase II. The experiments in phase II were done by varying each selected variable in three levels: low, medium, and high. In both phases, the individual runs were randomly performed in order to average out the effect of non-random factors.

Phase I : Preliminary Experiments

Surfactant Selection

Three commercial non-ionic surfactants were evaluated: (1) Pluronic L-10 (BASF), (2) Nonatell MT 1120 (SHELL OIL COMPANY), and (3) Nonatell MT 1087 (SHELL OIL COMPANY). The results are described in Table 7.

Concentration of surfactants below 0.6 % based on O.D. fiber were also tried. The froths were not stable and did

Table 7

The Flotation Results From Different Surfactants

Surfactant	Condition	Observation
Pluronic L-10	Concentration 0.6 % O.D. pH 8	Froth was not stable, thus could not collec the floated part
	Concentration 0.6 % O.D. pH 9	Same results as above
	Concentration 0.7 % O.D. pH 9	Same results as above
	Concentration 0.8 % O.D. pH 8	Same results as above
MT 1120	Concentration 0.6 % O.D. pH 8.5	A little froth overflowed to the concentrate stem
	Concentration 0.7 % O.D. pH 8.5	Same results as above
	Concentration 0.8 % O.D.pH 9.0	Same results as above
MT 1087	Concentration 0.6 % O.D. pH 8.0	Froth was rather stable and could collect the floated part
	Concentration 0.8 % O.D. pH 8	Froth was very stable

Note : The consistency was 0.2 % and other variables were held at medium conditions.

not accumulate high enough to overflow to the concentrate stem. Since surfactant MT 1087 gave the most stable froth suitable for operating the Hallimond tube, it was selected for this study.

Variables Selection

The summaries of the flotation results from phase I are shown in Table 8 and Figure 4-10.

Table 8

Effects of Flotation Variables on Flotation Efficiency and Fiber Loss

	Flotation Efficiency								
Varia-bles	No. of Particle			Area of Ink			Loss		
	L	M	H	L	M	H	L	M	H
pH	66.03	65.83	64.56	83.85	80.57	80.75	8.53	8.20	8.30
Surf. Conc.	77.77	65.83	64.91	90.37	80.57	85.10	8.22	8.20	9.85
Cons.	68.47	65.83	62.88	82.65	80.57	73.98	5.18	8.20	11.78
Bub. Size	67.43	65.83	65.84	79.65	80.57	77.68	9.20	8.20	8.08
Air Flow Rate	74.91	65.83	69.31	88.23	80.57	80.65	9.06	8.20	7.75
Agit.	63.69	65.83	70.57	76.25	80.57	83.30	9.60	8.20	6.72
Flot. Time	64.16	65.83	65.83	78.25	80.57	80.57	8.65	8.20	8.20

Note: L,M,H denote low, medium, and high levels of each variable. The underlines indicate no significant difference at $\alpha = 0.05$.

Flotation time and pH (Figures 4 and 10) showed little effect on efficiency and fiber loss, thus, they were not selected. The other variables (Figures 5-9) showed different degrees of influence on efficiency and fiber loss.

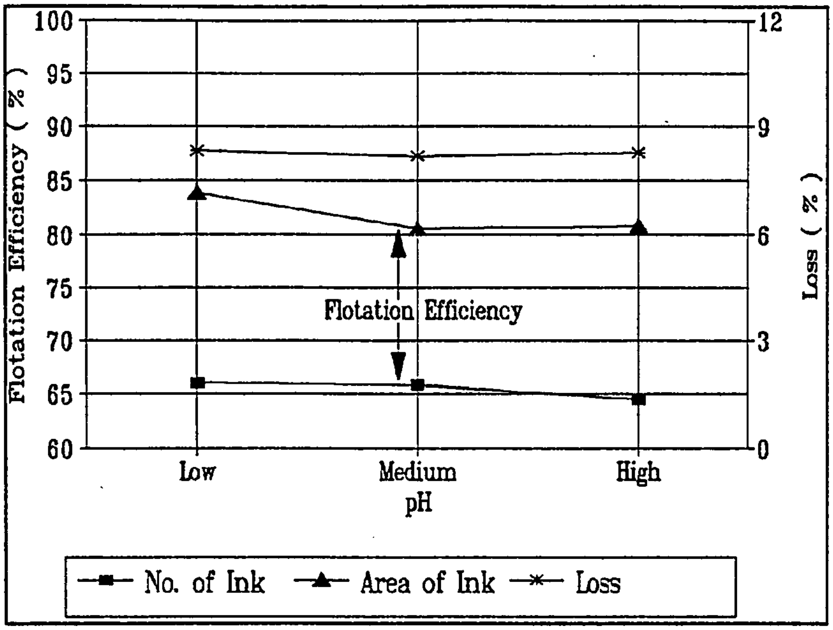

Figure 4. Effects of pH on Flotation Efficiency and Fiber Loss.

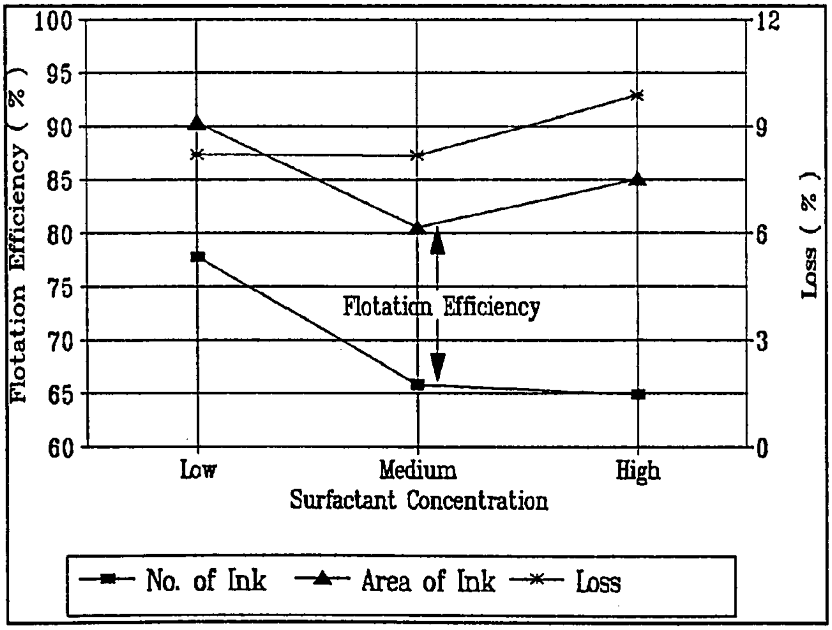

Figure 5. Effects of Surfactant Concentration on Flotation Efficiency and Fiber Loss.

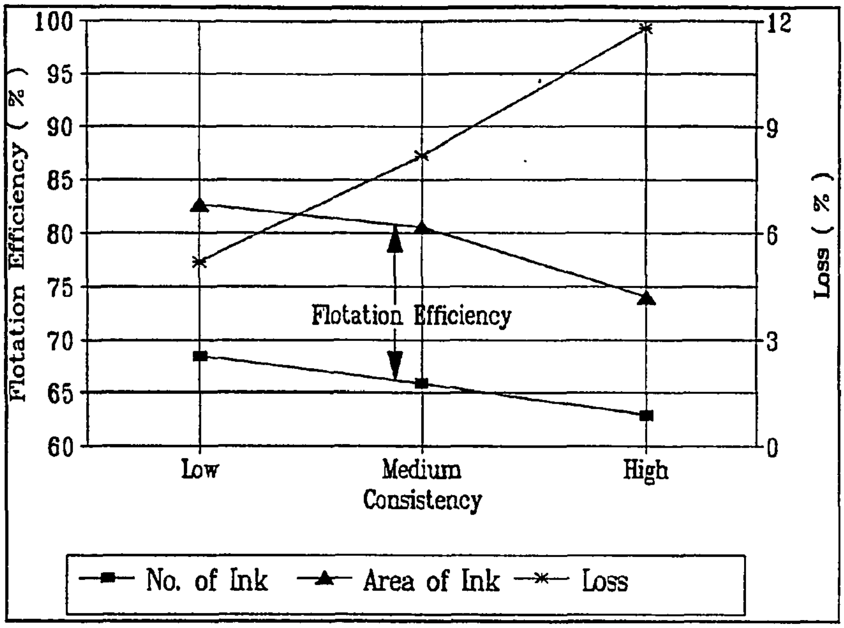

Figure 6. Effects of Consistency on Flotation Efficiency and Fiber Loss.

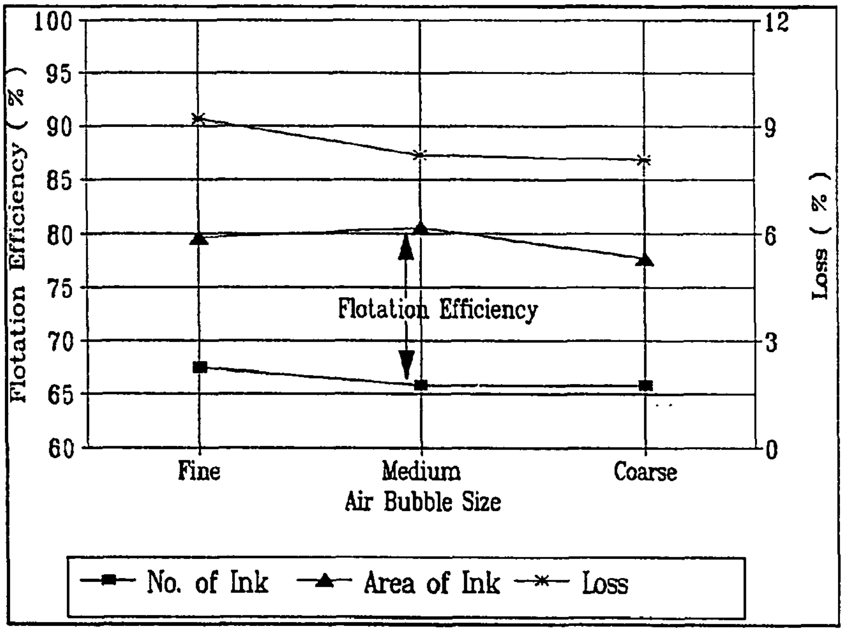

Figure 7. Effects of Air Bubble Size on Flotation Efficiency and Fiber Loss.

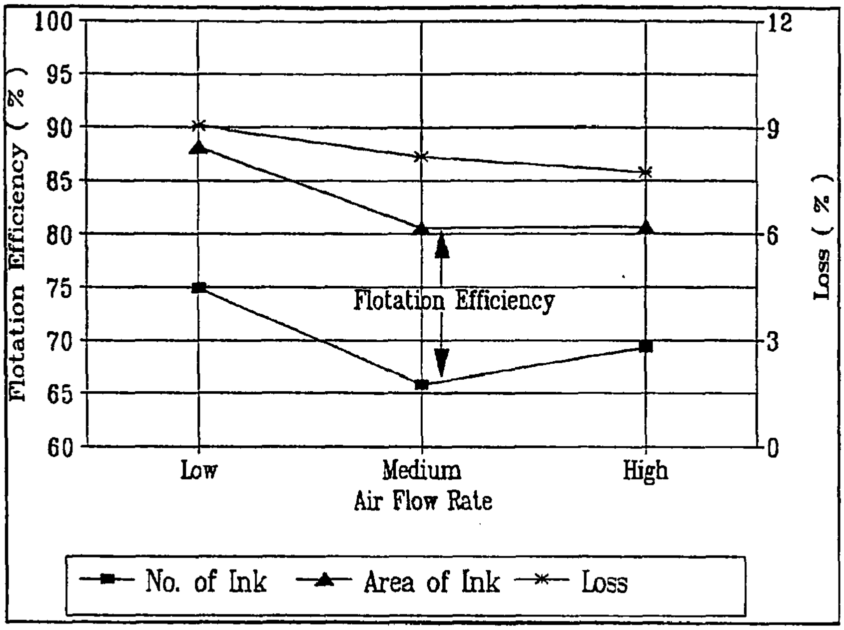

Figure 8. Effects of Air Flow Rate on Flotation Efficiency and Fiber Loss.

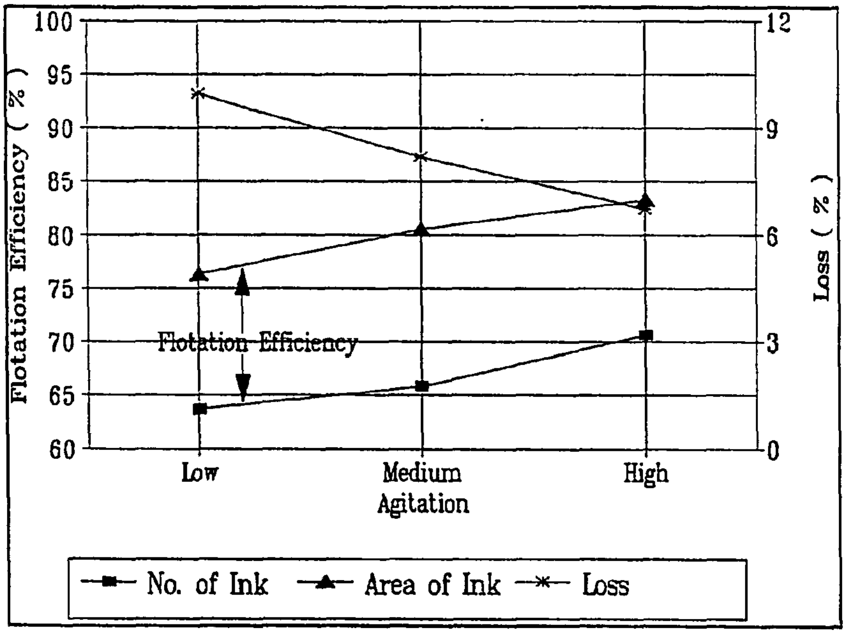

Figure 9. Effects of Agitation on Flotation Efficiency and Fiber Loss.

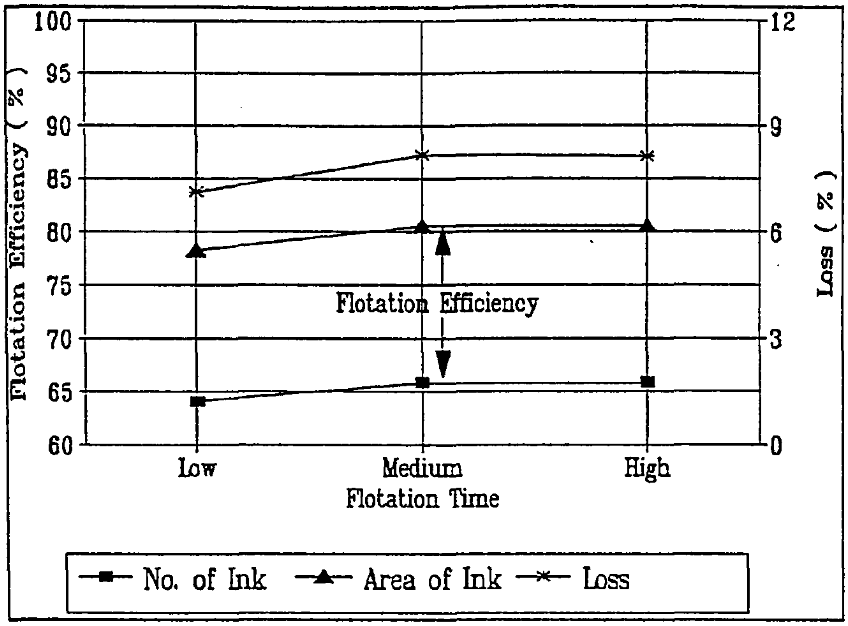

Figure 10. Effects of Flotation Time on Flotation Efficiency and Fiber Loss.

influence on efficiency and fiber loss.

Among these variables, consistency, agitation, and bubble size were selected for phase II. Air flow rate was not selected because changing air also flow rate affects bubble size. Surfactant concentration was not selected because of foaming problems at the high level of concentration.

Phase II : Optimization Experiments

A summary of the flotation results is shown in Table 9. Since the experiments in phase II were balanced and completely cross-designed, a three-way analysis of variance method was used to check the significance of each variable on flotation efficiency and loss. The SAS computer programs were used to generate the ANOVA tables. The detail of SAS computer programs are in Appendix F. The ANOVA tables from SAS are shown in Table 10-12.

Table 9

Summaries of Phase II Flotation Results

Run No.	Cons.	Bubble Size	Agit.	Flotation Efficiency(%) No. of Particle	Flotation Efficiency(%) Area of Ink	Fiber Loss (%)
1	H	F	L	58.19	74.69	3.81
2	L	M	H	72.34	87.98	3.75
3	M	M	M	70.56	88.64	7.47
4	M	F	M	74.26	88.12	7.81
5	M	F	H	74.67	87.36	5.70
6	H	F	M	66.48	84.98	9.58
7	L	F	M	76.06	88.88	3.71
8	L	M	M	74.49	91.20	4.48
9	M	C	L	60.35	76.86	4.32
10	H	C	H	53.91	82.40	5.37
11	L	F	L	66.79	81.36	9.74
12	M	M	H	69.23	85.41	5.85
13	H	M	H	61.53	83.49	6.60
14	H	C	L	52.22	75.53	3.89
15	H	M	M	60.87	83.79	8.94
16	H	F	H	65.28	86.50	6.35
17	M	M	L	61.28	76.98	4.05
18	M	C	H	65.21	84.62	5.19
19	M	F	L	63.22	79.32	4.08
20	H	M	L	57.48	73.73	3.79
21	M	C	M	66.04	87.21	7.05
22	L	C	H	69.63	86.01	3.10
23	L	C	L	62.60	80.33	6.13
24	L	C	M	70.55	89.28	4.76
25	L	F	M	78.38	92.12	5.34
26	L	M	L	65.14	79.59	7.33
27	H	C	M	55.40	85.00	8.77

Note: L,M,H,F,C denote low, medium, high, fine and coarse, respectively.

Table 10

The ANOVA Table From SAS Program for Flotation Efficiency by Number of Particles

```
                         The SAS System

                General Linear Models Procedure
                    Class Level Information

                  Class     Levels     Values

                  AGIT           3     1 2 3
                  BUB            3     1 2 3
                  CONS           3     1 2 3

          Number of observations in data set = 81

                         The SAS System

                General Linear Models Procedure

Dependent Variable: EFF

Source      DF Sum of Squares  Mean Square  F Value  Pr > F

Model       26        4014.71       154.41   294.59  0.0001

Error       54          28.31         0.52

Total       80        4043.01

        R-Square         C.V.      Root MSE          EFF Mean
            0.99         1.10          0.72             65.75

Source            DF   Type I SS  Mean Square  F Value  Pr > F

AGIT               2     1012.78       506.39   966.09  0.0001
BUB                2      766.80       383.40   731.45  0.0001
CONS               2     2016.50      1008.25  1923.53  0.0001
AGIT*BUB           4       69.22        17.30    33.01  0.0001
AGIT*CONS          4       86.40        21.60    41.21  0.0001
BUB*CONS           4        6.42         9.10    17.37  0.0001
AGIT*BUB*CONS      8       26.59         3.32     6.34  0.0001
```

Table 11

The ANOVA Table From SAS Program for Flotation Efficiency by Area of Ink

```
                        The SAS System

               General Linear Models Procedure
                  Class Level Information

                Class      Levels     Values

                 AGIT           3     1 2 3
                 BUB            3     1 2 3
                 CONS           3     1 2 3

            Number of observations in data set = 81

                        The SAS System

               General Linear Models Procedure

Dependent Variable: EFF

Source     DF Sum of Squares  Mean Square  F Value  Pr > F

Model      26        2056.70        79.10   224.74  0.0001

Error      54          19.01         0.35

Total      80        2075.71

       R-Square          C.V.     Root MSE          EFF Mean
           0.99          0.71         0.59             83.75

Source            DF   Type I SS  Mean Square  F Value  Pr > F

AGIT               2     1582.62       791.31  2248.18  0.0001
BUB,               2       47.94        23.97    68.10  0.0001
CONS               2      362.84       181.42   515.42  0.0001
AGIT*BUB           4       19.63         4.91    13.94  0.0001
AGIT*CONS          4       20.17         5.04    14.32  0.0001
BUB*CONS           4        7.64         1.91     5.42  0.0010
AGIT*BUB*CONS      8       15.87         1.98     5.64  0.0001
```

Table 12

The ANOVA Table From SAS Program for Loss

```
                           The SAS System

                  General Linear Models Procedure
                      Class Level Information

                    Class     Levels     Values

                     AGIT          3     1 2 3
                     BUB           3     1 2 3
                     CONS          3     1 2 3

            Number of observations in data set = 81

                           The SAS System

                  General Linear Models Procedure

Dependent Variable: Loss

Source      DF Sum of Squares  Mean Square  F Value  Pr > F

Model       26         298.01        11.50    90.27  0.0001

Error       54           6.88         0.13

Total       80         305.89

        R-Square          C.V.     Root MSE          Loss Mean
            0.98          6.14         0.36               5.81

Source          DF    Type I SS  Mean Square  F Value  Pr > F

AGIT             2        70.42        35.21   276.36  0.0001
BUB              2         9.33         4.67    36.63  0.0001
CONS             2        13.26         6.63    52.05  0.0001
AGIT*BUB         4         2.75         0.69     5.39  0.0010
AGIT*CONS        4       187.95        46.99   368.81  0.0001
BUB*CONS         4         4.51         1.13     8.84  0.0001
AGIT*BUB*CONS    8        10.80         1.35    10.60  0.0001
```

According to the ANOVA tables, it can be concluded for all models, i.e. flotation efficiency by number of particle and by area of ink and loss, that

1. The main effects of consistency (CONS), bubble size (BOB), and agitation (AGIT) were all significant at $\alpha = 0.05$.

