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NL-339 (3/77)

THE DEVELOPMENT OF A NOVEL FOAM BATCHING AND GENERATING SYSTEM

Wagdi Henein

A MAJOR TECHNICAL REPORT

in the

Faculty of Engineering

Presented in Partial Fulfillment of the Requirements for
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Montreal, Quebec, Canada

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ABSTRACT

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WAGDI HENEIN

THE DEVELOPMENT OF A FOAM BATCHING AND GENERATING SYSTEM

This technical report introduces a foam batching and generating system developed by the author in the course of his employment at Domtar Construction Materials Ltd., and in this context, represents a solution to an industrial problem.

The generating system includes a special design in the method of air-solution mixing, allowing high air entrainment efficiencies, and provides accurate control of the density of the generated foam in the range of 8-14 lb/cu.ft. while using a solution flow rate of 2-8 IGPM of a highly surface-active foaming agent. The generated foam is highly stable with a maximum air bubble size of 1/64th of an inch in diameter. The factors controlling the quality of the foam are presented and their interrelationships are demonstrated. The possibility of broadening the range of satisfactory performance of this system are suggested wherever applicable.

ACKNOWLEDGEMENTS

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INTRODUCTION

CHAPTER I

INTRODUCTION

1.1 OBJECTIVE

The objective of this project is to design and build a system capable of generating a continuous stream of foam, of specific qualities, utilizing a synthetic foaming agent for use in the manufacturing process of Gypsum board.

The new system is needed due to the following reasons:

1) The old system cannot generate the desired quality foam.

2) An increase in the production speed dictates higher generation rates beyond the capabilities of the old system.

1.2 THE MANUFACTURING PROCESS OF GYPSUM BOARD AND THE ROLE OF FOAM

Gypsum board is manufactured by a high-speed continuous method, wherein a fluid slurry consisting of stucco ($CaSO_4.\frac{1}{2}H_2O$), water, foam, starch, paper fibre and an accelerator (potassium sulphate) is spread between two continuous paper sheets, the resultant whole is formed by two large rolls into a continuous flat sheet of paper - enclosed unset gypsum board. As the board moves along the long belt conveyor the core sets and the now rigid board is cut into the desired length and fed into a dryer where the free water is evaporated. The fluid slurry is produced instantaneously in a "pin mixer" revolving at a high speed, into which a continuous metered supply of foam, water, and dry ingredients are fed through three separate ports.

In the drying process the evenly distributed dried foam leaves minute air bubbles in the core. The primary use of foam in the board is therefore weight reduction by replacing stucco volume (weight) by air. The weight of 1,000 sq.ft. of ½ in. thick board is approximately 3,000 lb. if manufactured without foam and is approximately 1,800 lb. when manufactured with foam. It is important to keep the board light enough within specifications so that it can be handled easily in construction. There are definite economical advantages resulting from the replacement of stucco by foam and from lower freight costs.

Foam is a wetting agent and therefore reduces the amount of water needed for the fluidity of the stucco during the lamination phase, thus allowing faster drying of the board which means conservation of energy and faster production rates. Foam is therefore an essential constituent of gypsum board, and it is very important to control its quality.

1.3 DESCRIPTION OF THE OLD SYSTEM

The principle behind the old generating system is that if air is injected into a 'soap solution' and restrictions are placed in the path of the solution flow, it foams as it passes through the small areas. The old generating system consisted of a 26 in. long brass tube filled with steel wool. As the solution passed through the perforations in the steel wool and mixed with air it foamed. The generated foam was delivered to the open 'pot mixer' which produced the gypsum fluid slurry.

This method of direct air introduction into the solution generates foam with large air bubbles which produces voids in the board. Foam generated by this system was sporadic and of very low density and stability. Improvements could not be achieved. As mentioned earlier, this system represented a bottleneck at the new sought production speeds, since feeding the solution faster into the generator resulted in less foam generation. The foaming agent solution was purchased in 45 gallon drums and pumped from the drums to the generator.

1.4 REQUIREMENTS OF THE NEW SYSTEM

1) The new system should be capable of producing stable foam in the density range of 8 lb/cu.ft. to 14 lb/cu.ft. Since the new system is to be installed at different plants running at different produc-

tion speeds it has to be capable of producing the above density foam in the solution flow rate range of 2 IGPM to 8 IGPM.

2) The air bubbles within the generated foam are to be less than 1/64 of an inch in diameter.

3) From an economic point of view the new system should be capable of producing the above densities utilizing a foaming agent solution of no greater than 1% concentration by weight.