2. The two interaction effects (AGIT*BUB, AGIT*CONS, and BUB*COBS) were significant at $\alpha = 0.25$.

3. The three interaction effect (AGIT*BUB*CONS) was significant at $\alpha = 0.25$.

4. Pr-value for each model was 0.0001 which means that the hypothesis that all means are equal, was rejected at $\alpha = 0.05$.

The α -level was raised to 0.25 for two and three interaction because it is easier to reject the hypothesis that no interaction if there is any evidence of two and three interaction. From the conclusions above, it was decided, for each model, to analyze all pairwise differences of means between levels of consistency, bubble size and agitation.

Flotation Efficiency

Effects of Consistency on Flotation Efficiency

Flotation efficiencies for each level of consistency are summarized in Table 13.

Table 13

Effects of Consistency on Flotation Efficiency at Different Levels of Agitation and Bubble Size

	Air Bubble Size								
	Fine			Medium			Coarse		
Agitation	Consistency			Consistency			Consistency		
	L	M	H	L	M	H	L	M	H
by Number of Ink Particle									
Low	66.79	63.22	58.19	65.14	61.28	57.48	62.60	60.35	52.22
Medium	78.38	74.26	66.48	67.49	70.56	60.87	70.55	66.04	55.40
High	76.06	74.67	65.28	72.34	69.23	61.53	69.63	65.21	53.91
by Area of Ink									
Low	81.36	79.32	74.69	79.59	76.98	73.73	80.33	76.86	75.53
Medium	92.12	88.12	84.98	91.20	88.46	83.79	89.28	87.21	85.00
High	88.88	87.36	86.50	87.98	85.41	83.49	86.01	84.62	82.40

Note : L,M,H denote low, medium and high levels of consistency. The underline indicates that the difference is not significant at $\alpha = 0.05$

According to the output from the SAS program for flotation efficiency, most of the flotation efficiencies at different consistencies were significantly different at $\alpha = 0.05$. The flotation efficiency difference between medium and high consistency for fine bubble size and high agitation was not significantly different at $\alpha = 0.05$ as indicated by an underline in Table 13.

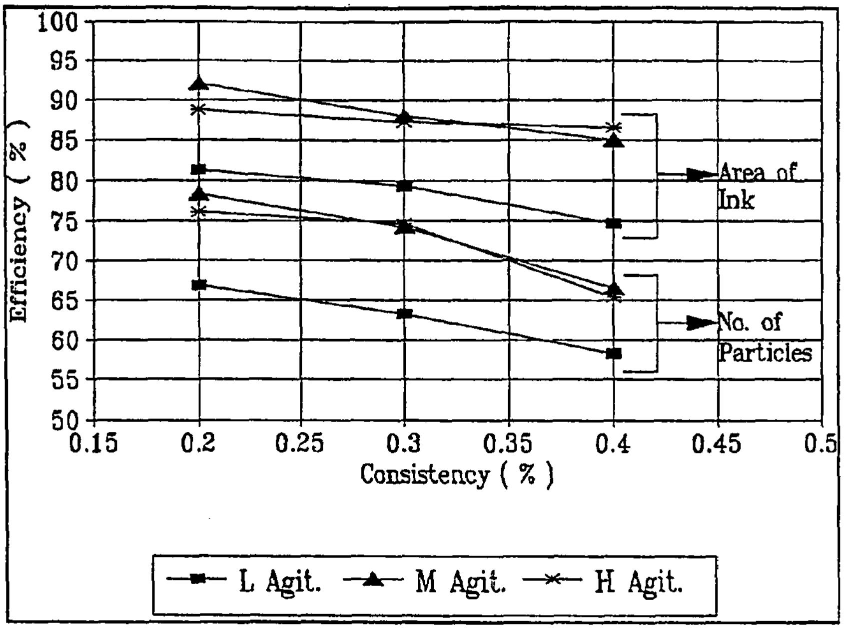

Figure 11. Effects of Consistency and Agitation on Flotation Efficiency for Fine Bubbles.

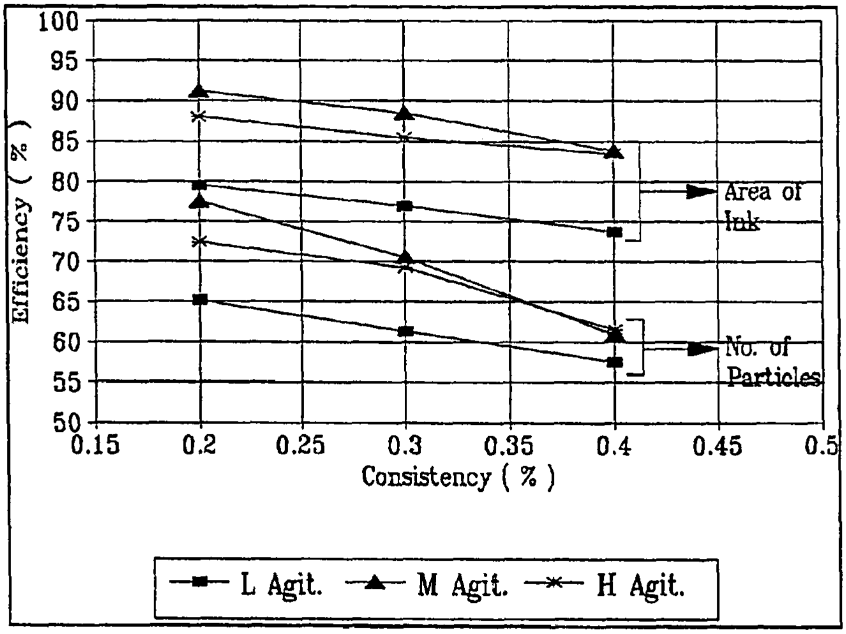

Figure 12. Effects of Consistency and Agitation on Flotation Efficiency for Medium Bubbles.

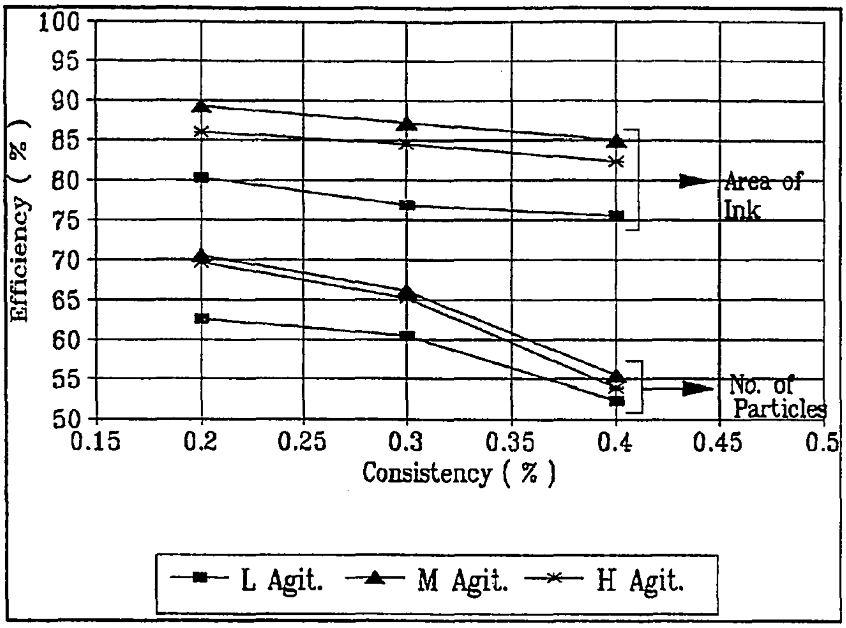

Figure 13. Effects of Consistency and Agitation on Flotation Efficiency for Coarse Bubbles.

Figures 11-13 show the effects of consistency on flotation efficiency. It can be seen that flotation efficiency decreases as consistency increases for every level of bubble size and agitation. When fibers are present in the system, air bubbles may be nearly entrapped in fiber networks, which may loosen ink particles from the air bubbles. Thus, higher consistency, i.e. more contacts between bubbles and fibers, may decrease flotation efficiency.

The efficiency by number of ink particle was more dependent on consistency than the efficiency by area of ink, especially at high consistency. This result may be because many small ink particles were loosened from the air bubbles. Loss of small ink particles affected the total number of ink particles more than the total area of ink.

Effects of Agitation on Flotation Efficiency

Table 14 shows the effects of agitation on flotation efficiency. From the output of SAS program for flotation efficiency, the efficiency at low agitation was significantly different from medium and high agitation at $\alpha = 0.05$.

Table 14

Effects of Agitation on Flotation Efficiency at Different Levels of Consistency and Bubble Size

	Air Bubble Size								
	Fine			Medium			Coarse		
Consis-tency	Agitation L	M	H	Agitation L	M	H	Agitation L	M	H
by Number of Ink Particle									
Low	66.79	78.38	76.06	5.14	77.49	72.34	62.60	70.55	69.63
Medium	63.22	74.26	74.64	61.28	70.56	69.23	60.35	66.04	65.21
High	58.19	66.48	65.28	57.48	60.87	61.53	52.22	55.40	53.91
by area of ink									
Low	81.36	92.12	88.88	79.59	91.20	87.98	80.33	89.28	86.01
Medium	79.32	88.12	87.36	76.98	88.46	85.41	76.86	87.21	84.62
High	74.69	84.98	86.50	73.73	83.79	73.49	75.33	85.00	82.40

Note : L, M, H denotes low, medium and high level of agitation. The underlines indicate that the difference was not significant at $\alpha = 0.05$.

From Figures 11-13, it can be seen that low agitation gives the lowest flotation efficiency. Flotation efficiency was highest at medium agitation and dropped when agitation was increased to the high level. Increasing agitation increases the frequency of collisions between air bubbles and ink particles which, in turn, promoted the probability of adhesion. This may be the reason for increasing efficiency with agitation rate. However, too high agitation gave negative results, i.e., lower flotation efficiency. A possible explanation is that when agitation is too high, air bubbles collide with each other and become larger bubbles. This phenomenon reduces the probability of collision of bubble with ink particles according to equation (1). At consistency 0.4 %, flotation efficiency by number of ink particle did not increase as much as at 0.2 % and 0.3 % consistency when agitation was increased. This result may be because higher agitation was less effective at higher consistency since hydrodynamic turbulence was dampeded more by the fiber networks.

Effects of Air Bubble Size on Flotation Efficiency

Table 15 shows the effects of bubble size on flotation efficiency at different levels of consistency and agitation. According to the output of the SAS program for efficiency, many pairs of efficiency were not significantly different at α = 0.05. In the other words, bubble size seemed not to have as much influence on flotation efficiency, especially flotation efficiency by area of ink, as consistency and agitation.

Table 15

Effects of Bubble Size on Flotation Efficiency at Different Levels of Consistency and Agitation

	Agitation								
	Low			Medium			High		
Consistency	Bubble Size			Bubble Size			Bubble Size		
	F	M	C	F	M	C	F	M	C
by Number of Ink Particle									
Low	66.79	65.14	62.60	78.38	77.49	70.55	76.06	72.34	69.63
Medium	63.22	61.28	60.35	74.26	70.56	66.04	74.67	69.23	65.21
High	58.19	57.48	52.22	66.48	60.87	55.40	65.28	61.53	53.91
by Area of Ink									
Low	81.36	79.59	80.33	92.12	91.20	89.28	88.88	87.98	86.01
Medium	79.32	76.98	76.86	88.12	88.46	87.21	87.36	85.41	84.26
High	74.69	73.73	75.53	84.98	83.79	85.00	86.50	83.49	82.40

Note : F,M,C denote fine medium and coarse bubble size. The underlines indicate no significant difference at α =0.05.

The bubble sizes in this study are categorized according to pore size of fritted glass in the Hallimond tube. Even though the air flow rate was kept constant, it is not certain that the bubble size will be only one size for a certain pore size of fritted glass. However, it is believed that the mean bubble size was smaller for fine pore size and larger for coarse pore size. Figures 14-16 show that at the same agitation and consistency, flotation efficiency tended to decrease when size of air bubble was increased. This result agrees with the hypothesis of probability of collision. It also can be seen from Figures 14-16 that increasing agitation improved flotation efficiency more than reducing bubble size. This means that agitation showed stronger influence on flotation efficiency than bubble size.

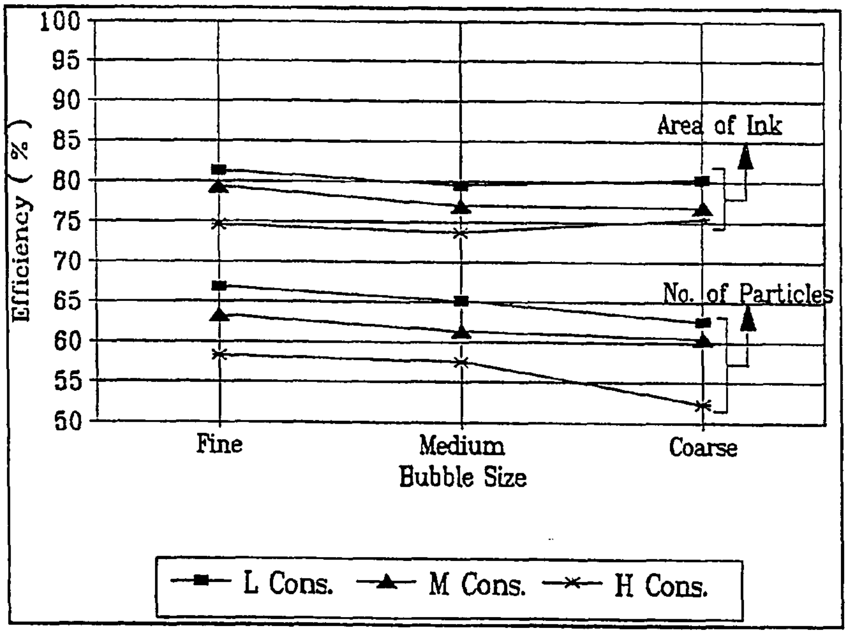

Figure 14. Effects of Bubble Size and Consistency on Flotation Efficiency at Low Agitation.

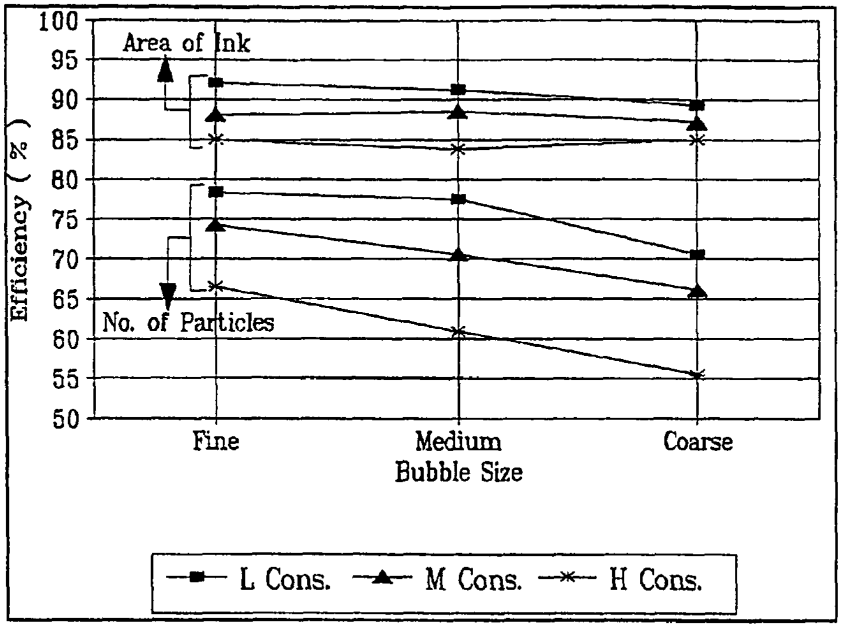

Figure 15. Effects of Bubble Size and Consistency on Flotation Efficiency at Medium Agitation.

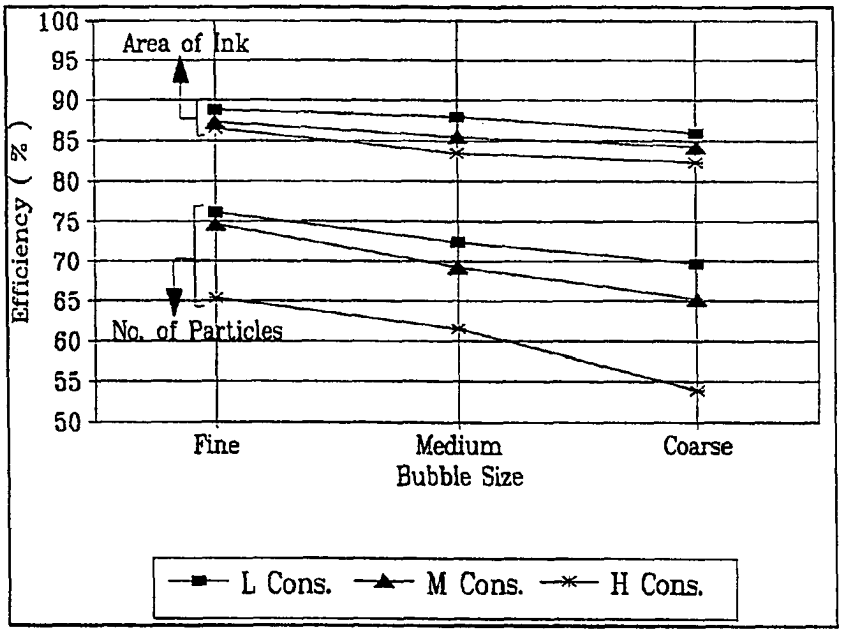

Figure 16. Effects of Bubble Size and Consistency on Flotation Efficiency at High Agitation.

Fiber Loss

Effects of Consistency on Fiber Loss

Table 16 shows the effects of consistency on fiber loss during flotation. From the output of the SAS program for loss, most of the loss values at different levels of consistency were significantly different at $\alpha = 0.05$. Three pairs of losses were not significantly different at $\alpha = 0.05$ as indicated by underlines in Table 16.

Table 16

Effects of Consistency on Fiber Loss from Flotation at Different Levels of Agitation and Bubble Size

	Air Bubble Size								
	Fine			Medium			Coarse		
Agitation	Consistency			Consistency			Consistency		
	L	M	H	L	M	H	L	M	H
L	9.74	4.08	3.81	7.33	4.05	3.79	6.13	4.32	3.89
M	5.34	7.81	9.58	4.48	7.47	8.94	4.76	7.05	8.77
H	3.71	5.70	6.35	3.75	5.85	6.60	3.10	5.19	5.37

Note : L,M,H denote low, medium and high level of agitation and consistency. The underlines indicates no significant difference at $\alpha = 0.05$.

From Figures 17-19, it can be seen that, for medium and high agitation, loss increases with increasing consistency. For low agitation, the curves are obviously different from the other levels of agitation.

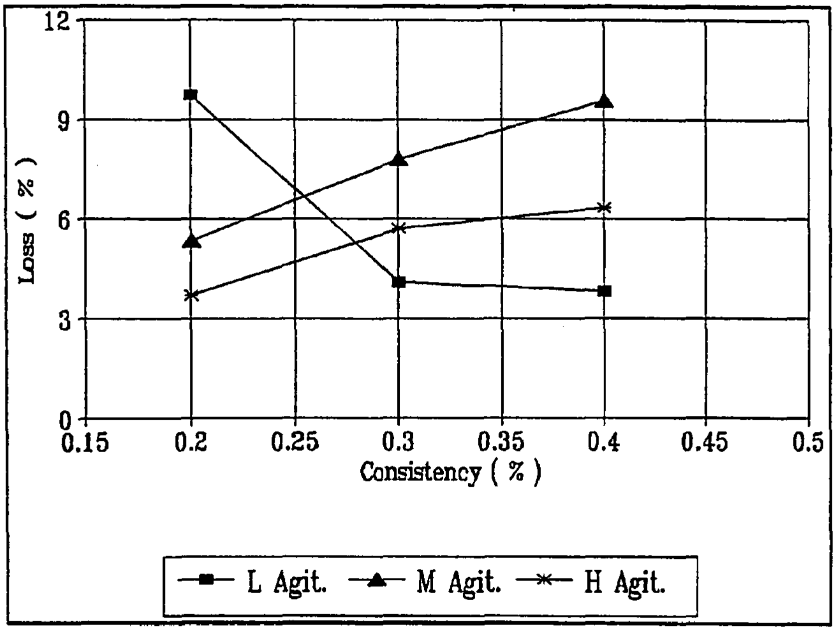

Figure 17. Effects of Consistency and Agitation on Fiber Loss for Fine Bubbles.

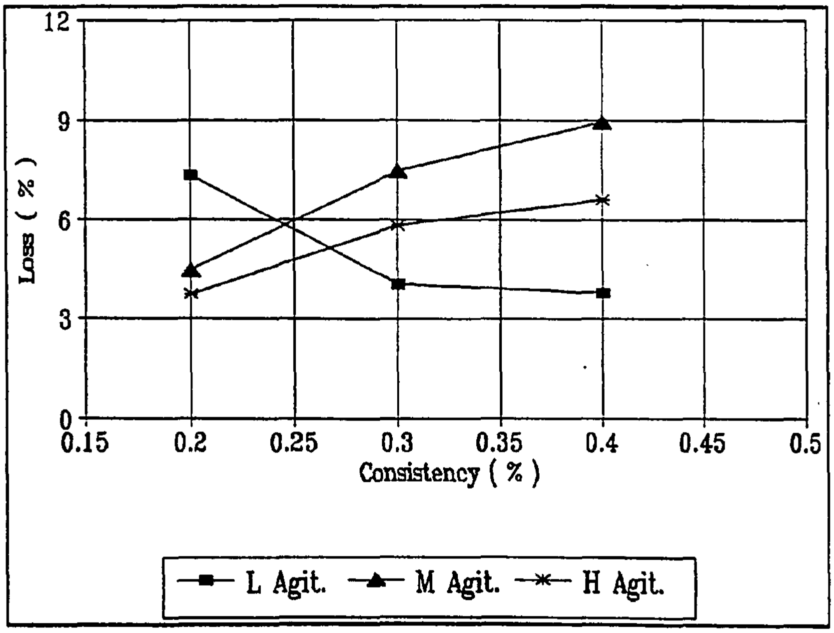

Figure 18. Effects of Consistency and Agitation on Fiber Loss for Medium Bubbles.

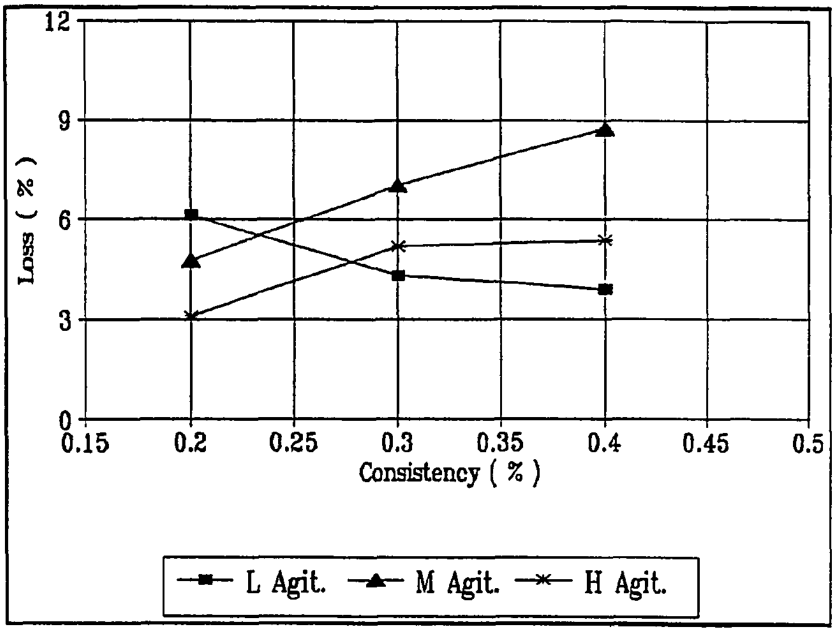

Figure 19. Effects of Consistency and Agitation on Fiber Loss for Coarse Bubbles.

The losses were very low for 0.3 % and 0.4 % consistency at low agitation. This is because low agitation did not produce enough turbulence to break the fiber networks. When air bubbles were introduced into the tube, they brought the networks to the surface. The fiber networks at the surface shredded fibers off of the air bubbles when they passed through the networks. This phenomenon was actually observed during flotation. When agitation was high enough to break the fiber networks, such as medium and high agitation, increasing consistency enhanced the number of fibers entrained with the foam which gave a high loss of yield.

Effects of Agitation on Fiber Loss

Table 17 shows the effects of agitation on loss during flotation at different levels of consistency and bubble size. From the output of the SAS program for loss, all of the losses at different levels of agitation were significantly different at α =0.05.

Table 17

Effects of Agitation on Fiber Loss From Flotation at Different Levels of Consistency and Bubble Size

	Air Bubble Size								
	Fine			Medium			Coarse		
Consistency	Agitation L	M	H	Agitation L	M	H	Agitation L	M	H
Low	9.74	5.34	3.71	7.33	4.48	3.75	6.13	4.76	3.10
Medium	4.08	7.81	5.70	4.05	7.47	5.85	4.32	7.05	5.19
High	3.81	9.58	6.35	3.79	8.94	6.60	3.89	8.77	5.37

Note : L,M,H denote low, medium and high level of agitation

From Figures 17-19, it can be seen that loss decreased with agitation for 0.2 % consistency. For 0.3 % and 0.4 % consistency, loss decreased as agitation was increased from medium to high but loss was the lowest at low agitation. The reason why the loss was very low was already explained in the effect of consistency section. The decrease in loss with increasing agitation may be caused by the turbulence which loosens entrained fibers from air bubbles.

Effects of Bubble Size on Fiber Loss

Table 18 shows the effects of bubble size on fiber loss at different levels of consistency and agitation. According to the output from the SAS program for loss most of the losses were not significantly different at $\alpha=0.05$.

Table 18

Effects of Bubble Size on Fiber Loss From Flotation at Different Levels of Consistency and Agitation

				Agitation					
	Low			Medium			High		
Consistency	Bubbles Size			Bubble Size			Bubble Size		
	F	M	C	F	M	C	F	M	C
Low	9.74	7.33	6.13	5.34	4.48	4.76	3.71	3.75	3.10
Medium	4.08	4.05	4.32	7.81	7.47	7.05	5.70	5.85	5.19
High	3.81	3.79	3.89	9.58	8.94	8.77	6.35	6.60	5.37

Note : F,M,C denote fine, medium and coarse bubble size. Underlines indicate no significant difference at $\alpha=0.05$

The decrease in fiber loss with increasing bubble size was significant only at the low levels of consistency and agitation. Figures 20-22 show that the bubble size did not have as much influence on fiber loss as agitation and consistency. However, the fiber loss tended to decrease when the bubble size increased.

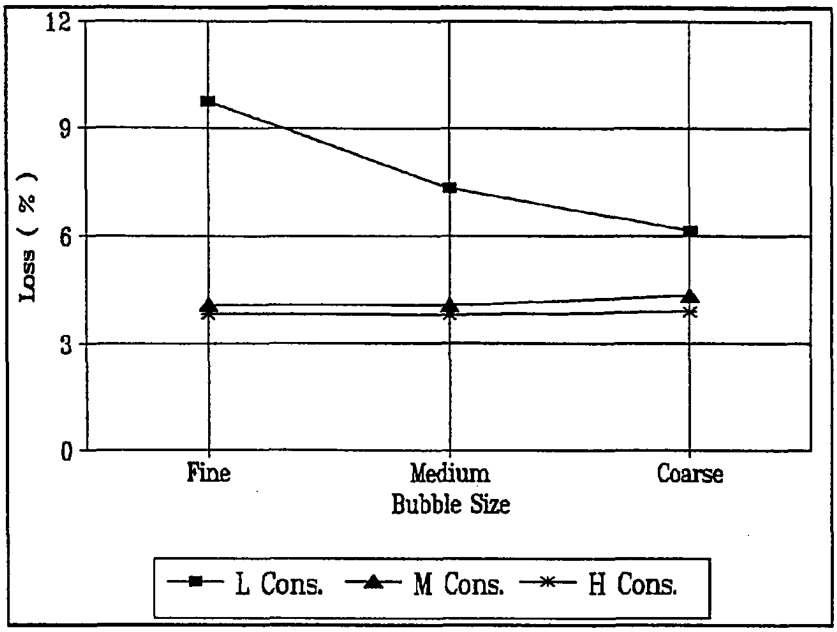

Figure 20. Effects of Bubble Size and Consistency on Fiber Loss at Low Agitation.

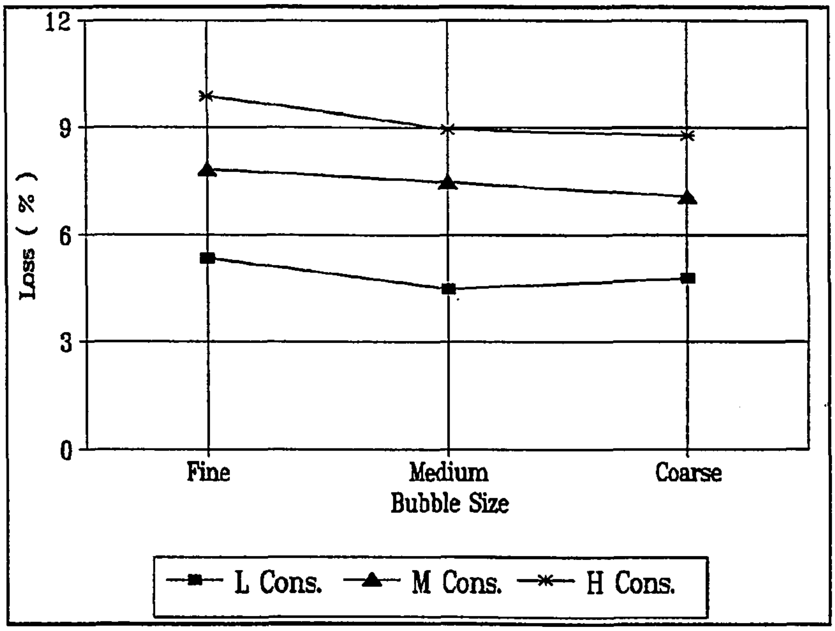

Figure 21. Effects of Bubble Size and Consistency on Fiber Loss at Medium Agitation.

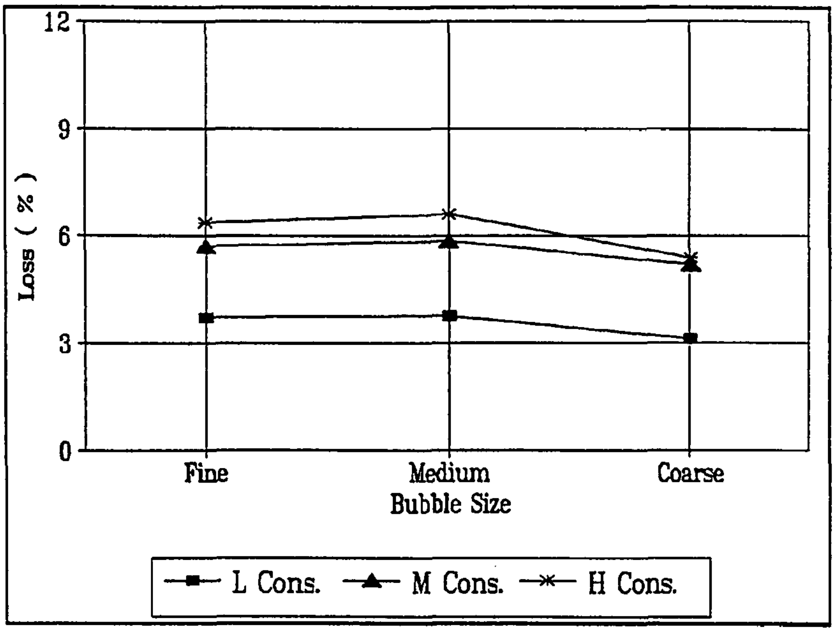

Figure 22. Effects of Bubbles Size and Consistency on Fiber Loss at High Agitation.

Fiber Length Distribution of Fiber in Floated Part

The floated part from each flotation was sampled and the sample was analyzed by a KAJAANI fiber analyzer. The summaries of fiber length distribution and arithmetic length average for each run number are shown in Table 47 in Appendix G. Figures 23-31 show fiber length distribution for three levels of consistency at different levels of agitation and bubble size compared with original pulp.

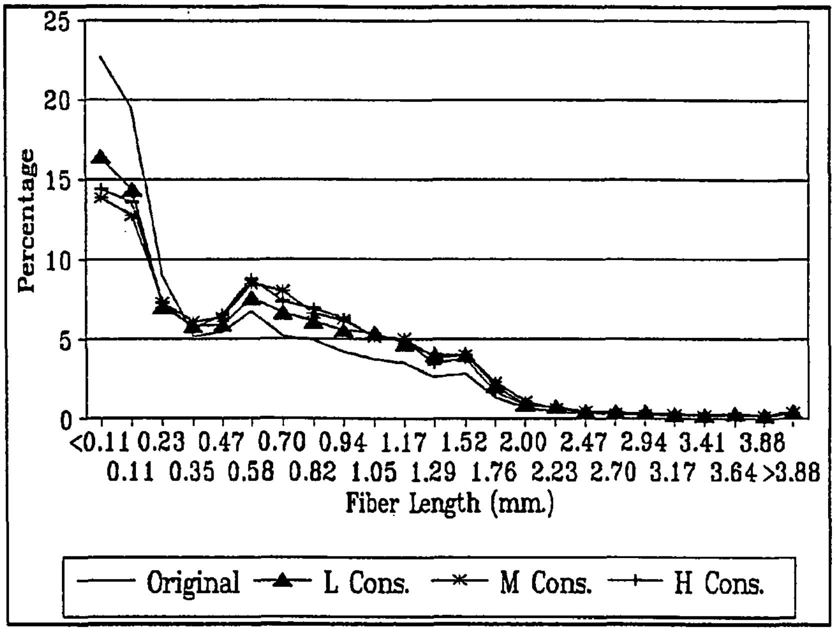

Figure 23. Fiber Length Distribution of Fiber in Floated Part: Fine Bubbles, Low Agitation.

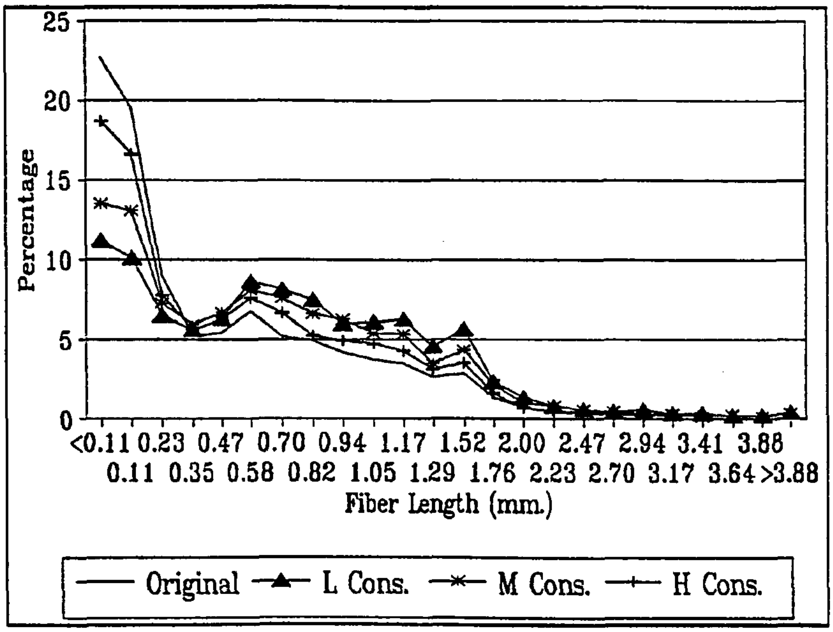

Figure 24. Fiber Length Distribution of Fiber in Floated Part: Fine Bubbles, Medium Agitation.

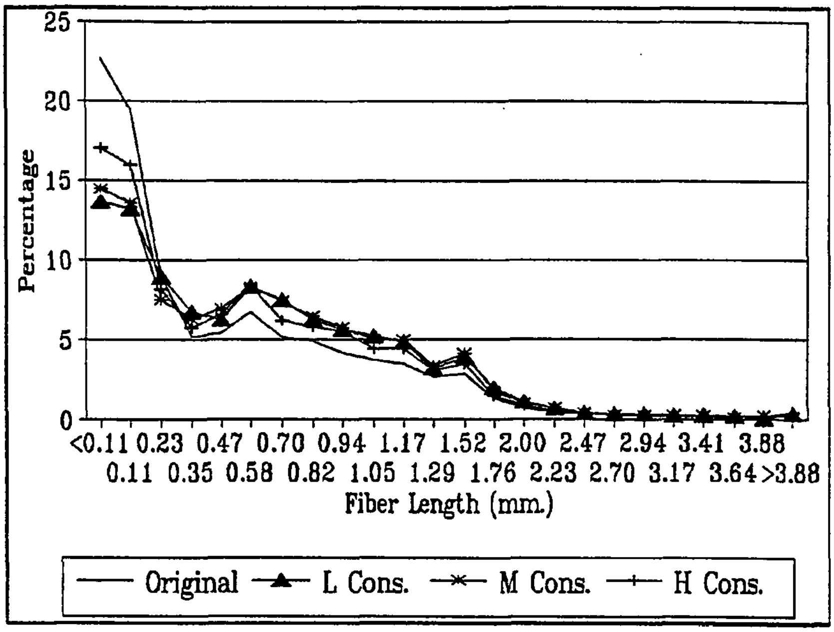

Figure 25. Fiber Length Distribution of Fiber in Floated Part: Fine Bubbles, High Agitation.

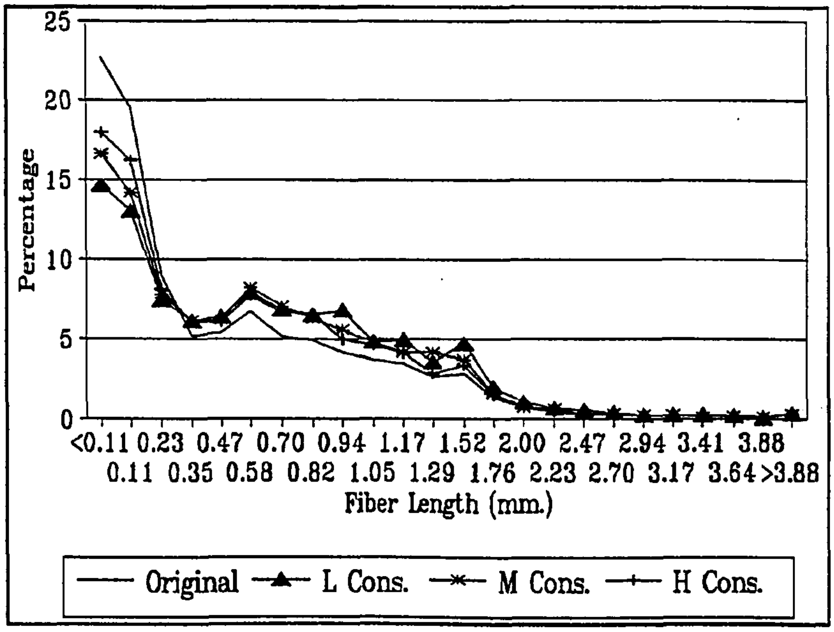

Figure 26. Fiber Length Distribution of Fiber in Floated Part: Medium Bubbles, Low Agitation.

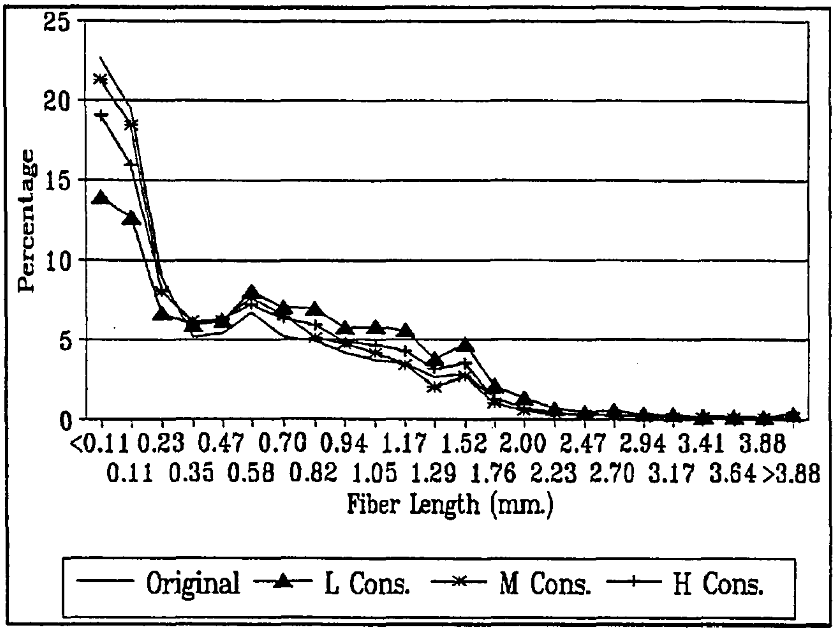

Figure 27. Fiber Length Distribution of Fiber in Floated Part: Medium Bubbles, Medium Agitation.

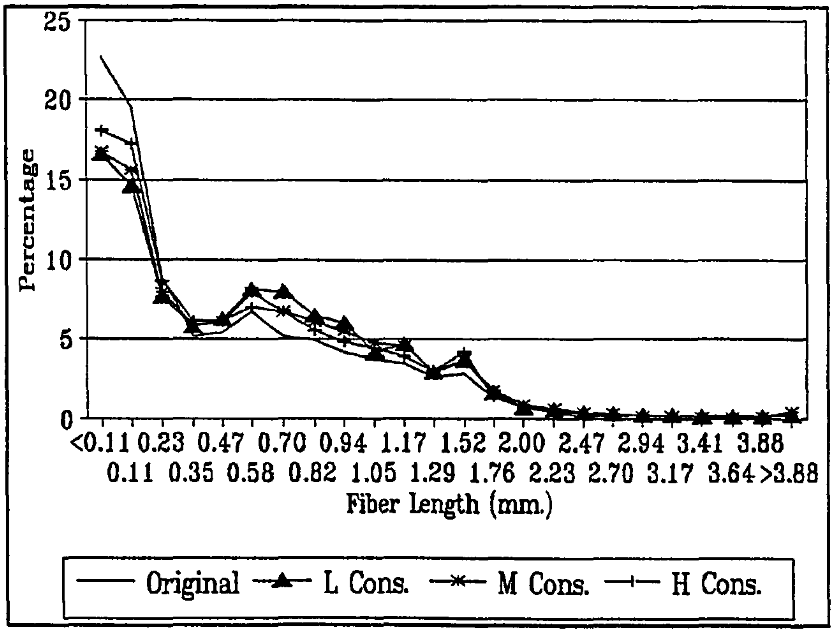

Figure 28. Fiber Length Distribution of Fiber in Floated Part: Medium Bubbles, High Agitation.