4) The cost of the new system should not exceed $15,000 including installation labour.

5) The new system must not require any operator supervision.

6) The new system components must be simple not requiring special maintenance skills. The layout of the system must provide easy access to components for maintenance.

7) System layout and dimensions should fit available areas within 40 ft. of the pin mixer at the different plants of the company.

1.5 BASIC DESCRIPTION OF THE NEW SYSTEM

The new system is made up of two connected systems:

1) The Batching System
2) The Generating System

The function of the Batching System is to prepare an aqueous dilute foaming agent solution from the concentrate foaming agent. The percentage concentration by weight of the solution can be varied according to requirements. The solution is prepared in batches with a supply being always available for continuous board production. The system consists mainly of one mixing tank and two batching tanks, three mixers and interconnected piping. A supply line leads to the generating system.

The generating system combines the dilute aqueous foaming agent solution with air, in fixed proportions to form a highly stable foam of the required density. The resulting foam - similar in appearance to shaving lather or whipped cream - is metered into the gypsum slurry as it is formed at a continuous controlled flow rate.

The system consists mainly of a metering pump which continuously meters out a constant flow rate from one of the batching tanks and feeds it into two centrifugal pumps connected in series. Air is fed into the first pump and foam is conveyed into the pin mixer at the board line through a plastic hose.

Figure 1 shows the system arrangement and the above-mentioned main components.

A complete description of both systems will be presented in later chapters. The generating system is presented in Chapter III, ahead of the batching system presented in Chapter IV. The sequence of presentation is in the opposite sequence of liquid flow because the generating system is much more important. As will be shown in Chapter III, the range of foam densities which can be obtained from the generating system depends on the concentration of the solution prepared in the batching system, but it is the generating system which can control the foam density at different solution strengths.