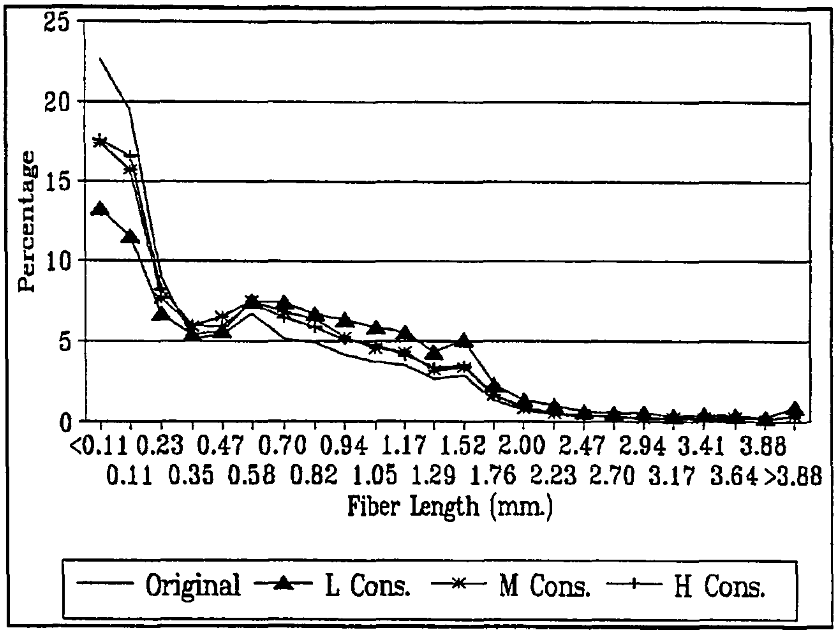

Figure 29. Fiber Length Distribution of Fiber in Floated Part: Coarse Bubbles, Low Agitation.

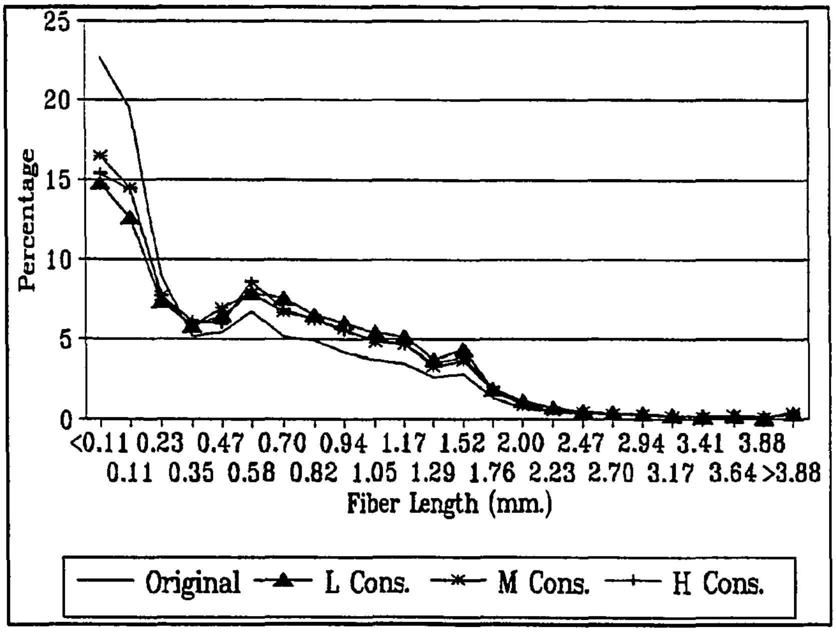

Figure 30. Fiber Length Distribution of Fiber in Floated Part: Coarse Bubbles, Medium Agitation.

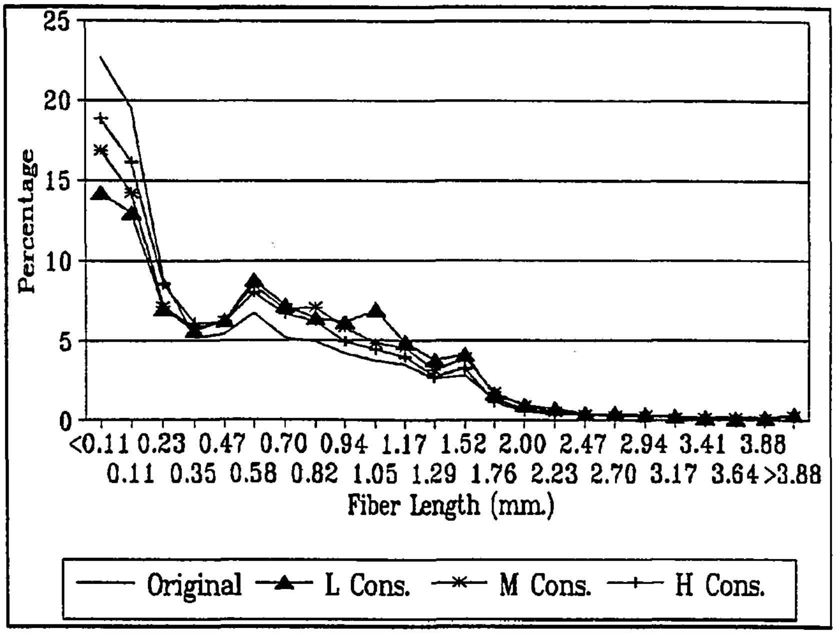

Figure 31. Fiber Length Distribution of Fiber in Floated Part: Coarse Bubbles, High Agitation.

It can be seen from the figures that the floated part contained more fiber with length from 0.35 to 2.00 mm. but less fiber with length shorter than 0.25 mm. than the original pulp. This means that fiber length fractionation occured in flotation process, with long fiber floating preference to the short fiber. Average fiber length based on number of fibers, i.e. arithmetic average, is summarized in Table 19. The average fiber length of original pulp was 0.59 mm. Average fiber length of fiber in the floated parts at all conditions was longer than original pulp.

Table 19

The Average Fiber Length (mm.) of Fiber in Floated Part

	Air Bubble Size								
	Fine			Medium			Coarse		
Agitation	Consistency			Consistency			Consistency		
	L	M	H	L	M	H	L	M	H
Low	0.71	0.71	0.70	0.71	0.66	0.63	0.79	0.65	0.64
Medium	0.79	0.72	0.65	0.73	0.65	0.63	0.71	0.67	0.68
High	0.68	0.69	0.64	0.66	0.65	0.60	0.70	0.66	0.61

Note : L,M,H denote low, medium and high level of consistency.

Figures 32-34 show that average fiber length of fiber in floated part decreased as consistency was increased. This result may be because long fibers were caught more easily by networks at high consistency. The influence of agitation and bubble size on the average fiber length of the floated part was not so obvious. However, high levels of agitation gave shorter average fiber length than low and medium agitation.

In order to examine in more detail the fibers in the floated part, fiber length was divided into three groups: short, medium and long. Short fiber was defined as fibers with length less than 0.35 mm. Medium fiber was fibers with length from 0.35 to 1.76 mm. Long fiber was fibers with length longer than 1.76 mm. Total percent fiber in

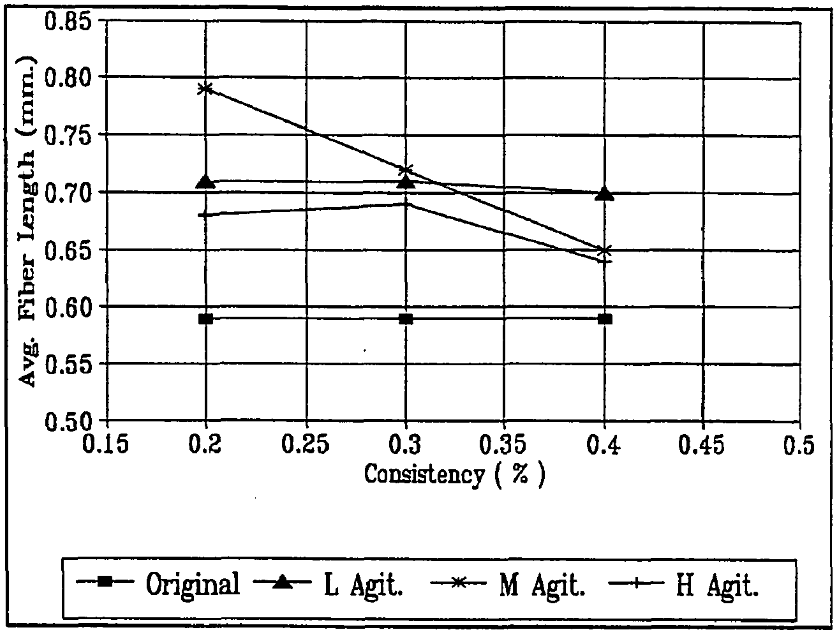

Figure 32. Average Fiber Length of the Original Pulp and Fiber in Floated Part: Fine Bubbles.

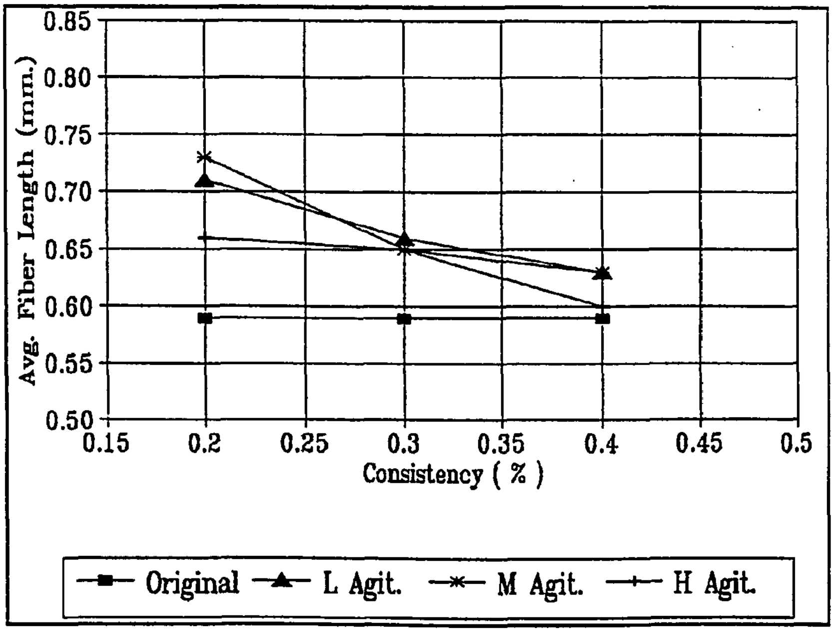

Figure 33. Average Fiber Length of the Original Pulp and Fiber in Floated Part: Medium Bubbles.

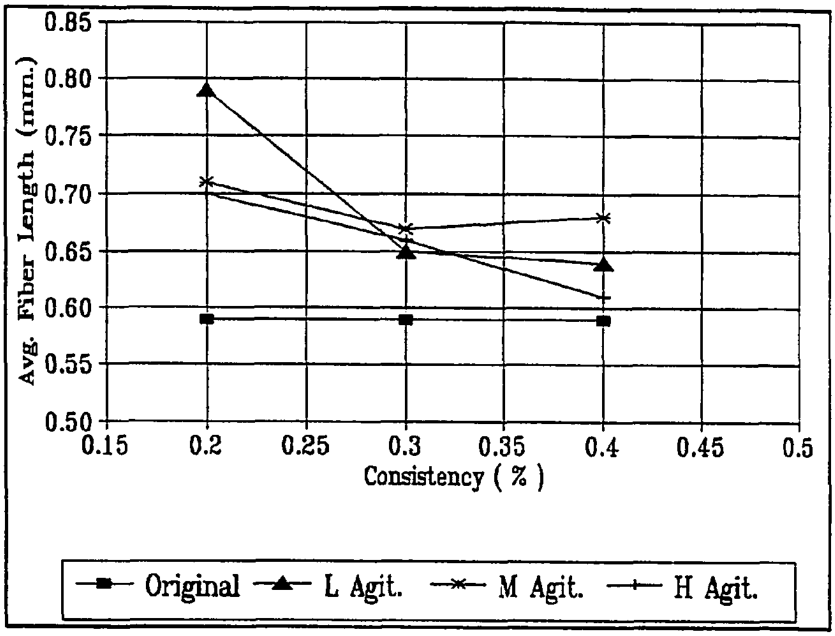

Figure 34. Average Fiber Length of the Original Pulp and Fiber in Floated Part: Coarse Bubbles.

each group was calculated and shown in Table 20.

Figures 35-43 show the percentages of short, medium, and long fiber at different flotation conditions. It can be concluded that the percentage of short fiber increased when consistency was increased. For the medium fiber and long fiber group, the percentages decreased with increasing cosistency. It is hypothesized that when consistency was increased, medium fibers and long fibers were caught more readily in fiber networks. Thus, the percentages of medium fiber and long fiber was reduced. It is also hypothesized that long fiber are caught much easier in fiber networks than short and medium fibers. Thus, the percentage of long

Table 20

Summaries of Percentage of Floated Fiber in Short, Medium and Long Fiber Group

		Air Bubble Size								
		Fine			Medium			High		
Agitation		Consistency			Consistency			Consistency		
		L	M	H	L	M	H	L	M	H
L	S	37.82	33.99	35.28	35.19	38.61	42.32	31.47	40.83	42.42
	M	57.84	62.03	60.64	60.76	58.13	54.61	62.15	55.71	54.25
	L	4.34	3.98	4.08	4.05	3.26	3.07	6.38	3.46	3.33
M	S	27.75	33.88	43.08	33.35	47.78	43.08	34.78	38.72	37.56
	M	66.95	61.82	53.56	62.15	50.01	53.77	60.99	57.72	58.61
	L	5.30	4.30	3.36	4.50	2.21	3.14	4.23	3.55	3.83
H	S	35.82	35.59	41.21	38.92	40.35	44.04	34.25	38.32	43.55
	M	60.07	60.72	55.41	57.88	56.21	53.57	61.94	58.68	53.87
	L	4.11	3.68	3.38	3.20	3.44	2.40	3.81	3.00	2.58

Note : S,L,M,H denote short,low and long, medium, and high, respectively.

fiber was much lower than short and medium fiber.

Average percentages of short, medium and long fiber at each level of consistency were calculated and normalized by dividing by average percentages at low consistency. For low, medium and high consistency, the calculated figures are 1.00, 1.12 and 1.20 for short fiber, 1.00, 0.95 and 0.90 for medium fiber, and 1.00, 0.77 and 0.73 for long fiber. It can be seen that as consistency raised, proportion of long fiber was reduced more than medium fiber.

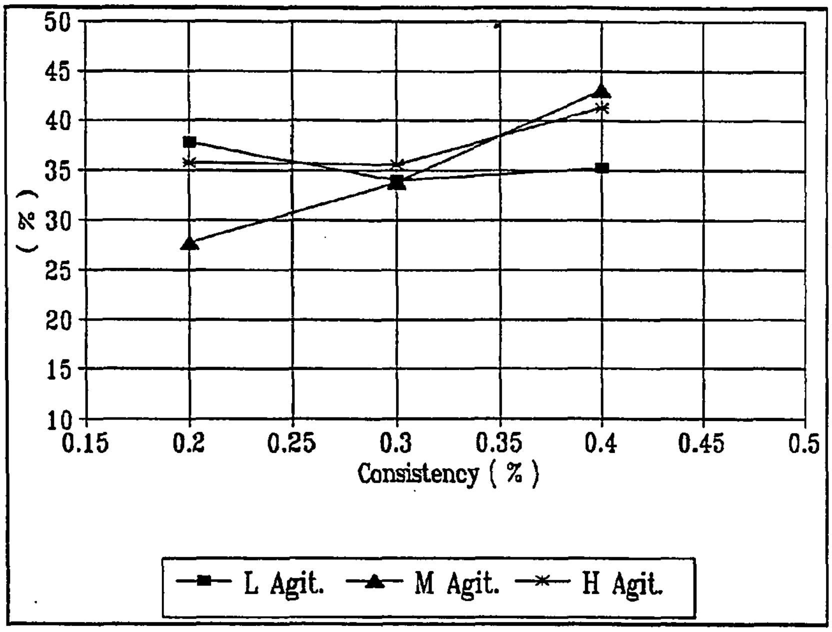

Figure 35. Percentage of Short Fiber in Floated Part: Fine Bubbles.

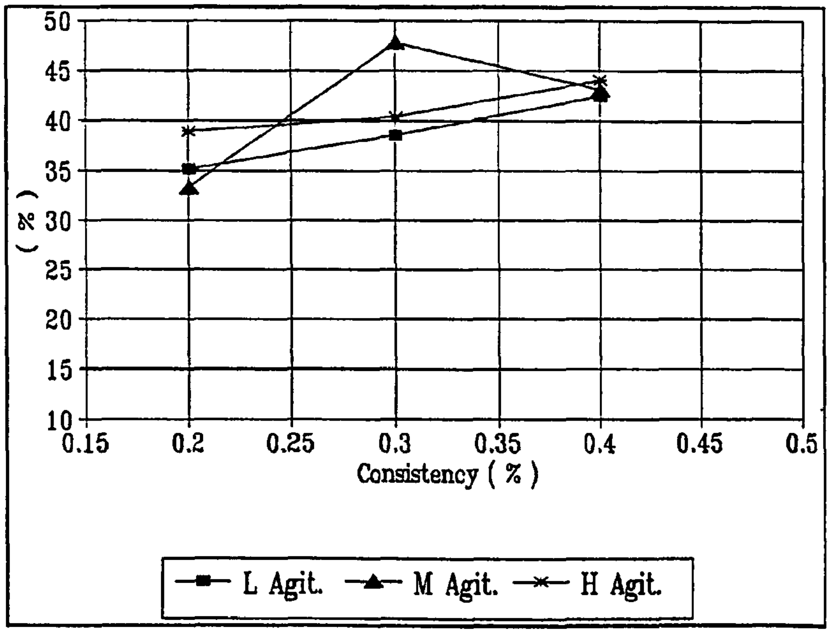

Figure 36. Percentage of Short Fiber in Floated Part: Medium Bubbles.

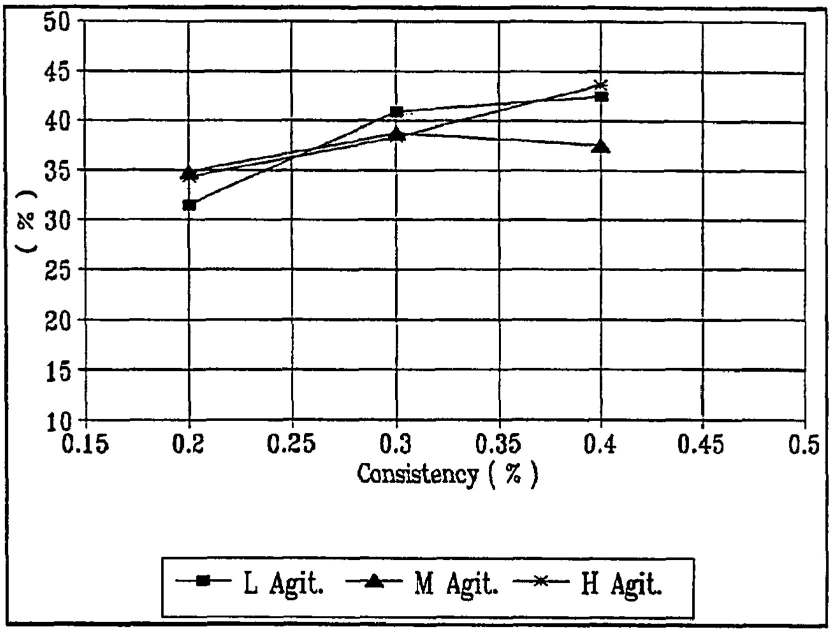

Figure 37. Percentage of Short Fiber in Floated Part: Coarse Bubbles.

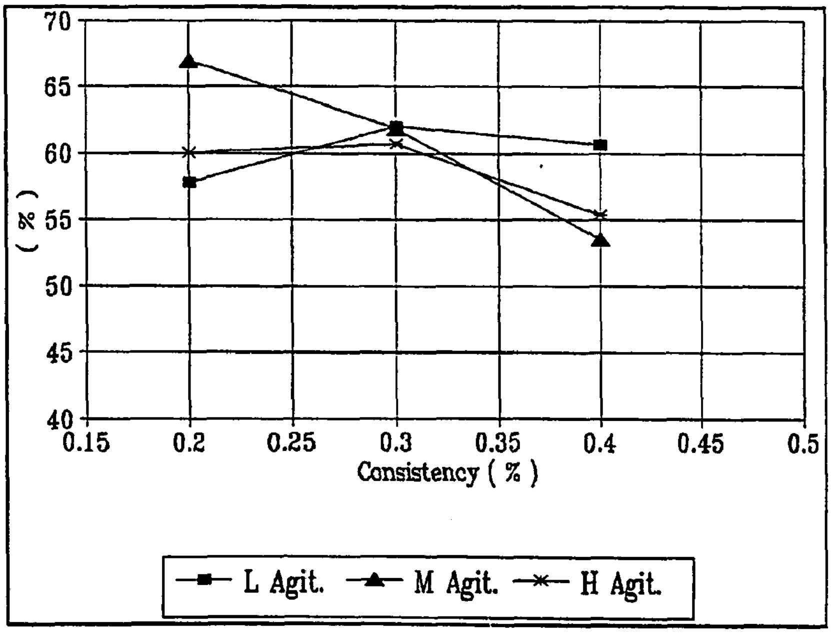

Figure 38. Percentage of Medium Fiber in Floated Part: Fine Bubbles.

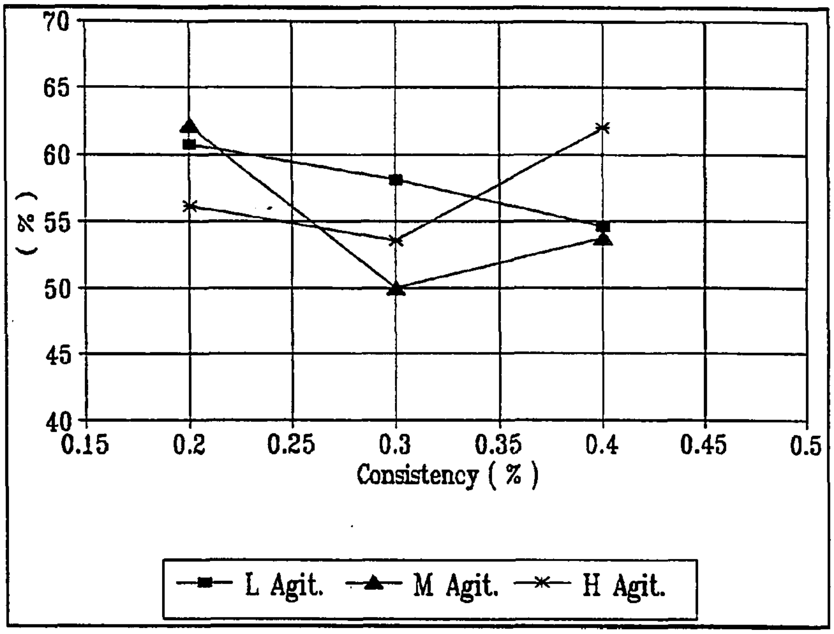

Figure 39. Percentage of Medium Fiber in Floated Part: Medium Bubbles.

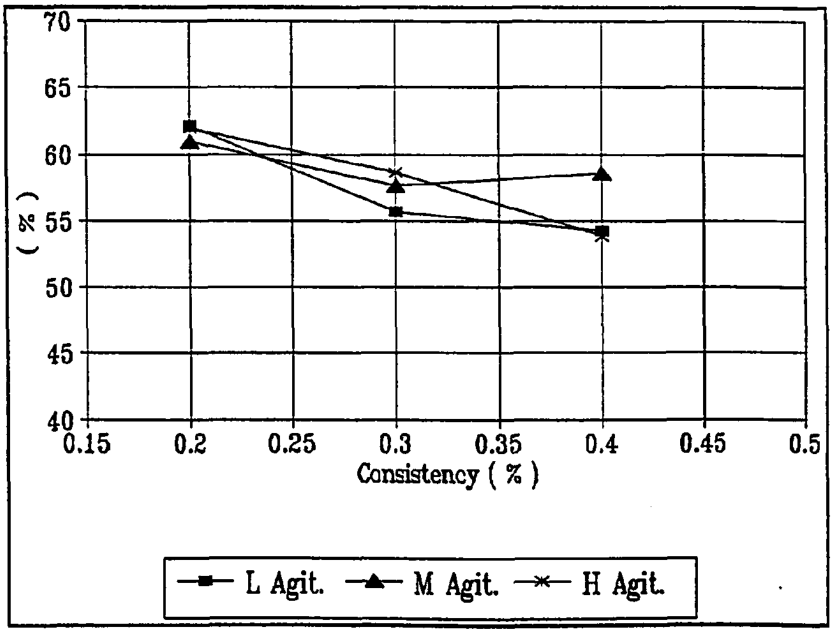

Figure 40. Percentage of Medium Fiber in Floated Part: Coarse Bubbles.

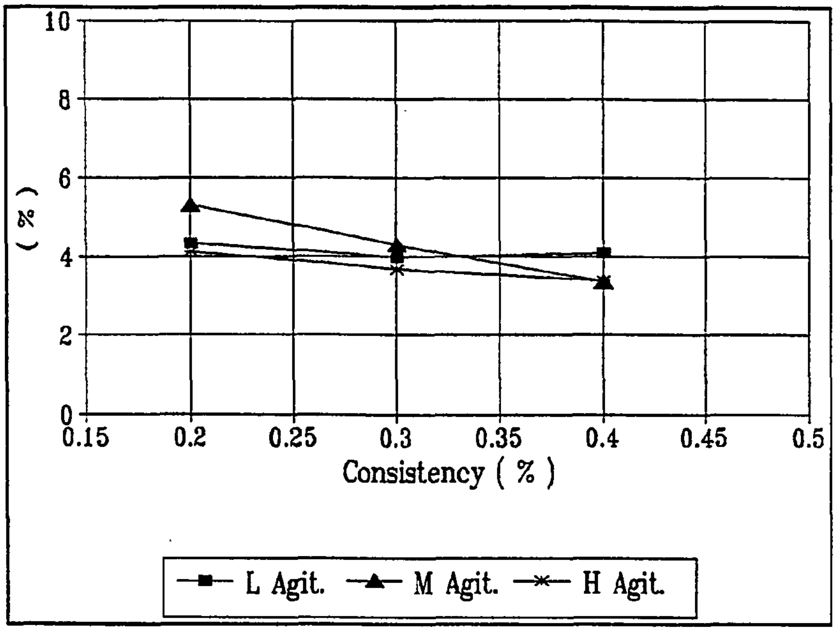

Figure 41. Percentage of Long Fiber in Floated Part: Fine Bubbles.

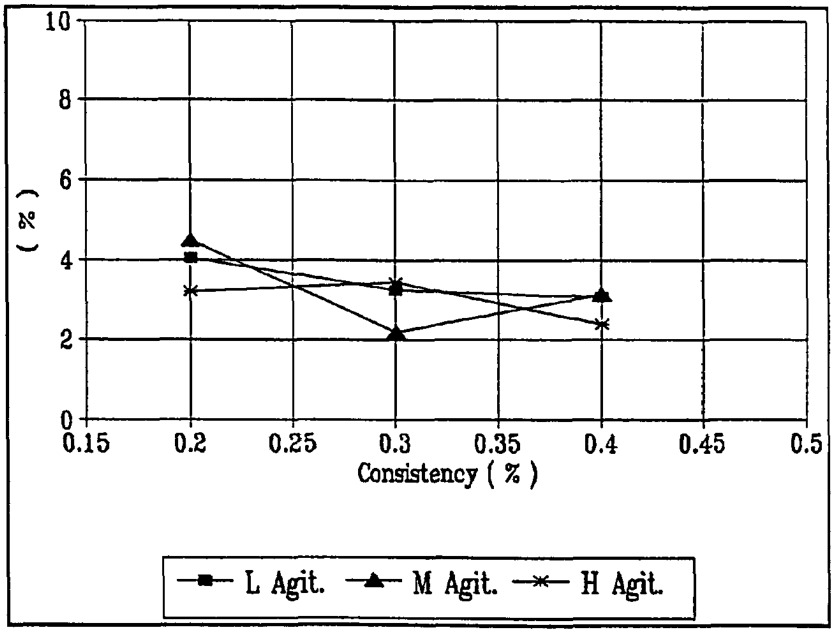

Figure 42. Percentage of Long Fiber in Floated Part: Medium Bubbles.

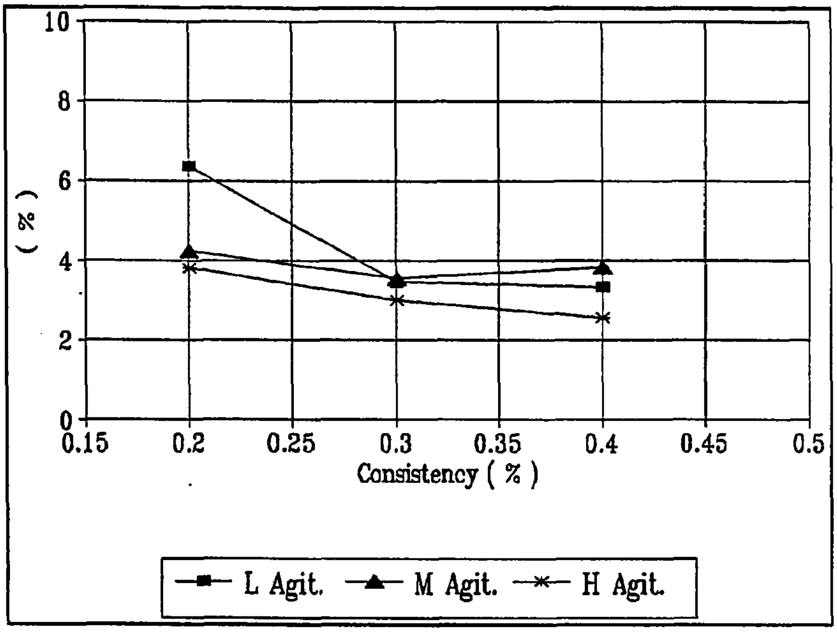

Figure 43. Percentage of Long Fiber in Floated Part: Coarse Bubbles.

Regression Models

Linear regression analysis was used to characterize the relationships between dependent variables and independent variables. In this study, dependent variables were flotation efficiency and fiber loss. Another dependent variable called "fractionation" was calculated according to equation (7).

$$\text{Fractionation (\%)} = \frac{L_f - L_o}{L_o} \times 100 \qquad (7)$$

where L_f = average fiber length of fiber in floated part

L_o = average fiber length of fiber in original pulp

Fractionation shows the percentage increase in average fiber length of fibers in the floated part over the original pulp. The results of this calculation are shown in Table 21.

Table 21

Summaries of Calculated Percent Increase in Average Fiber Length of Fiber in Floated Part

	Air Bubble Size								
	Fine			Medium			Coarse		
Agitation	Consistency L	M	H	Consistency L	M	H	Consistency L	M	H
L	20.34	20.34	18.64	20.34	11.86	6.78	33.90	10.17	8.47
M	33.90	22.03	10.17	23.73	10.17	6.78	20.34	13.56	15.25
H	15.25	16.95	8.47	11.86	10.17	1.69	18.64	11.86	3.39

Note : L,M,H denote low, medium and high level of consistency.

The independent variables are consistency, agitation and bubble size. The consistency used in regression analysis were 0.2, 0.3, and 0.4 %. For agitation, rpm. of the magnetic stirrer bar was used. Actual rpm. of the bar was measured at each level of consistency since increasing consistency reduced the speed of the bar at the same setting. At low consistency, the rpm's were 645, 1100, and

2030. At medium consistency, the rpm's were 550, 1010, and 1950. At high consistency, the rpm's were 450, 900, and 1900. For bubble size, average pore size of fritted glass from Fisher catalog, 4.75, 12.5, and 50 µm. were used. The SAS programs for stepwise regression were written and given together with the printout results, in Appendix F. The models for each dependent variable are shown in Table 22.

Table 22

The Regression Models for Flotation Efficiency, Fiber Loss and Fiber Fractionation

	Model	Prob>F	R^2
Flotation Efficiency			
number of particle	$78.230+0.004x_1-56.462x_3-0.491x_2x_3$	0.0001	0.76
area of ink	$84.861+0.005x_1-21.848x_3$	0.0001	0.47
Fiber Loss	$6.547-0.003x_1-0.022x_2+13.329x_3$	0.0001	0.78
Fractionation	$41.252-0.005x_1-69.857x_3$	0.0001	0.59

Note: x_1 = Agitation; x_2 = Bubble Size; x_3 = Consistency

Every model had rather low R^2 which means poor correlation between independent variables and dependent variables. This may be because the linear model was not proper or other independent variables must be included. However, the F statistic for the overall model for every model was significant, indicating that the models explain a significant portion of variation of the data.

CHAPTER VI

SUMMARY OF RESULTS

The results of these experiments show that consistency of pulp during flotation, agitation level and bubble size affected flotation efficiency and fiber loss.

Increasing consistency decreased the flotation efficiency. A possible mechanism is that collisions between air bubble and fiber are more frequent at higher consistency, thereby, ink particles might be loosened. The efficiency based on number of ink particles was more depen-dent on consistency than the efficiency base on area of ink. Fiber loss increased when consistency was increased. This is probably because more fiber was entrained the with foam.

Increasing agitation improved flotation efficiency. It is proposed that higher agitation increases the frequency of collisions between bubbles and ink particles and at the same time breaks down fiber networks, resulting in better flotation efficiency. Too high agitation decreased flotation efficiency. This may be because air bubbles collide with each other and become larger bubbles. Larger bubbles reduce the probability of collision of bubbles with ink particles. Increasing agitation decreased fiber loss. It is possible that fibers were knocked off from the air bubbles when agitation was increased.

Bubble size also affected flotation efficiency. When the bubble size was reduced, more bubbles were formed and the bubble surface area can favor attachment of more ink particles, resulting in better flotation efficiency. The results showed that consistency and agitation affected the efficiency more than bubble size. Bubble size showed the least effect on fiber loss compared to consistency and agitation. However, fiber loss tended to decrease when bubble size decreased.

The floated part was analyzed for fiber length. The results showed that fractionation occurred during the flotation process. Average fiber length was longer in the floated part than the original pulp. Consistency affected the percentage of short, medium, and long fiber in the floated part. The percentage of short fibers increased while the percentage of medium and long fibers decreased as consistency increased. A possible mechanism is that medium and long fibers are more easily trapped in fiber networks than the short fibers. Increasing consistency affected the percentage of short and long fibers more than medium fibers. Agitation and bubble size did not show clear effects on the fractionation.

Linear regression analysis was applied to the data to find models for flotation efficiency, fiber loss and fractionation. The resulting models gave low correlation coefficients. This may be because of improper model or more variables are required in the models. However, the F statistic for every model was significant, indicating that the models explain a significant portion of variation of the data.

CHAPTER VI

CONCLUSIONS

1. Increasing consistency decreased flotation efficiency but increased fiber loss.

2. Increasing agitation resulted in increased flotation efficiency and decreased fiber loss.

3. Bubble size showed smaller effects on flotation efficiency and fiber loss than consistency and agitation. However, increasing bubble size tended to decrease flotation efficiency and fiber loss.

4. Fractionation occurred in the flotation process. The average fiber length of fiber in the floated part was longer than in the original pulp.

5. The percentage of short fiber in the floated part increased but the percentage of medium and long fibers in floated part decreased when consistency was increased.

6. Increasing consistency affected the percentage of short and long fibers in the floated part more than medium fibers.

CHAPTER VII

SUGGESTIONS FOR FURTHER STUDY

1. Other variables such as surfactant type and concentration, and air flow rate should be investigated.

2. The results showed that flotation efficiency based on area of ink was higher than efficiency based on number of particles. A further study of particles size distribution vs. time should be performed so that the kinetics of the process could be explained.

3. To control fiber loss, a study of fiber fractionation in the flotation process should be undertaken.

4. Surface properties of ink particles and fibers in the system such as zeta potential, hydrophobicity, etc., should be investigated. The results might be helpful for better understanding of the mechanisms of control of flotation efficiency and fiber loss.

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APPENDICES

Appendix A

Image Analysis System

The image analysis system used in this project is OMNICON 3600. The system consists of

1. Scanner: The IS-3 Precision Image Scanner is a camera which transforms optical images precisely into video signal suitable to image analysis.

2. Instrument: The instrument cabinet contains a compatible PC and some special electronics. The PC contains the software which controls the instrument. The special electronics handle functions such as thresholding and frame control, and processes the image for taking the measurement.

3. Monitors: Two television monitors provide information about what the Omnicon 3600 is doing. One monitor displays the image from the scanner. The other monitor displays the menu which is used to control instrument, display messages and question from the system, and lists the result of the measurement.

4. Alpha-numeric Keyboard: This keyboard is used to make menu selection and enter information about the measurement.

5. Image Keyboard: This keyboard has several keys dedicated to image analysis functions.

The image displayed on the monitor screen is divided into an array picture(pixels). The light intensity of each pixel is determined and given a numerical value called gray level. Thus by selecting a specific gray level threshold, each pixel can either be classified as an object(i.e. ink particle) and counted or as background and ignored. Once the object part of the image is detected, the area and number of the object can be determined.

Seenivasan*(45)* used the image analysis system to determine flotation efficiency in his work . A technique for making sample and measuring by the image analyzer based on his technique was developed, described in Appendix C and E, and used in this study.

Appendix B

KAJAANI FS-100 Fiber Size Analyzer

The KAJAANI FS-100 fiber analyzer has been developed in cooperation with Central Research Laboratory of Finland for the need of pulp and paper industry. The instrument is for measuring the size of fiber. It consist of a capillary tube through which the flow of fibers to be measured in solution. At one side of the capillary tube there is a light and at the other side there is a photo cell. This provides information from which the size of the fibers can be determined.

The measuring procedure is shown in Figure 44. The fibers are sucked downward through the capillary tube . An image having the same shape as fiber is obtained on the diode matrix with the aid of the light and lenses. The photocell consists of a diode matrix. The diodes calculate the size of the fibers from the image which is casted by the passing fiber. The passing fiber covers a specific part of the diodes and this provides numerical information which can serve as the basis for calculation the size of the fibers.

When the bottom part of the projected fiber comes to the lowest diode on the diode matrix, the image covers some of diodes reading upward. This enable the fiber size to be recognized immediately.

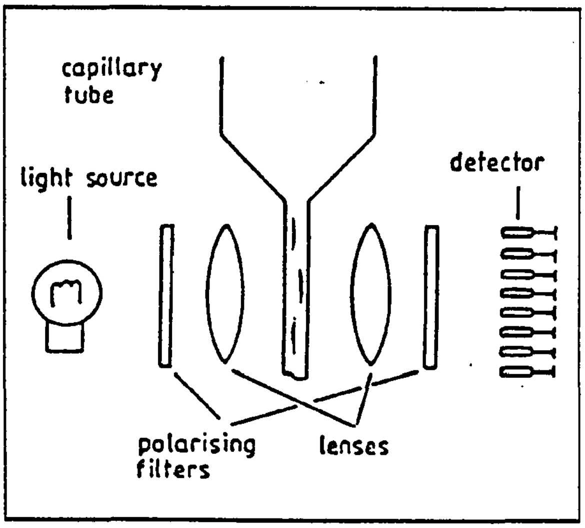

Figure 44. Measuring Procedure.

Appendix C

Monolayer Preparation

The monolayer Millipore samples were prepared with a procedure similar to that of Peel and Nanda*(46)*. The samples of floated and non-floated part which were diluted with deionized water were filtered through Millipore membrane with pore size of 0.65 µm.. The Millipore membrane was held under vacuum after wetting in the filter holder to avoid the formation of air bubbles in between the membrane and the disc. The vacuum was adjusted so that no impression of the disc was formed on the membrane filter and also avoided swirling of contents under filtration. The sample was poured without any splashing outside the holder and a monolayer filter was made without any significant overlapping of the ink particles. As soon as the filtration was completed, the filter was removed and dried at room temperature (25 °C) for 24 hours before it was analyzed by the image analyzer.

In order to make a sample pad represent its original, the following monolayer sample preparation procedures were performed.

Sampling Method

It was recommended *(47)* that mass of fiber plus ink be 1 mg. in order to deposit a mono-layer on the sample pad. In order to maintain the mass of fiber plus ink of not more than 1 mg., sampling was done as follows;

1. After flotation, floated and non-floated part were diluted with deionized water to match the original weight, i.e. 90 g.

2. 5 g. was sampled from each part and diluted with water to match the calculated total weight as shown Table 23.

3. After dilution, a 5 g. sample was added to 95 g. of water.

4. The 100 g. of mixture in c) was filtered through Millipore membrane.

Table 23

Calculated Total Weight for Dilution.

Consistency (%)	Total Weight (g.)
0.2	50
0.3	75
0.4	100

A syringe with 5 mm. opening at the tip was used for sampling to prevent fractionation. Samples were taken from the middle of the mixture while it was eing mixed by a magnetic stirrer.

The procedure was verified by balance checking for both area and number of ink particles. Table 24 shows eight balance checks for area and number of ink particles, respectively.

Table 24

The Balance Check for Area of Ink and Number of Ink Particles

Run No.	Original	Floated	Non-floated	Total	Error (%)
Number of Particle					
1	156	90	65	155	0.64
4	143	100	35	135	5.59
7	128	96	30	126	1.56
11	160	103	51	154	3.75
14	192	97	89	186	3.12
17	134	79	50	129	3.70
22	158	104	45	149	5.70
25	138	101	28	129	6.52
Area of Ink (μm^2)					
1	46146	33002	11196	44198	4.22
4	32817	26870	3618	30488	7.10
7	25345	21142	2645	23787	6.15
11	37868	28130	6442	34572	8.70
14	43557	30245	9797	40042	8.07
17	39087	31012	9275	40287	3.08
22	21052	17382	2828	20210	4.00
25	31252	27209	2325	29534	5.50

Note :Figures in the table are average values from three determinations. The error was calculated from the difference between original and total divided by original.

The balance check for both number of ink particles and area of ink gave satisfactory results of less than 10 % error for all eight determinations.

Appendix D

Material Balance

For a particular experiment, flotation started with 90 g. of mixture (water+fiber+ink). After flotation, the mixture was separated into floated and non-floated parts by the process. To make a sample pad for the image analyzer, only a small amount of mixture was required, thus, sampling was necessary. Before sampling, the floated and non-floated part were added with deionized water to match the starting weight, i.e. 90 g. Then the same weight of mixture was sampled from each part. By this procedure, the material was balanced automatically. Table 25 shows an example of calculation for the material balance. Basis for the calculation are:

1. Specific gravity of ink and fiber are 1.00 and 1.30 respectively.
2. Consistency of the original pulp is 0.4 %.
3. Weight of ink in the original pulp is 1.78 % of total dry weight.
4. Solid weight loss is 10 %.
5. Ink removal efficiency is 85 %.

The calculation shows that material balance was correct when the sample weight of each part, i.e. original, floated and non-floated, was the same.

Table 25

Example of Calculation for Material Balance.

		Weight		
	Total (g)	Water (g)	Fiber (mg)	Ink (mg)
Original	90	89.64	353.592	6.4080
Non-floated	87	86.676	323.039	0.9612
Floated	3	2.964	30.553	5.4470
Add Water				
Original (+ 0 g. Water)	90	89.64	353.592	0.036
		(0.996)	(3.93E-3)	(7.12E-5)
Non-floated(+ 3 g. Water)	90	89.676	323.039	0.014
		(0.9964)	(3.59E-3)	(1.07E-5)
Floated (+87 g. Water)	90	89.964	30.553	0.022
		(0.9996)	(3.39E-4)	(6.05E-5)
Sampling 5 g.				
Original	5	4.980	19.6440	0.3560
Non-floated	5	4.982	17.9465	0.0534
Floated	5	4.998	1.6974	0.3026

Note : The figures in parentheses are weight fraction of total weight.