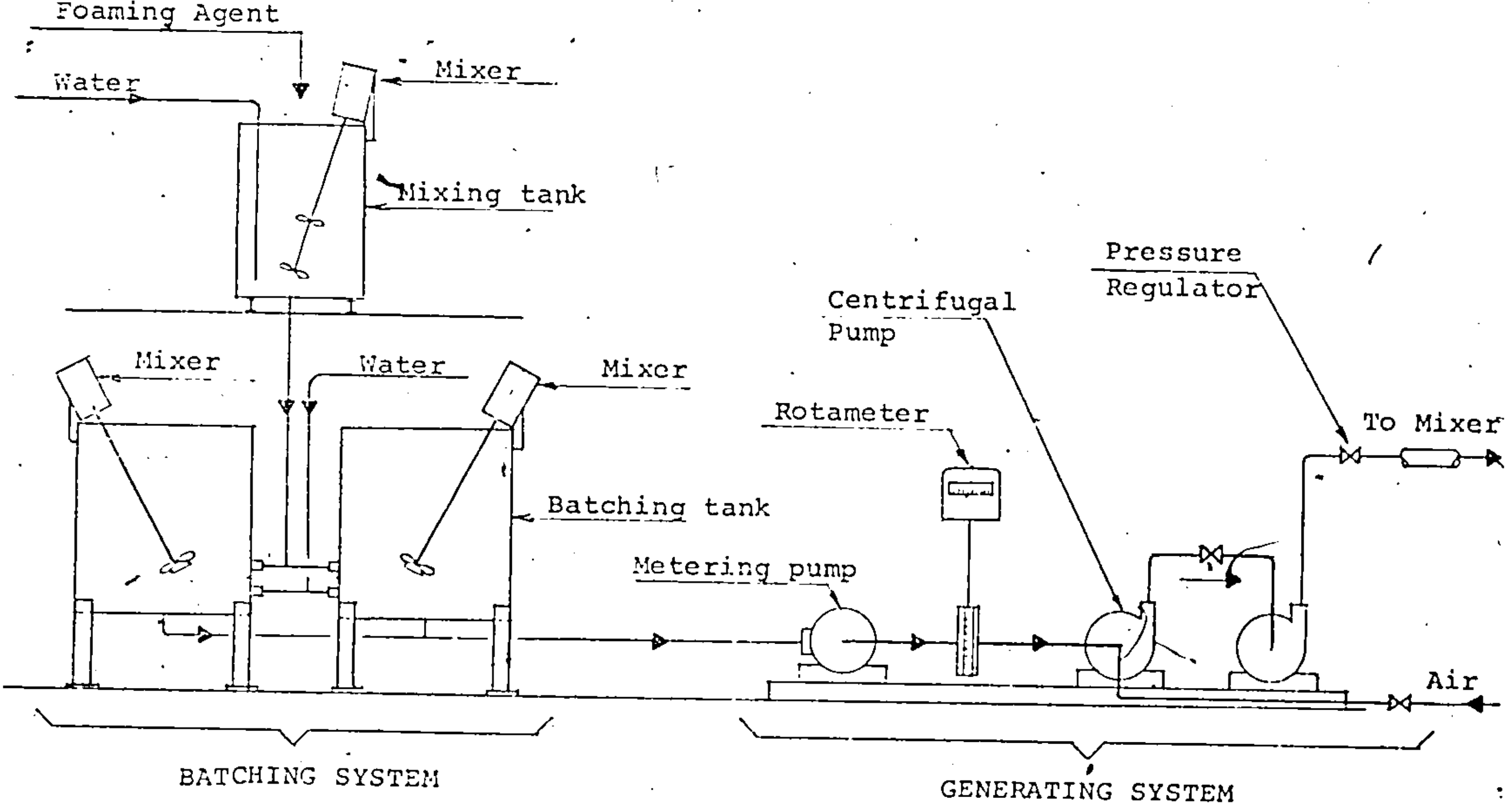

FIG. 1.1 Foam System Arrangement and Main Components.

CHAPTER II

SURVEY - THEORY OF FOAMING

CHAPTER II

SURVEY - THEORY OF FOAMING

2.1 FORMATION OF CELLULAR STRUCTURES

The fundamental means of forming solid cellular structures is by dispersing a gaseous phase within a fluid mass which subsequently becomes solid. The fluid may be a homogeneous hot melt which solidifies on cooling, it may be a liquid which polymerizes chemically, or it may be a heterogeneous slurry of fine solids and liquid as in the case of gypsum board which stiffens and sets to a solid. [1]

2.2 CLASSIFICATION OF FOAMS AND METHODS OF GENERATION

Foams may be classified as either "chemical" or "mechanical", depending on the process used to produce the gas voids.

Chemically formed solid foams result from a gas-evolving chemical reaction within the initially fluid medium. The gas forms bubbles which are then trapped within the slurry. The resultant foaming product is then allowed to set. With chemical foaming methods the homogeneity of the cellular structure depends on the rate and degree of completion of the chemical reaction. This, in turn, varies with the temperature, pH, water hardness, the relative amounts of reactants, and other process variables.

Mechanically formed foams are made by introducing the gaseous phase from an external source into the fluid mass before it solidifies and may be generated by either of two mechanical techniques, using foaming agents which must be physically and chemically compatible with the other components:

1) *"In Situ"* Foaming - The concentrated foaming agent is introduced directly into the aqueous slurry of solids and violently agitated in a high shear mixer which entrains air and homogenizes the mix to give a uniform cellular structure. Sometimes the solids are added after the foam is formed by high speed mixing of the foaming agent and water. In either case, the density and stability of the resulting foamed or aerated mixture will depend on the amount of foaming agent, its chemical composition, the intensity and duration of mixing, mixer design and the physical and chemical nature of the solids being dispersed.

2) Preformed Foam Blending - This technique which is often more adaptable to diverse raw material systems, and usually more reproducible, is to first preform the foam in a foam generator and then meter it into the slurry as it is formed and blend it uniformly into the suspension of solids to produce a cellular product of any predetermined density. At

this point, the precisely controlled foaming process is complete.

In general, the mechanical processes have proven to be simpler than the chemical processes and more amenable to producing foam solids with a wide range of physical and chemical properties. This is particularly true for the systems in which a heterogeneous slurry is aerated and the resulting fluid foam cured by one of several mechanisms, to a rigid foam. [1]

2.3 APPLICATION TO THE PRODUCTION OF GYPSUM BOARD

Extensive research on the application of the chemically generated foams to the production of gypsum board has been carried out. Several patents on this subject have been issued. For example, slurries of calcined gypsum may be foamed by incorporating aluminum sulphate and calcium carbonate in the slurry, which releases carbon dioxide gas in the presence of the water in the slurry. Another known method is by the catalytic decomposition of hydrogen peroxide to oxygen by means of a manganese dioxide catalyst. [2] Chemical methods have not received wide acceptance in the gypsum board industry due to associated quality problems relative to each method.

The mechanical preformed foam blending method lends itself readily to continuous operations and is the method most applicable to this industry. The initially fluid foam is stabilized into a cellular configuration by the formation of an interlocking network of dihydrate crystals which result from the hydration of gypsum hemihydrate.

2.4 THEORY AND PROPERTIES OF FOAM

Foams, in one form or another, are frequently encountered in chemical technology. Sometimes they are beneficial but more often than not their presence heralds difficulties in process and equipment operation. As a result, the great bulk of foam study has been devoted either to preventing their formation or destroying them,once formed. Recently, however, interest in the more useful aspects of foam has been on the rise.

2.4.1 Foam Structure

All foams have an essentially identical structure, a honey-combed arrangement of gas bubbles separated by thin liquid walls. As such, foam is a dispersion of gas in liquid. It differs from the more common dispersions of gas in liquid in that the volume ratio of gas-to-liquid is very great.

The ability to foam is conditioned on there being present in the liquid small amounts of special substances known as foaming agents. Without these a foam is unstable, and this is why it has not been possible to produce foams in pure liquids, which only contain one component. The foaming agent evidently produces a surface layer, differing in composition from the bulk of the liquid phase, which acts as a "buffer" preventing the coalescence of gas bubbles dispersed in the liquid. As a rule; the foaminess of aqueous solutions of inorganic compounds is small compared to solutions of alcohols, organic acids, bases and esters. More persistant froths are formed when solutions of colloidal materials are foamed. These materials are all strongly adsorbed at the surface and, in addition, add mechanical strength to the films so formed. [3]

The molecules of nearly all foaming agents are made up of two distinct portions. The first, the 'head', consists of such groups as - OH(hydroxl), - COOH (carboxylic acid), etc.; the second, the 'tail' of long chains of carbon and hydrogen atoms, e.g., sodium oleate:

$$CH_3 - (CH_2)_7 - CH = CH - (CH_2)_7 \; COON_a$$

where $COON_a$ represents the 'head'. The 'heads' are soluble in water, while the 'tails' are insoluble in water. As bubbles are produced in an aqueous soap solution the molecules of soap migrate to the air/water boundaries and orientate themselves with their 'heads' in the water and their 'tails' in the air [4],(Figure 2.1).

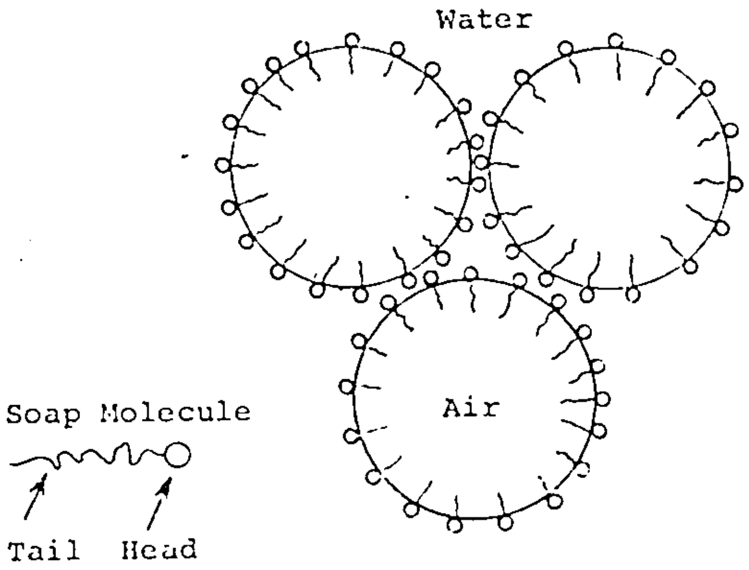

FIG. 2.1 Orientation of Soap Molecules in Foam

In this way, contact between water and the insoluble 'tails' is reduced to a minimum and this represents the most stable arrangement for the molecules. The result of the migration is that the concentration of soap in the boundary layers becomes higher than in the bulk of the liquid, and this leads to a decrease in the surface tension, and an increase in the viscosity and elasticity of the boundaries.

2.4.2 Foam Stability

Foam stability is affected by many properties of the gas - liquid system. Rarely is it dependent on one alone. In most practical cases that have been observed, foam persistence is the result of the interaction of several of these factors, including surface tension, viscosity, surface area, temperature, pH concentration and bubble size. [3]

2.4.2.1 Surface tension

For a foam to be stable, the surface tension of the solution must be considerably less than that of the pure solvent. Low surface tension alone does not, however, ensure a stable foam. The nature of the adsorbed layer is more important to foam stability than just a low surface tension.