Appendix E

Measuring With Image Analyzer

Mono-layer samples were analyzed by the image analyzer for area and number of ink particle. The image analyzer measures area and number of ink particle within a small area, 5.399 x 10^6 μm^2, called "field". Each sample was measured for 50 fields. Table 26 is an example of a printout from the system.

Table 26

Printout from the Image Analyzer.

Analysis Results

1)	Number of Particles Detected	53
2)	Total Area of Particles (μm^2)	1.4428E+ 4
3)	Total Field Areas (μm^2)	2.6995E+ 7
4)	Percentage Area	0.05
5)	Minimum Area Detectable (μm^2)	2.85
6)	Maximum Area Detected (μm^2)	6595.10
7)	Mean Area (μm^2)	272.23
8)	Standard Deviation	924.04
9)	Parts per Million ($\mu m^2/mm^2$)	534.47

The values of 1) and 2) were used for calculating flotation efficiency by area and by number of ink particle respective.

To find a suitable moving pattern of the microscope, four moving patterns were performed (Figure 45.). Pattern 1 gave lowest standard deviation of measurement. Thus, pattern 1 was used for measuring every sample. Table 27 shows the results from measuring three samples with five repetitions on each sample using pattern 1.

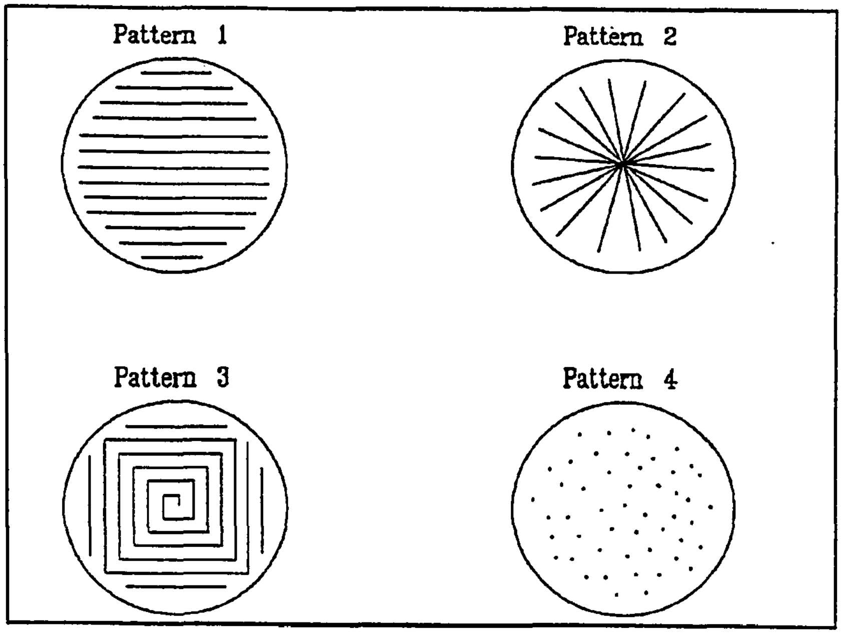

Figure 45. Moving Patterns of the Microscope.

Table 27

The Results of Measuring Three Samples with Five Repetitions

Sample	Number of Particle	Average (std.)	Area of Ink (μm^2)	Average (std.)
1	168 163 170 167 165	167 (2.702)	63591 66036 64158 67025 68791	65920 (2122)
2	163 160 165 165 166	164 (2.387)	69104 68295 69751 64651 64949	67350 (2387)
3	173 170 167 168 175	171 (3.362)	66271 59259 64451 61505 66559	63609 (3156)
Average (std.)		167 (3.512)	Average (std.)	65626 (1888)

The standard deviations within samples and between samples gave coefficient of variation below 5%.

Appendix F

SAS Program and Selected Printouts

Table 28

SAS Program to Generate ANOVA Table and Means Comparison for Flotation Efficiency by Number of Particles

```
OPTION LS=80 PS=66 NODATE;
DATA PAR;
INPUT EFF AGIT BUB CONS @@;
CARDS;
67.18 1 1 1 66.67 1 1 1 66.52 1 1 1
62.09 1 1 2 63.29 1 1 2 64.29 1 1 2
58.35 1 1 3 58.37 1 1 3 57.85 1 1 3
65.01 1 2 1 65.42 1 2 1 65.00 1 2 1
61.73 1 2 2 61.48 1 2 2 60.62 1 2 2
57.79 1 2 3 56.80 1 2 3 57.84 1 2 3
62.36 1 3 1 63.05 1 3 1 62.38 1 3 1
59.63 1 3 2 61.38 1 3 2 60.05 1 3 2
52.96 1 3 3 51.91 1 3 3 51.78 1 3 3
79.12 2 1 1 78.44 2 1 1 77.58 2 1 1
74.94 2 1 2 74.70 2 1 2 73.15 2 1 2
67.33 2 1 3 65.85 2 1 3 66.27 2 1 3
76.69 2 2 1 77.87 2 2 1 77.90 2 2 1
69.95 2 2 2 70.77 2 2 2 70.97 2 2 2
60.49 2 2 3 61.75 2 2 3 60.35 2 2 3
70.19 2 3 1 70.07 2 3 1 71.39 2 3 1
65.59 2 3 2 65.85 2 3 2 66.67 2 3 2
56.79 2 3 3 55.26 2 3 3 54.17 2 3 3
76.55 3 1 1 75.72 3 1 1 75.93 3 1 1
73.22 3 1 2 75.55 3 1 2 75.25 3 1 2
65.80 3 1 3 65.21 3 1 3 64.82 3 1 3
72.59 3 2 1 71.61 3 2 1 72.82 3 2 1
70.03 3 2 2 69.17 3 2 2 68.49 3 2 2
61.41 3 2 3 61.14 3 2 3 62.04 3 2 3
68.86 3 3 1 69.84 3 3 1 70.18 3 3 1
64.20 3 3 2 65.77 3 3 2 65.66 3 3 2
53.99 3 3 3 54.00 3 3 3 53.74 3 3 3
;
PROC GLM;
CLASS AGIT BUB CONS;
MODEL EFF = AGIT BUB CONS AGIT*BUB AGIT*CONS BUB*CONS
            AGIT*BUB*CONS;
LSMEANS     AGIT BUB CONS AGIT*BUB AGIT*CONS BUB*CONS
            AGIT*BUB*CONS/TDIFF;
```

Table 29

SAS Program to Generate ANOVA Table and Means Comparison for Flotation Efficiency by Area of Ink

```
OPTION LS=80 PS=66 NODATE;
DATA AREA;
INPUT EFF AGIT BUB CONS @@;
CARDS;
81.41 1 1 1 81.66 1 1 1 81.02 1 1 1
79.79 1 1 2 79.37 1 1 2 78.80 1 1 2
73.95 1 1 3 74.50 1 1 3 75.61 1 1 3
79.56 1 2 1 78.85 1 2 1 80.36 1 2 1
76.79 1 2 2 76.99 1 2 2 77.15 1 2 2
73.20 1 2 3 74.69 1 2 3 73.29 1 2 3
81.31 1 3 1 79.21 1 3 1 80.47 1 3 1
76.95 1 3 2 77.23 1 3 2 76.39 1 3 2
75.50 1 3 3 75.73 1 3 3 75.36 1 3 3
92.40 2 1 1 92.18 2 1 1 91.78 2 1 1
87.53 2 1 2 88.74 2 1 2 88.10 2 1 2
84.43 2 1 3 85.48 2 1 3 85.02 2 1 3
90.99 2 2 1 91.35 2 2 1 91.27 2 2 1
88.83 2 2 2 87.92 2 2 2 88.61 2 2 2
84.21 2 2 3 83.55 2 2 3 83.60 2 2 3
89.71 2 3 1 88.72 2 3 1 89.40 2 3 1
87.16 2 3 2 86.87 2 3 2 87.60 2 3 2
84.42 2 3 3 85.88 2 3 3 84.71 2 3 3
88.89 3 1 1 89.01 3 1 1 88.72 3 1 1
86.85 3 1 2 87.12 3 1 2 88.11 3 1 2
85.32 3 1 3 87.28 3 1 3 86.89 3 1 3
87.85 3 2 1 88.22 3 2 1 87.87 3 2 1
85.00 3 2 2 85.52 3 2 2 85.71 3 2 2
83.19 3 2 3 84.20 3 2 3 83.08 3 2 3
86.78 3 3 1 85.31 3 3 1 85.93 3 3 1
85.02 3 3 2 84.88 3 3 2 83.97 3 3 2
82.66 3 3 3 81.46 3 3 3 83.08 3 3 3
;
PROC GLM;
CLASS AGIT BUB CONS;
MODEL EFF = AGIT BUB CONS AGIT*BUB AGIT*CONS BUB*CONS
            AGIT*BUB*CONS;
LSMEANS AGIT BUB CONS AGIT*BUB AGIT*CONS BUB*CONS
            AGIT*BUB*CONS/TDIFF;
```

Table 30

SAS Program to Generate ANOVA Table and Means Comparison for Fiber Loss

```
OPTION LS=80 PS=66 NODATE;
DATA LOSS;
INPUT LOSS AGIT BUB CONS @@;CARDS;
9.51 1 1 1 9.59 1 1 1 10.13 1 1 1
4.38 1 1 2 3.83 1 1 2 4.03 1 1 2
4.20 1 1 3 3.55 1 1 3 3.70 1 1 3
7.31 1 2 1 7.75 1 2 1 6.94 1 2 1
4.05 1 2 2 4.41 1 2 2 3.70 1 2 2
4.05 1 2 3 3.74 1 2 3 3.58 1 2 3
6.58 1 3 1 6.09 1 3 1 5.74 1 3 1
4.23 1 3 2 3.95 1 3 2 4.78 1 3 2
4.08 1 3 3 3.60 1 3 3 3.99 1 3 3
5.68 2 1 1 4.97 2 1 1 5.20 2 1 1
8.25 2 1 2 7.16 2 1 2 8.00 2 1 2
9.92 2 1 3 9.70 2 1 3 9.12 2 1 3
4.23 2 2 1 4.81 2 2 1 4.39 2 2 1
7.57 2 2 2 7.45 2 2 2 7.39 2 2 2
8.69 2 2 3 9.19 2 2 3 8.94 2 2 3
5.17 2 3 1 4.44 2 3 1 4.68 2 3 1
6.76 2 3 2 7.29 2 3 2 7.10 2 3 2
9.09 2 3 3 8.89 2 3 3 8.33 2 3 3
3.75 3 1 1 4.03 3 1 1 3.34 3 1 1
5.85 3 1 2 6.02 3 1 2 5.24 3 1 2
5.96 3 1 3 6.88 3 1 3 6.22 3 1 3
3.51 3 2 1 4.02 3 2 1 3.70 3 2 1
6.20 3 2 2 5.47 3 2 2 5.89 3 2 2
6.82 3 2 3 6.29 3 2 3 6.67 3 2 3
3.17 3 3 1 3.39 3 3 1 2.74 3 3 1
5.62 3 3 2 4.87 3 3 2 5.07 3 3 2
5.76 3 3 3 5.39 3 3 3 4.96 3 3 3
;
PROC GLM;
CLASS AGIT BUB CONS;
MODEL LOSS = AGIT BUB CONS AGIT*BUB AGIT*CONS BUB*CONS
             AGIT*BUB*CONS;
LSMEANS      AGIT BUB CONS AGIT*BUB AGIT*CONS BUB*CONS
             AGIT*BUB*CONS/TDIFF;
```

Table 31

SAS Program for Linear Regression of Flotation Efficiency by Number of Particles

```
OPTION LS=80 PS=66 NODATE;
DATA PAR;
INPUT EFF AGIT BUB CONS @@;
W = AGIT*BUB;
X = AGIT*CONS;
Y = BUB*CONS;
Z = AGIT*BUB*CONS;
CARDS;
67.18 645 4.75 0.2 66.67 645 4.75 0.2 66.52 645 4.75 0.2
62.09 550 4.75 0.3 63.29 550 4.75 0.3 64.29 550 4.75 0.3
58.35 450 4.75 0.4 58.37 450 4.75 0.4 57.85 450 4.75 0.4
65.01 645 12.5 0.2 65.42 645 12.5 0.2 65.00 645 12.5 0.2
61.73 550 12.5 0.3 61.48 550 12.5 0.3 60.62 550 12.5 0.3
57.79 450 12.5 0.4 56.80 450 12.5 0.4 57.84 450 12.5 0.4
62.36 645 50.0 0.2 63.05 645 50.0 0.2 62.38 645 50.0 0.2
59.63 550 50.0 0.3 61.38 550 50.0 0.3 60.05 550 50.0 0.3
52.96 450 50.0 0.4 51.91 450 50.0 0.4 51.78 450 50.0 0.4
79.12 1100 4.75 0.2 78.44 1100 4.75 0.2 77.58 1100 4.75 0.2
74.94 1010 4.75 0.3 74.70 1010 4.75 0.3 73.15 1010 4.75 0.3
67.33 900 4.75 0.4 65.85 900 4.75 0.4 66.27 900 4.75 0.4
76.69 1100 12.5 0.2 77.87 1100 12.5 0.2 77.90 1100 12.5 0.2
69.95 1010 12.5 0.3 70.77 1010 12.5 0.3 70.97 1010 12.5 0.3
60.49 900 12.5 0.4 61.75 900 12.5 0.4 60.35 900 12.5 0.4
70.19 1100 50.0 0.2 70.07 1100 50.0 0.2 71.39 1100 50.0 0.2
65.59 1010 50.0 0.3 65.85 1010 50.0 0.3 66.67 1010 50.0 0.3
56.79 900 50.0 0.4 55.26 900 50.0 0.4 54.17 900 50.0 0.4
76.55 2030 4.75 0.2 75.72 2030 4.75 0.2 75.93 2030 4.75 0.2
73.22 1950 4.75 0.3 75.55 1950 4.75 0.3 75.25 1950 4.75 0.3
65.80 1900 4.75 0.4 65.21 1900 4.75 0.4 64.82 1900 4.75 0.4
72.59 2030 12.5 0.2 71.61 2030 12.5 0.2 72.82 2030 12.5 0.2
70.03 1950 12.5 0.3 69.17 1950 12.5 0.3 68.49 1950 12.5 0.3
61.41 1900 12.5 0.4 61.14 1900 12.5 0.4 62.04 1900 12.5 0.4
68.86 2030 50.0 0.2 69.84 2030 50.0 0.2 70.18 2030 50.0 0.2
64.20 1950 50.0 0.3 65.77 1950 50.0 0.3 65.66 1950 50.0 0.3
53.99 1900 50.0 0.4 54.00 1900 50.0 0.4 53.74 1900 50.0 0.4
;
PROC REG;
VAR W X Y Z;
MODEL EFF = AGIT BUB CONS  W X Y Z / SELECTION = STEPWISE
SLE=0.05 SLS=0.05;
```

Table 32

Output from Linear Regression of Flotation Efficiency by Number of Particles

```
                          The SAS System
   Stepwise Procedure for Dependent Variable EFF
Step 1   Variable CONS Entered       R-square =  0.48
                                     C(p)     = 91.05

              DF   Sum of Squares  Mean Square     F   Prob>F

Regression     1          1930.94      1930.94 72.20   0.0001
Error         79           2112.67       26.74
Total         80           4043.61

             Parameter  Standard  Type II Sum
Variable      Estimate     Error   of Square         F  Prob>F
INTERCEP        83.687      2.19    39122.71 1462.93  0.0001
CONS           -59.798      7.04     1930.94   72.20  0.0001
Bounds on condition number:              1,1
---------------------------------------------------------------
Step 2   Variable Y Entered        R-square =  0.66
                                   C(p)     = 34.47

              DF   Sum of Squares  Mean Square       F Prob>F
Regression     2          2667.38      1333.69   75.59 0.0001
Error         78          1376.23        17.64
Total         80          4043.61

             Parameter    Standard Type II Sum
Variable      Estimate       Error of Squares        F Prob>F
INTERCEP        83.687        1.78   39122.71 2217.34 0.0001
CONS           -48.796        5.96    1180.93   66.93 0.0001
Y              - 0.491        0.08     736.44   41.74 0.0001

Bounds on condition number:              1.09,4.35
```

Table 32--Continued

```
Step 3   Variable AGIT Entered       R-square = 0.76
                                     C(p)     = 4.12

             DF   Sum of Squares  Mean Square     F   Prob>F

Regression   3          3074.02       1024.67 81.37   0.0001
Error        77          969.59         12.59
Total        80         4043.61

           Parameter     Standard  Type II Sum
Variable   Estimate         Error  of Squares          F Prob>F
INTERCEP     78.230          1.78     24264.19 1926.93 0.0001
AGIT          0.004          0.00       406.63   32.29 0.0001
CONS        -45.464          5.07      1011.49   80.33 0.0001
Y           - 0.491          0.06       736.44   58.48 0.0001
Bounds on condition number:       1.01, 9.09
-----------------------------------------------------------------
All variables left in the model are significant at the 0.05
level. No other variable met the 0.05 significance level
for entry into the model.

          Summary  of  Stepwise  Procedure  for  Dependent
Variable EFF

       Variable Number  Partial  Model
Step   Entered      In     R**2   R**2    C(p)       F Prob>F
       Removed
   1   CONS          1     0.48   0.48   91.05 72.21 0.0001
   2   Y             2     0.18   0.66   34.47 41.74 0.0001
   3   AGIT          3     0.10   0.76    4.12 32.29 0.0001
```

Table 33

SAS Program for Linear Regression of Flotation Efficiency by Area of Ink

```
OPTION LS=80 PS=66 NODATE;
DATA AREA;
INPUT EFF AGIT BUB CONS @@;
W = AGIT*BUB;
X = AGIT*CONS;
Y = BUB*CONS;
Z = AGIT*BUB*CONS;
CARDS;
81.41 645 4.75 0.2 81.66 645 4.75 0.2 81.02 645 4.75 0.2
79.79 550 4.75 0.3 79.37 550 4.75 0.3 78.80 550 4.75 0.3
73.95 450 4.75 0.4 74.50 450 4.75 0.4 75.61 450 4.75 0.4
79.56 645 12.5 0.2 78.85 645 12.5 0.2 80.36 645 12.5 0.2
76.79 550 12.5 0.3 76.99 550 12.5 0.3 77.15 550 12.5 0.3
73.20 450 12.5 0.4 74.69 450 12.5 0.4 73.29 450 12.5 0.4
81.31 645 50.0 0.2 79.21 645 50.0 0.2 80.47 645 50.0 0.2
76.95 550 50.0 0.3 77.23 550 50.0 0.3 76.39 550 50.0 0.3
75.50 450 50.0 0.4 75.73 450 50.0 0.4 75.36 450 50.0 0.4
92.40 1100 4.75 0.2 92.18 1100 4.75 0.2 91.78 1100 4.75 0.2
87.53 1010 4.75 0.3 88.74 1010 4.75 0.3 88.10 1010 4.75 0.3
84.43 900 4.75 0.4 85.48 900 4.75 0.4 85.02 900 4.75 0.4
90.99 1100 12.5 0.2 91.35 1100 12.5 0.2 91.27 1100 12.5 0.2
88.83 1010 12.5 0.3 87.92 1010 12.5 0.3 88.61 1010 12.5 0.3
84.21 900 12.5 0.4 83.55 900 12.5 0.4 83.60 900 12.5 0.4
89.71 1100 50.0 0.2 88.72 1100 50.0 0.2 89.40 1100 50.0 0.2
87.16 1010 50.0 0.3 86.87 1010 50.0 0.3 87.60 1010 50.0 0.3
84.42 900 50.0 0.4 85.88 900 50.0 0.4 84.71 900 50.0 0.4
88.89 2030 4.75 0.2 89.01 2030 4.75 0.2 88.72 2030 4.75 0.2
86.85 1950 4.75 0.3 87.12 1950 4.75 0.3 88.11 1950 4.75 0.3
85.32 1900 4.75 0.4 87.28 1900 4.75 0.4 86.89 1900 4.75 0.4
87.85 2030 12.5 0.2 88.22 2030 12.5 0.2 87.87 2030 12.5 0.2
85.00 1950 12.5 0.3 85.52 1950 12.5 0.3 85.71 1950 12.5 0.3
83.19 1900 12.5 0.4 84.20 1900 12.5 0.4 83.08 1900 12.5 0.4
86.78 2030 50.0 0.2 85.31 2030 50.0 0.2 85.93 2030 50.0 0.2
85.02 1950 50.0 0.3 84.88 1950 50.0 0.3 83.97 1950 50.0 0.3
82.66 1900 50.0 0.4 81.46 1900 50.0 0.4 83.08 1900 50.0 0.4
;
PROC REG;
VAR W X Y Z;
MODEL EFF = AGIT BUB CONS W X Y Z / SELECTION=STEPWISE
SLE=0.05 SLS=0.05;
```

Table 34

Output from Linear Regression of Flotation Efficiency by Area of Ink

```
                     The SAS System
      Stepwise Procedure for Dependent Variable EFF
Step 1   Variable AGIT Entered       R-square =  0.34
                                     C(p)     = 18.22

            DF   Sum of Squares  Mean Square     F    Prob>F
Regression   1          714.58       714.58 41.47    0.0001
Error       79         1361.13        17.23
Total       80         2075.71

          Parameter     Standard  Type II Sum
Variable   Estimate       Error  of Squares         F Prob>F
INTERCEP    77.882        1.02    100286.91 5820.66 0.0001
AGIT         0.005        0.00       714.58   41.47 0.0001

Bounds on condition number:              1,1
---------------------------------------------------------
Step 2   Variable CONS Entered       R-square = 0.47
                                         C(p) = 2.44

            DF   Sum of Squares  Mean Square     F    Prob>F
Regression   2          968.60       484.30 34.12    0.0001
Error       78         1107.11        14.20
Total       80         2075.71

           Parameter    Standard  Type II Sum
Variable    Estimate      Error  of Squares         F Prob>F
INTERCEP     84.861       1.89     28551.72 2011.58 0.0001
AGIT          0.005       0.00       605.94   42.69 0.0001
CONS        -21.848       5.16       254.02   17.90 0.0001

Bounds on condition number:     1.01,4.06
---------------------------------------------------------
```

Table 34--Continued

```
All variables left in the model are significant at the 0.05
level. No other variable met the 0.05 significance level
for entry into the model.

              Summary  of  Stepwise  Procedure  for  Dependent
Variable EFF
        Variable  Number Partial  Model
Step    Entered      In     R**2   R**2   C(p)        F  Prob>F
        Removed
   1    AGIT          1     0.34   0.34  20.19   41.47  0.0001
   2    CONS          2     0.12   0.47   4.05   17.90  0.0001
```

Table 35

SAS Program for Linear Regression of Fiber Loss

```
OPTION LS=80 PS=66 NODATE;
DATA LOSS;
INPUT LOSS AGIT BUB CONS @@;
W = AGIT*BUB;
X = AGIT*CONS;
Y = BUB*CONS;
Z = AGIT*BUB*CONS;
CARDS;
9.51 645 4.75 0.2 9.59 645 4.75 0.2 10.13 645 4.75 0.2
7.31 645 12.5 0.2 7.25 645 12.5 0.2 6.94 645 12.5 0.2
6.58 645 50.0 0.2 6.09 645 50.0 0.2 5.74 645 50.0 0.2
5.86 1100 4.75 0.2 4.97 1100 4.75 0.2 5.20 1100 4.75 0.2
8.25 1010 4.75 0.3 7.16 1010 4.75 0.3 8.00 1010 4.75 0.3
9.92 900 4.75 0.4 9.70 900 4.75 0.4 9.12 900 4.75 0.4
4.23 1100 12.5 0.2 4.81 1100 12.5 0.2 4.39 1100 12.5 0.2
7.57 1010 12.5 0.3 7.45 1010 12.5 0.3 7.39 1010 12.5 0.3
8.69 900 12.5 0.4 9.19 900 12.5 0.4 8.94 900 12.5 0.4
5.17 1100 50.0 0.2 4.44 1100 50.0 0.2 4.68 1100 50.0 0.2
6.76 1010 50.0 0.3 7.29 1010 50.0 0.3 7.10 1010 50.0 0.3
9.09 900 50.0 0.4 8.89 900 50.0 0.4 8.33 900 50.0 0.4
3.75 2030 4.75 0.2 4.03 2030 4.75 0.2 3.34 2030 4.75 0.2
5.85 1950 4.75 0.3 6.02 1950 4.75 0.3 5.24 1950 4.75 0.3
5.96 1900 4.75 0.4 6.88 1900 4.75 0.4 6.22 1900 4.75 0.4
3.51 2030 12.5 0.2 4.02 2030 12.5 0.2 3.70 2030 12.5 0.2
6.20 1950 12.5 0.3 5.47 1950 12.5 0.3 5.89 1950 12.5 0.3
6.82 1900 12.5 0.4 6.29 1900 12.5 0.4 6.67 1900 12.5 0.4
3.17 2030 50.0 0.2 3.39 2030 50.0 0.2 2.74 2030 50.0 0.2
5.62 1950 50.0 0.3 4.87 1950 50.0 0.3 5.07 1950 50.0 0.3
5.76 1900 50.0 0.4 5.39 1900 50.0 0.4 4.96 1900 50.0 0.4
;
PROC REG;
VAR W X Y Z;
MODEL LOSS = AGIT BUB CONS W X Y Z / SELECTION=STEPWISE
SLE=0.05 SLS=0.05;
```

Table 36

Output from Linear Regression of Fiber Loss

```
                          The SAS System
        Stepwise Procedure for Dependent Variable LOSS
Step 1   Variable AGIT Entered       R-square =   0.44
                                     C(p)     = 139.03

              DF     Sum of Squares  Mean Square       F Prob>F
Regression    1              98.95         98.95   47.52 0.0001
Error         61            127.01          2.08
Total         62            225.96

            Parameter    Standard    Type II Sum
Variable    Estimate       Error    of Squares          F Prob>F
INTERCEP       9.517        0.50         761.97 365.95 0.0001
AGIT          -0.002        0.00          98.94  47.52 0.0001
Bounds on condition number:               1, 1
---------------------------------------------------------------
Step 2   Variable CONS Entered       R-square =  0.78
                                     C(p)     = 21.80

              DF     Sum of Squares  Mean Square       F Prob>F
Regression    2             175.41         87.71  104.12 0.0001
Error         60             50.54          0.84
Total         62            225.96

            Parameter    Standard    Type II Sum
Variable    Estimate       Error    of Squares          F Prob>F
INTERCEP       6.060        0.48         133.46 158.44 0.0001
AGIT          -0.002        0.00         120.03 142.49 0.0001
CONS          13.329        1.40          76.47  90.78 0.0001
Bounds on condition number:     1.02, 4.06
---------------------------------------------------------------
```

Table 36--Continued

```
Step 3   Variable BUB Entered        R-square = 0.83
                                     C(p)     = 5.73

              DF   Sum of Squares  Mean Square       F Prob>F
Regression     3           187.01        62.33   94.42 0.0001
Error         59            38.95         0.66
Total         62           225.96

           Parameter   Standard    Type II Sum
Variable    Estimate      Error   of Squares         F Prob>F
INTERCEP       6.547       0.44        144.99   219.61 0.0001
AGIT          -0.002       0.00        120.03   181.81 0.0001
BUB           -0.022       0.00         11.59    17.55 0.0001
CONS          13.329       1.24         76.47   115.83 0.0001
Bounds on condition number:       1.02, 9.09
---------------------------------------------------------
All variables left in the model are significant at the 0.05
level. No other variable met the 0.05 significance level
for entry into the model.

  Summary of Stepwise Procedure for Dependent Variable LOSS

     Variable Number Partial  Model
Step Entered      In    R**2   R**2     C(p)        F Prob>F
     Removed
   1 AGIT          1    0.44   0.44   139.03    47.62 0.0001
   2 CONS          2    0.34   0.78    21.80    90.78 0.0001
   3 BUB           3    0.05   0.83     5.73    17.55 0.0001
```

Table 37

SAS Program for Linear Regression of Fiber Fractionation

```
OPTION LS=80 PS=66 NODATE;
DATA LENGTH;
INPUT LEN AGIT BUB CONS @@;
W = AGIT*BUB;
X = AGIT*CONS;
Y = BUB*CONS;
Z = AGIT*BUB*CONS;
CARDS;
20.339 645 4.75 0.2 20.339 550 4.75 0.3 18.664 450 4.75 0.4
20.339 645 12.5 0.2 11.864 550 12.5 0.3 6.7797 450 12.5 0.4
33.898 645 50.0 0.2 10.169 550 50.0 0.3 8.4756 450 50.0 0.4
33.898 1100 4.75 0.2 22.034 1010 4.75 0.3 10.169 900 4.75
0.4
23.729 1100 12.5 0.2 10.169 1010 12.5 0.3 6.7797 900 12.5
0.4
20.339 1100 50.0 0.2 13.559 1010 50.0 0.3 15.254 900 50.0
0.4
15.254 2030 4.75 0.2 16.949 1950 4.75 0.3 8.4746 1900 4.75
0.4
11.864 2030 12.5 0.2 10.169 1950 12.5 0.3 1.6949 1900 12.5
0.4
18.644 2030 50.0 0.2 11.864 1950 50.0 0.3 3.3898 1900 50.0
0.4
;
PROC REG;
VAR W X Y Z;
MODEL LEN= AGIT BUB CONS W X Y Z / SELECTION=STEPWISE
SLE=0.05 SLS=0.05;
```

Table 38

Output of Linear Regression for Fiber Fractionation

```
                     The SAS System
   Stepwise Procedure for Dependent Variable LEN
Step 1   Variable CONS Entered       R-square = 0.48
                                     C(p)     = 2.45

            DF  Sum of Squares  Mean Square        F Prob>F
Regression   1          781.74       781.74    22.73 0.0001
Error       25          859.90        34.40
Total       26         1641.64

          Parameter   Standard Type II Sum
Variable   Estimate      Error  of Squares         F Prob>F
INTERCEP     34.774       4.30     2251.70     65.46 0.0001
CONS        -65.902      13.82      781.74     22.73 0.0001

Bounds on condition number:                1, 1
-----------------------------------------------------------
Step 2   Variable AGIT Entered       R-square = 0.59
                                     C(p)     = -1.20

            DF  Sum of Squares  Mean Square        F Prob>F
Regression   2          972.77       486.39    17.45 0.0001
Error       24          668.87        27.87
Total       26         1641.65

          Parameter   Standard   Type II Sum
Variable  .Estimate      Error   of Squares        F Prob>F
INTERCEP     41.252       4.59      2248.93    80.69 0.0001
AGIT        - 0.004       0.00       191.03     6.85 0.0151
CONS        -69.857      12.53       865.63    31.06 0.0001

Bounds on condition number:     1.01, 4.06
-----------------------------------------------------------
All variables left in the model are significant at the 0.05
level. No other variable met the 0.05 significance level
for entry into the model.

Summary of Stepwise Procedure for Dependent Variable LEN

      Variable  Number  Partial  Model
Step  Entered     In      R**2   R**2  C(p)         F Prob>F
   1  CONS        1       0.48   0.48  2.45     22.73 0.0001
   2  AGIT        2       0.12   0.59 -1.20      6.85 0.0151
```

Appendix G

Supporting Data

Table 39

Summaries of Test Conditions for Experiments in Phase I

Run No.	Variables	Level
* 1	Agitation	M
2	Air Flow Rate	H
3	Bubble Size	L
4	Time	L
5	Surfactant Conc.	L
6	Surfactant Conc.	H
* 7	Surfactant Conc.	M
* 8	Consistency	M
9	Agitation	L
10	pH	H
11	pH	L
*12	Bubble Size	M
*13	Time	M
14	Agitation	H
*15	Air Flow Rate	M
16	Air Flow rate	L
17	Time	H
18	Consistency	L
19	Bubble Size	H
*20	pH	M
21	Consistency	H

Note : Run No. with * are at medium level for all variables, thus, experiment was don only Run No. 1.

Table 40

Flotation Efficiency by Number of Particles (Phase I)

Run No.	Rep	Number of Particle				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
1	1	159 165 159	161	81 96 74	84	65.80	65.83
	2	158 155 172	162	89 91 83	88	64.84	
	3	164 162 158	161	73 82 85	80	66.85	
2	1	184 185 184	184	82 70 89	80	69.65	69.31
	2	186 189 187	187	85 83 89	86	68.62	
	3	185 187 188	187	70 87 87	81	69.65	
3	1	112 124 117	118	57 62 50	56	67.62	67.43
	2	105 124 123	117	54 62 59	58	66.79	
	3	115 121 117	118	54 58 55	56	67.88	
4	1	167 159 161	162	75 84 85	81	66.62	66.16
	2	163 158 150	157	89 68 89	82	65.69	
	3	155 162 158	158	73 88 82	81	66.16	
5	1	157 156 152	155	44 45 36	42	78.81	77.77
	2	162 154 155	157	47 44 47	46	77.34	
	3	157 160 159	159	40 52 49	47	77.15	
6	1	159 165 143	156	85 87 90	87	64.06	64.91
	2	159 165 155	160	83 80 87	83	65.71	
	3	160 158 149	155	92 80 80	84	64.95	
9	1	144 136 143	141	85 89 85	86	62.02	63.69
	2	160 140 129	143	79 79 82	80	64.13	
	3	166 164 155	162	88 79 95	87	64.93	

Table 40--Continued

Run No.	Rep	Number of Particle				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
10	1	159 149 141	150	81 83 92	85	63.69	64.56
	2	158 144 148	150	79 83 83	82	64.75	
	3	148 153 161	150	75 86 85	82	65.25	
11	1	98 107 109	105	56 50 58	55	65.69	66.03
	2	115 93 117	108	55 55 52	54	66.74	
	3	98 110 96	101	51 59 49	53	65.66	
14	1	98 110 106	105	52 49 40	47	69.01	70.57
	2	118 99 104	107	42 41 43	42	71.81	
	3	111 116 97	108	44 47 42	44	70.90	
16	1	99 97 106	101	39 35 32	35	74.02	74.91
	2	105 116 101	107	31 33 37	34	76.12	
	3	106 91 114	104	38 32 36	35	74.58	
18	1	114 98 109	107	44 47 52	48	69.18	68.47
	2	99 102 113	101	48 47 44	46	68.62	
	3	108 97 108	104	56 49 45	50	67.60	
19	1	100 107 106	104	51 58 50	53	66.24	65.84
	2	107 101 108	105	56 52 58	55	64.42	
	3	102 110 114	109	51 53 59	54	66.87	
21	1	92 94 87	91	56 60 56	57	61.35	62.88
	2	93 83 93	90	55 44 51	50	64.20	
	3	92 93 85	90	59 51 48	53	63.08	

Table 41

Flotation Efficiency by Area of Ink (Phase I)

Run No.	Rep	Area of Ink(μm^2)				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
1	1	29666 29592 24150	27802.67	7790.70 7948.40 7299.10	7679.40	78.36	80.57
	2	27129 29928 28366	28474.33	6866.40 6377.50 5494.80	6232.90	82.04	
	3	27328 28738 29296	28454.00	5498.10 6640.90 7498.10	6545.70	81.30	
2	1	31483 28030 27536	29016.33	7327.20 6731.30 7850.00	7302.83	79.89	80.65
	2	29250 27790 28458	28499.33	6124.70 6813.00 6466.90	6468.20	81.50	
	3	27067 25158 27294	26506.33	6076.90 6582.10 6548.60	6402.53	80.54	
3	1	26797 19211 21046	22351.33	4504.80 6062.10 5736.50	5434.47	80.44	79.65
	2	24316 19565 21202	21694.33	6091.80 5877.30 4943.70	5637.60	79.37	
	3	18923 21114 17037	19024.67	4717.20 5409.10 4921.50	5014.93	79.14	

Table 41--Continued

Run No.	Rep	Area of Ink (µm²)				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
4	1	19570 26906 28680	25052.00	4978.20 5029.00 4912.80	4873.33	83.72	83.25
	2	17795 24123 26877	22931.67	4528.90 4380.00 5166.50	4691.80	83.02	
	3	28738 19296 24614	24125.00	5001.10 4807.70 4995.30	4934.70	83.02	
5	1	20073 22538 24047	22219.33	2873.90 2183.10 2803.60	2620.20	89.45	90.37
	2	20418 27779 23876	24024.33	2228.30 2415.20 2387.40	2343.63	91.11	
	3	24835 20905 26601	24113.67	2848.40 2313.30 2399.50	2520.40	90.50	
6	1	20040 30014 24777	24943.67	4140.80 4829.60 3480.90	4150.43	85.73	85.10
	2	18252 24412 24600	22421.33	3804.00 5006.50 3478.20	4096.23	84.55	
	3	20562 21603 19036	20400.33	3879.70 3357.30 3551.00	3596.00	85.01	
9	1	20443 19775 21100	20439.33	6226.40 5810.10 7166.40	6400.97	76.15	76.25
	2	23634 18761 19104	20499.67	9303.10 4445.30 7562.80	7103.73	74.27	
	3	24874 22326 22833	23344.33	5326.00 6869.10 7166.40	6453.83	78.34	

Table 41--Continued

Run No.	Rep	Area of Ink (μm^2)				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
10	1	27165 32321 22901	27426.33	5931.90 4952.20 6781.30	5888.47	82.34	80.75
	2	33032 19050 23673	25252.67	8797.40 3884.70 4652.00	5778.03	81.38	
	3	24186 24056 21828	23356.67	6500.20 7310.00 5362.70	6390.97	78.52	
11	1	24252 34756 35567	31525.00	7228.60 3938.50 6305.70	5824.23	84.41	83.85
	2	33511 31446 32663	32540.00	7446.40 5468.50 6546.00	6486.97	83.38	
	3	25146 39980 34701	33275.67	4836.10 7727.00 6770.00	6444.37	83.78	
14	1	27190 26032 38120	30447.33	7758.20 6603.00 4479.30	6280.17	82.90	83.30
	2	20457 22552 40614	27874.33	6637.00 4915.30 5328.40	5626.90	83.20	
	3	45663 27822 25483	32989.33	6770.10 6144.20 6217.60	6377.30	83.80	
16	1	38983 26177 37519	34226.33	4850.30 2064.10 6798.30	4570.91	88.22	88.23
	2	29114 32901 41681	34565.33	4588.40 5486.50 3923.05	4665.98	88.11	
	3	35744 32671 29962	32792.33	4098.10 4233.00 4628.10	4319.73	88.36	

Table 41--Continued

Run No.	Rep	Area of Ink (μm^2)				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
18	1	32023 39810 34261	35367.67	7242.60 8763.80 6758.70	7588.37	82.33	82.65
	2	34084 35403 25570	31685.67	6277.30 5793.20 6397.20	6155.90	83.73	
	3	28000 37183 33413	32865.33	8420.40 7098.40 6315.60	7278.13	81.87	
19	1	26089 31618 28124	28609.00	8394.50 9103.20 7372.70	8290.10	77.53	77.68
	2	28073 29716 33324	30371.00	8742.20 9139.10 9505.30	9128.90	76.86	
	3	37252 33159 21248	30553.00	8712.00 7000.40 9168.70	8293.70	78.65	
21	1	11946 16499 16649	15031.33	5267.30 6063.40 5708.20	5679.63	72.58	73.98
	2	16258 17796 13549	15867.67	4233.00 5470.30 6937.10	5546.80	74.10	
	3	13780 16598 15284	15220.67	5895.10 4669.00 4448.20	5004.10	75.26	

Table 42

Fiber Loss from Flotation (Phase I)

Run No.	Weight (mg.)						Loss (%)			Avg. Loss (%)
	Floated			Non-Floated						
1	25.0	25.6	24.7	282	278	283	8.14	8.42	8.03	8.20
2	24.1	23.4	24.2	285	289	280	7.80	7.49	7.96	7.75
3	29.2	30.2	30.3	305	291	289	8.72	9.40	9.49	9.20
4	21.0	23.2	25.1	302	303	292	9.49	7.07	7.90	7.15
5	25.6	24.3	24.5	276	272	283	8.49	8.20	7.97	8.22
6	29.5	28.3	30.1	268	263	270	9.92	9.72	9.93	9.85
9	29.0	30.6	30.6	273	265	278	9.61	10.36	9.20	9.96
10	28.0	25.7	26.8	291	302	296	8.78	7.84	8.29	8.30
11	25.9	24.0	25.0	271	267	285	8.72	8.25	8.06	8.35
14	17.5	18.5	17.5	236	253	254	6.91	6.81	6.45	6.72
16	29.8	27.5	28.0	281	293	283	9.60	8.58	9.00	9.06
18	10.6	9.5	10.1	181	187	186	5.54	4.83	5.15	5.18
19	25.5	24.3	25.6	286	284	288	8.19	7.88	8.16	8.08
21	60.9	55.6	56.9	435	428	432	12.28	11.50	11.63	11.80

Table 43

Summary of Test Conditions for Experiment in Phase II

Run No.	Consistency	Bubble Size	Agitation
1	H	F	L
2	L	M	H
3	M	M	M
4	M	F	M
5	M	F	H
6	H	F	M
7	L	F	H
8	L	M	M
9	M	C	L
10	H	C	H
11	L	F	L
12	M	M	H
13	H	M	H
14	H	C	L
15	H	M	M
16	H	F	H
17	M	M	L
18	M	C	H
19	M	F	L
20	H	M	L
21	M	C	M
22	L	C	H
23	L	C	L
24	L	C	M
25	L	F	M
26	L	M	L
27	H	C	M

Note: L,M,H,F,C denote low, medium, high, fine and coarse respectively.

Table 44

Flotation Efficiency by Number of Particles (Phase II).

Run No.	Rep	Number of Particles				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
1	1	88 89 92	90	63 65 64	64	58.35	58.19
	2	86 94 92	91	67 62 65	65	58.37	
	3	87 93 89	90	64 67 65	65	57.85	
2	1	97 95 94	95	36 35 37	36	72.59	72.34
	2	92 95 93	93	37 35 39	37	71.61	
	3	93 96 95	95	35 37 34	35	72.82	
3	1	95 98 98	97	43 42 40	42	69.95	70.56
	2	98 97 98	98	40 39 42	40	70.77	
	3	94 95 97	95	39 38 40	39	70.97	
4	1	104 98 100	101	33 33 35	34	74.94	74.26
	2	103 105 99	102	35 37 32	35	74.70	
	3	99 97 101	99	34 37 38	36	73.15	
5	1	102 97 99	99	35 39 35	36	73.22	74.67
	2	104 101 104	103	32 34 34	33	75.55	
	3	99 105 100	101	32 33 35	33	75.25	
6	1	90 91 91	91	43 45 44	44	67.33	66.48
	2	89 92 87	89	48 46 45	46	65.85	
	3	94 91 92	92	48 45 48	47	66.27	
7	1	96 94 94	95	27 29 31	29	76.55	76.06
	2	97 97 96	97	30 31 32	31	75.72	
	3	96 94 97	96	32 29 30	30	75.93	
8	1	96 92 95	94	30 29 27	29	76.69	74.49
	2	98 99 95	97	28 26 29	28	77.87	
	3	97 92 93	94	28 25 27	27	77.90	

Table 44--Continued

Run No.	Rep	Number of Particles				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
9	1	75 74 77	75	48 52 53	51	59.63	60.35
	2	79 76 77	77	50 47 49	49	61.38	
	3	75 77 78	77	49 52 52	51	60.05	
10	1	78 80 79	79	69 67 66	67	53.99	53.91
	2	79 81 83	81	69 68 70	69	54.00	
	3	82 82 80	81	69 70 71	70	53.74	
11	1	103 100 102	102	48 52 49	50	67.18	66.79
	2	107 104 101	104	53 51 52	52	66.67	
	3	105 104 101	103	53 53 50	52	66.52	
12	1	92 90 89	90	39 37 40	39	70.03	69.23
	2	88 89 90	89	41 42 38	40	69.17	
	3	86 87 90	88	38 41 42	40	68.49	
13	1	85 87 89	87	53 55 56	55	61.41	61.53
	2	86 87 85	86	56 54 54	55	61.14	
	3	86 84 85	85	52 51 53	52	62.04	
14	1	97 99 99	98	85 87 90	87	52.96	52.22
	2	97 94 95	95	85 91 89	88	51.91	
	3	98 96 97	97	90 92 89	90	51.78	
15	1	82 79 84	82	52 55 53	53	60.49	60.87
	2	82 80 85	82	49 54 50	51	61.75	
	3	80 78 81	80	52 52 53	52	60.35	
16	1	82 85 87	85	46 42 44	44	65.80	65.28
	2	83 84 86	84	45 43 47	45	65.21	
	3	85 86 87	86	47 48 45	47	64.82	

Table 44--Continued

Run No.	Rep	Number of Particle				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
17	1	82 81 79	81	49 50 51	50	61.73	61.28
	2	76 79 78	78	49 47 50	49	61.48	
	3	79 80 75	78	52 49 51	51	60.62	
18	1	85 87 88	87	50 47 48	48	64.20	65.21
	2	90 89 90	90	47 46 47	47	65.77	
	3	89 87 86	87	44 47 46	46	65.66	
19	1	77 76 73	75	46 47 45	46	62.09	63.22
	2	75 72 72	73	44 43 40	42	63.29	
	3	77 75 73	75	44 40 41	42	64.29	
20	1	82 80 79	80	57 58 61	59	57.79	57.48
	2	79 79 80	79	61 61 59	60	56.80	
	3	78 78 80	79	56 59 57	57	57.84	
21	1	104 100 101	102	55 52 53	53	65.59	66.04
	2	98 100 99	99	51 51 52	51	65.85	
	3	103 99 102	101	51 49 52	51	66.67	
22	1	106 105 103	105	46 49 47	47	68.86	69.63
	2	101 103 104	103	45 46 42	44	69.84	
	3	106 103 104	104	46 43 44	44	70.18	
23	1	93 95 92	93	58 56 55	56	62.36	62.60
	2	92 91 90	91	53 55 52	53	63.05	
	3	87 89 91	89	55 52 54	54	62.38	
24	1	99 97 96	97	40 43 41	41	70.19	70.55
	2	100 97 98	98	42 41 43	42	70.07	
	3	97 96 94	96	38 39 38	38	71.39	

Table 44--Continued

Run No.	Rep	Number of Particle				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
25	1	100 103 104	102	26 28 27	27	79.12	78.38
	2	101 99 102	101	28 26 29	28	78.44	
	3	103 98 100	100	28 29 30	29	77.58	
26	1	78 78 80	79	44 41 42	42	65.01	65.14
	2	79 83 82	81	42 44 43	43	65.42	
	3	77 78 79	78	44 39 43	42	65.00	
27	1	78 76 76	77	57 59 59	58	56.79	55.40
	2	77 74 75	75	62 60 61	61	55.26	
	3	72 74 75	74	64 62 61	62	54.17	

Table 45

Flotation Efficiency by Area of Ink (Phase II)

Run No.	Rep	Area of Ink (μm^2)				Eff. (%)	Avg. Eff. (%)
		Floa-ted	Avg.	Non-Floated	Avg.		
1	1	29218 37723 36880	34607.00	13033.00 11115.00 12428.00	12192.00	73.95	74.69
	2	28924 34895 31180	31666.33	12862.00 8686.00 10976.00	10841.33	74.50	
	3	35674 33259 29263	32732.00	8547.00 12465.00 10656.00	10556.00	75.61	
2	1	25239 26921 27198	26452.67	3728.30 3712.90 3535.10	3658.77	87.85	87.98
	2	29814 27219 26612	27881.67	3767.00 3567.50 3834.70	3723.07	88.22	
	3	27286 25902 25321	26169.67	3545.70 3611.70 3676.90	3611.43	87.87	
3	1	34776 30527 31517	32273.33	4117.90 3832.60 4218.50	4056.33	88.83	88.64
	2	30510 30157 28086	29584.33	4202.20 3835.40 4153.70	4063.77	87.92	
	3	32160 29726 30706	30864.00	3826.10 4122.80 3947.90	3965.60	88.61	

Table 45--Continued

Run No.	Rep	Area of Ink (μm^2)				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
4	1	28001 26258 25456	26571.67	3986.60 3626.10 3747.30	3786.67	87.53	88.12
	2	31377 35153 27848	28126.00	3749.90 3534.30 3417.40	3567.20	88.74	
	3	27114 24332 26294	25913.33	3302.90 3422.10 3778.40	3501.13	88.10	
5	1	28025 27052 30122	28399.67	4444.60 4106.80 4344.80	4298.73	86.85	87.36
	2	29842 30177 26933	28964.00	4024.10 4470.90 4345.70	4280.23	87.12	
	3	30235 29873 29854	29987.33	3842.70 4251.60 4042.40	4045.57	88.11	
6	1	25012 26321 27195	26176.00	4942.80 4923.50 4612.50	4826.27	84.43	84.98
	2	29797 26480 28352	28209.67	4966.7 4557.10 4855.90	4793.23	85.48	
	3	28897 30385 26246	28509.33	4801.10 5261.00 5011.90	5024.67	85.02	
7	1	22431 20542 21151	21374.67	2644.50 2549.30 2818.50	2670.77	88.89	88.88
	2	21675 20191 22490	21452.00	2644.60 2515.90 2782.20	2647.57	89.01	
	3	19275 21771 20754	20600.00	2648.30 2754.80 2453.50	2618.87	88.72	

Table 45--Continued

Run No.	Rep	Area of Ink (μm^2)				Eff. (%)	Avg. Eff. (%)
		Floa-ted	Avg.	Non-Floated	Avg.		
8	1	24094 26784 25749	25542.33	2411.80 2559.10 2617.20	2529.37	90.99	91.20
	2	26841 23206 24315	24787.33	2322.10 2301.50 2418.00	2347.20	91.35	
	3	26889 25958 23829	25558.67	2317.90 2441.10 2574.90	2444.63	91.27	
9	1	17561 19441 20289	19097.00	5517.60 5702.90 5941.40	5720.63	76.95	76.86
	2	18733 20490 19553	19592.00	5873.90 5667.80 5792.10	5777.93	77.23	
	3	17820 19567 18290	18559.00	5591.50 5821.30 5794.10	5735.63	76.39	
10	1	25618 28851 26181	26883.33	5790.10 5621.70 5506.50	5639.43	82.66	82.40
	2	24605 24309 26791	25235.00	5831.50 5671.90 5722.60	5742.00	81.46	
	3	28297 25641 27115	27017.67	5497.40 5633.10 5371.90	5500.80	83.08	
11	1	28125 27861 30114	28700.00	6419.80 6513.20 6724.80	6552.60	81.41	81.36
	2	29872 27819 26964	28218.33	6309.10 6452.30 6252.40	6337.27	81.66	
	3	27939 28231 26252	27474.00	6314.90 6576.90 6415.80	6435.87	81.02	

Table 45--Continued

Run No.	Rep	Area of Ink (μm^2)				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
12	1	29760 31915 28215	29963.33	5420.80 5257.50 5180.40	5286.23	85.00	85.41
	2	31820 30178 28744	30247.33	4990.50 5223.40 5149.00	5120.97	85.52	
	3	30158 33975 28386	30839.67	5268.20 4981.20 5173.60	5141.00	85.71	
13	1	31720 30710 32290	31573.33	6477.50 6371.60 6291.00	6380.03	83.19	83.49
	2	34794 31910 32371	33025.00	6163.20 6267.50 6155.70	6195.47	84.20	
	3	30167 31153 32457	31259.00	6290.30 6452.50 6360.70	6367.83	83.08	
14	1	30522 30142 29666	30110.00	9820.10 9831.30 9663.90	9771.77	75.50	75.53
	2	32156 29311 31152	30873.00	9995.40 9721.50 9962.70	9893.20	75.73	
	3	28674 31069 29516	29753.00	9623.20 9812.30 9747.10	9727.53	75.36	
15	1	25221 27552 26040	26271.00	4830.90 4911.90 5035.20	4926.00	84.21	83.79
	2	27223 26543 24351	26039.00	5167.10 4936.00 5274.40	5125.83	83.55	
	3	25080 25001 24197	24759.33	4840.50 4991.70 4740.20	4857.47	83.60	

Table 45--Continued

Run No.	Rep	Area of Ink (μm²)				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
16	1	17796 19474 18342	18537.33	3327.10 3016.70 3222.60	3188.80	85.32	86.50
	2	21884 20815 19821	20840.00	3218.40 2874.50 3021.90	3038.27	85.28	
	3	19529 22119 21353	21000.33	3304.80 3080.30 3116.70	3167.27	86.89	
17	1	30958 30971 30712	30880.33	9325.20 9416.70 9251.80	9331.23	76.79	76.98
	2	31108 30967 31012	31029.00	9296.60 9178.70 9353.40	9276.23	76.99	
	3	31287 31089 30992	31122.67	9170.00 9207.30 9277.90	9218.40	77.15	
18	1	32956 32377 29689	31674.00	5513.70 5441.60 5790.30	5581.87	85.02	84.62
	2	30015 32546 30746	31102.33	5427.30 5578.90 5614.40	5540.20	84.88	
	3	30088 28715 30495	29766.00	5743.70 5760.90 5540.30	5681.63	83.97	
19	1	18036 20865 18530	19143.67	4791.60 4860.40 4897.20	4849.73	79.79	79.32
	2	18774 17764 17912	18150.00	4624.50 4733.40 4792.90	4716.93	79.37	
	3	17978 17005 18813	17932.00	4834.40 4901.60 4734.20	4823.40	78.80	

Table 45--Continued

Run No.	Rep	Area of Ink (μm^2)				Eff. (%)	Avg. Eff. (%)
		Floa-ted	Avg.	Non-Floated	Avg.		
20	1	26593 26977 25491	26353.67	9104.60 8985.90 10855.00	9648.50	73.20	73.73
	2	23634 24631 26333	24866.00	9119.30 7587.10 8570.10	8425.50	74.69	
	3	23977 25526 22171	23891.33	7906.80 9808.30 8408.30	8707.80	73.29	
21	1	32588 33292 35395	33758.33	5052.20 4801.50 5070.00	4974.57	87.16	87.21
	2	33583 34427 35164	34391.33	5176.60 5442.90 4976.30	5198.60	86.87	
	3	34421 32669 34478	33856.00	4855.50 4816.00 4709.10	4793.53	87.60	
22	1	15062 20100 18091	17751.00	2578.10 2873.30 2661.90	2704.43	86.78	86.01
	2	17208 16719 18554	17493.67	3251.90 2911.50 2871.90	3011.77	85.31	
	3	16034 16954 17719	16902.33	2696.40 2716.60 2892.00	2768.33	85.93	
23	1	25141 23677 22891	23903.00	5571.10 5304.70 5602.30	5492.70	81.31	80.33
	2	19439 22315 20937	20897.00	5635.70 5490.80 5332.40	5486.30	79.21	
	3	23345 24691 20157	22731.00	5502.70 5629.70 5421.90	5518.30	80.47	

Table 45--Continued

Run No.	Rep	Area of Ink (µm^2)				Eff. (%)	Avg. Eff. (%)
		Floated	Avg.	Non-Floated	Avg.		
24	1	24438 22517 21393	22782.67	2831.00 2433.90 2577.70	2614.20	89.71	89.28
	2	20188 19386 21675	20416.33	2623.50 2490.10 2674.20	2595.93	88.72	
	3	22267 20198 21677	21379.67	2519.00 2334.30 2677.70	2534.33	89.40	
25	1	28559 29126 27711	28465.33	2519.90 2199.90 2309.00	2342.93	92.40	92.12
	2	25740 28682 26389	26937.00	2205.10 2329.20 2325.00	2286.43	92.18	
	3	24478 26677 27518	26224.33	2321.20 2431.70 2288.90	2347.27	91.78	
26	1	19231 18961 20677	19623.00	5172.70 5002.90 4952.10	5042.57	79.56	79.59
	2	17428 19167 20665	19086.67	5166.90 4978.10 5217.40	5120.80	78.85	
	3	21030 22097 19151	20759.33	5054.50 5167.30 4997.80	5073.20	80.36	
27	1	20106 18273 21011	19796.67	3464.90 3705.50 3792.20	3654.20	84.42	85.00
	2	19163 21001 22948	21037.33	3405.20 3391.30 3578.10	3458.20	85.88	
	3	22506 18665 20234	20468.33	3676.70 3617.50 3788.60	3694.27	84.71	

Table 46

Fiber Loss from Flotation (Phase II)

Run No.	Weight (mg.)		Loss (%)	Avg. Loss (%)
	Floated	Non-Floated		
1	15.0 12.5 13.2	342 340 344	4.20 3.55 3.70	3.81
2	6.3 7.2 6.5	173 172 169	3.51 4.02 3.70	3.75
3	20.8 20.7 20.1	254 257 252	7.57 7.45 7.39	7.47
4	21.5 19.2 21.4	239 249 246	8.25 7.16 8.00	7.81
5	15.6 16.2 14.2	251 253 257	5.85 6.02 5.24	5.70
6	35.7 34.6 32.0	324 322 319	9.92 9.70 9.12	9.58
7	6.5 7.1 5.8	167 169 168	3.75 4.03 3.34	3.71
8	7.5 8.7 7.8	170 172 170	4.23 4.81 3.34	4.48
9	11.0 10.4 12.1	249 253 241	4.23 3.95 4.78	4.32
10	20.1 18.7 17.7	329 328 339	5.76 5.39 4.96	5.37
11	16.5 15.8 17.8	157 149 158	9.51 9.59 10.13	9.74
12	16.4 14.8 15.9	248 256 254	6.20 5.47 5.89	5.85
13	24.3 22.5 23.6	332 335 330	6.82 6.29 6.67	6.60
14	14.5 13.0 14.1	341 348 339	4.08 3.60 3.99	3.89
15	31.2 32.2 31.9	328 318 325	8.69 9.19 8.94	8.94
16	21.3 24.6 22.4	336 333 338	5.96 6.88 6.22	6.35
17	10.6 11.5 9.9	251 249 258	4.05 4.41 3.70	4.05
18	14.9 12.9 13.3	250 252 249	5.62 4.87 5.07	5.19
19	11.4 10.0 10.7	249 251 255	4.38 3.83 4.03	4.08
20	14.1 13.2 12.9	334 340 347	4.05 3.74 3.58	3.79

Table 46--Continued

Run No.	Weight (mg.)						Fiber Loss (%)			Avg. Loss (%)
	Floated			Non-Floated						
21	17.9	19.2	19.1	247	244	250	6.76	7.29	7.10	7.05
22	5.4	6.0	4.9	165	171	174	3.17	3.39	2.74	3.10
23	11.2	10.5	10.1	159	162	166	6.58	6.09	5.74	6.13
24	9.1	7.9	8.1	167	170	165	5.17	4.44	4.68	4.76
25	10.2	8.9	9.1	164	170	166	5.86	4.97	5.20	5.34
26	13.1	13.7	12.3	166	163	165	7.31	7.75	6.94	7.33
27	32.5	31.5	29.9	325	323	329	9.09	8.89	8.33	8.77

Table 47

Fiber Length Distribution of Fiber in Floated Part

	Run No.								
Fiber Length	1	2	3	4	5	6	7	8	9
0.00	1440	1661	1831	1357	1452	1871	1246	1394	1747
0.11	1357	1463	1743	1308	1361	1663	1210	1270	1575
0.23	731	768	809	724	753	776	820	673	771
0.35	568	579	624	591	635	562	618	596	597
0.47	652	625	726	667	697	624	574	623	657
0.58	877	815	772	805	836	757	761	807	752
0.70	736	800	759	760	744	663	688	707	680
0.82	694	651	510	661	650	524	574	700	646
0.94	631	604	473	625	580	496	520	578	528
1.05	511	419	417	540	503	474	478	582	460
1.17	497	468	340	535	504	430	445	559	434
1.29	346	294	254	350	339	313	293	381	323
1.52	378	369	272	436	416	351	359	474	339
1.76	174	165	159	214	180	164	184	212	168
2.00	86	70	78	100	100	68	103	136	79
2.23	69	59	56	80	72	48	62	66	51
2.47	47	41	48	59	43	48	40	49	48
2.70	45	37	37	44	22	36	35	57	33
2.94	31	25	24	29	25	21	32	33	20
3.17	28	23	21	30	27	31	23	23	24
3.41	23	14	13	14	22	20	23	15	24
3.64	21	12	15	26	16	17	17	16	23
3.88	16	13	15	14	22	15	9	14	11
>3.88	42	26	14	34	20	32	32	37	34
Average Fiber Length (mm.)									
	0.70	0.66	0.65	0.72	0.69	0.65	0.68	0.73	0.65

Table 47--Continued

	Run No.								
Fiber Length	10	11	12	13	14	15	16	17	18
0.00	1883	1644	1677	1836	1761	1905	1707	1683	1694
0.11	1616	1438	1564	1752	1664	1599	1604	1436	1430
0.23	855	706	798	880	828	813	817	788	716
0.35	608	585	590	623	599	604	579	623	585
0.47	623	587	612	629	595	636	659	626	626
0.58	803	757	794	711	742	728	846	834	846
0.70	670	668	676	685	650	638	621	715	700
0.82	622	610	611	563	592	592	584	640	712
0.94	496	557	553	492	513	490	554	566	584
1.05	447	537	480	454	478	467	448	484	487
1.17	396	473	456	399	414	429	448	422	457
1.29	277	403	302	309	338	320	310	426	315
1.52	325	403	375	326	349	353	350	381	392
1.76	119	213	177	144	169	131	151	166	177
2.00	58	92	89	73	88	72	84	75	93
2.23	40	76	65	42	50	43	56	63	51
2.47	34	48	39	14	33	33	40	31	38
2.70	34	40	33	19	34	27	27	34	23
2.9	22	40	19	24	18	26	31	26	22
3.17	16	24	21	16	22	32	17	25	13
3.41	15	19	11	18	15	9	12	15	14
3.64	10	28	8	7	16	18	12	18	12
3.88	61	9	14	12	20	9	20	13	9
>3.88	23	49	45	18	38	46	34	30	26
	Average Fiber Length (mm.)								
	0.61	0.71	0.65	0.60	0.64	0.63	0.64	0.66	0.66

Table 47--Continued

	Run No.								
Fiber Length	19	20	21	22	23	24	25	26	27
0.00	1391	1800	1653	951	1328	1484	1121	1474	1542
0.11	1279	1622	1454	865	1150	1266	1008	1307	1440
0.23	734	816	774	468	672	735	649	751	777
0.35	609	604	578	378	544	582	561	617	616
0.47	638	611	701	418	565	651	636	645	599
0.58	848	777	794	585	751	792	863	793	860
0.70	800	671	673	481	742	761	813	688	688
0.82	658	658	629	427	669	657	745	656	627
0.94	622	502	567	410	638	603	601	685	558
1.05	510	463	486	363	587	546	611	487	500
1.17	506	412	467	327	554	516	626	496	468
1.29	386	286	333	252	434	376	456	357	355
1.52	403	335	372	277	512	440	566	473	392
1.76	232	150	185	112	225	187	234	202	202
2.00	112	77	84	64	136	116	136	107	95
2.23	61	49	54	51	100	74	80	67	67
2.47	46	36	47	28	65	54	56	55	45
2.70	36	23	34	28	50	39	47	42	41
2.94	27	25	29	22	60	38	60	26	24
3.17	23	19	18	15	38	25	38	24	26
3.41	19	21	13	10	40	15	35	25	15
3.64	16	13	23	5	36	21	20	18	15
3.88	19	7	15	9	25	7	18	9	8
>3.88	40	37	39	22	88	35	41	34	47
	Average Fiber Length (mm.)								
	0.71	0.63	0.67	0.70	0.79	0.71	0.79	0.71	0.68

Table 47--Continued

Original Pulp				
Fiber Length	1	2	3	4
0.00	2171	2301	2297	2313
0.11	1890	1910	1952	2037
0.23	865	907	876	929
0.35	510	521	526	513
0.47	506	536	571	558
0.58	701	701	674	628
0.70	546	498	524	513
0.82	511	506	473	484
0.94	463	399	413	412
1.05	382	391	359	372
1.17	372	351	333	328
1.29	287	260	259	263
1.52	316	299	267	272
1.76	145	144	148	110
2.00	74	71	69	63
2.23	52	53	50	41
2.47	37	37	40	36
2.70	32	33	31	20
2.94	32	17	25	20
3.17	28	17	18	20
3.41	28	15	16	18
3.64	14	10	23	22
3.88	14	13	15	15
>3.88	40	31	50	32
	Average Fiber Length (mm.)			
	0.61	0.59	0.59	0.57

Table 48

Rpm. of Magnetic Stirrer Bar

Dial No.	Consistency (%)			
	0.0	0.2	0.3	0.4
1	720	645	550	450
2	890	800	710	620
3	1180	1100	1010	900
4	1580	1500	1420	1350
5	2190	2030	1950	1900
6	2760	2730	2690	2640
7	3900	3850	3800	3760

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