2.4.2.2 Viscosity

A foam is stable if the gas bubbles do not coalesce, but remain separated by thin liquid walls. If the viscosity of these liquid partitions is sufficiently high, foam persistance is enhanced. More viscous liquid films tend to absorb shocks better and also reduce the velocity of approach of bubbles. There is reasonable evidence that liquid viscosity - rather than surface tension - is the primary factor in foam stability. Again as in the case of surface tension, foam stability cannot be related to viscosity alone.

2.4.2.3 Surface area

Liquid films of small surface area are more stable than those of large areas. In general, the persistence of a bubble is greater the smaller it is; it falls off roughly in inverse proportion to the square of bubble diameter. As a general proposition, then, finer initial gas dispersions promote greater foam stability.

2.4.2.4 Temperature

Foam persistence generally increases with decreasing temperature, probably owing to the combined effects of increased viscosity in the liquid film and decreased gas pressure within the bubbles.

2.4.5 pH value

Hydrogen-Ion concentration has little effect on foams except in the case of those produced with colloidal agents.

2.4.2.6 Concentration

Surface-active solutes - those which lower the surface tension of the solvent - concentrate in the surface layer since the rate of change of surface tension with concentration $(\frac{d\gamma}{dc})$ is negative. Surface - inactive substances for which $(\frac{d\gamma}{dc})$ is positive are negatively absorbed and concentrate in the solution interior. The surface layer is then more dilute.

As seen from Figure 2.2, foam persistance is nil at either end of the stability - concentration curve. For highly surface-active foaming agents (surfactants) there exists an optimum concentration, i.e., one which yields the greatest foam persistance. Foam generated at higher concentrations is less stable. Surfactants are characterized by a marked reduction in surface tension over a very narrow concentration range.

Surface tension-concentration relationships can be used to predict the foam behaviour of solutions, as shown in Figure 2.3.

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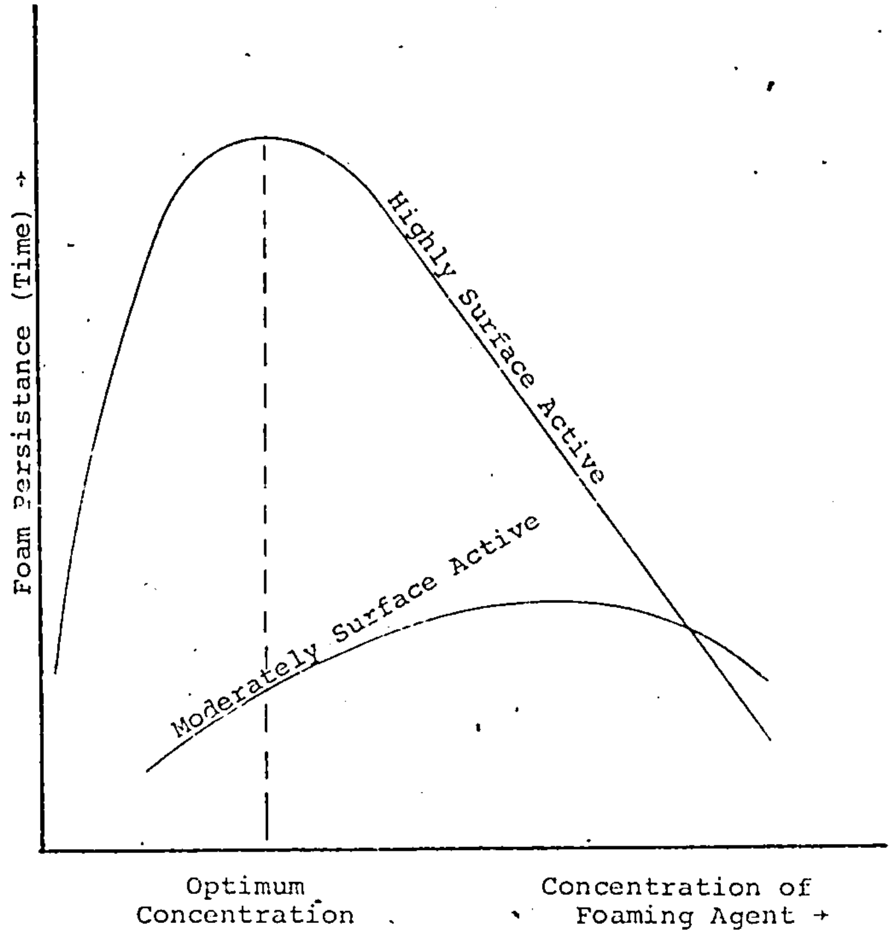


FIG. 2.2 Foam Stability as a Function of Solution Concentration

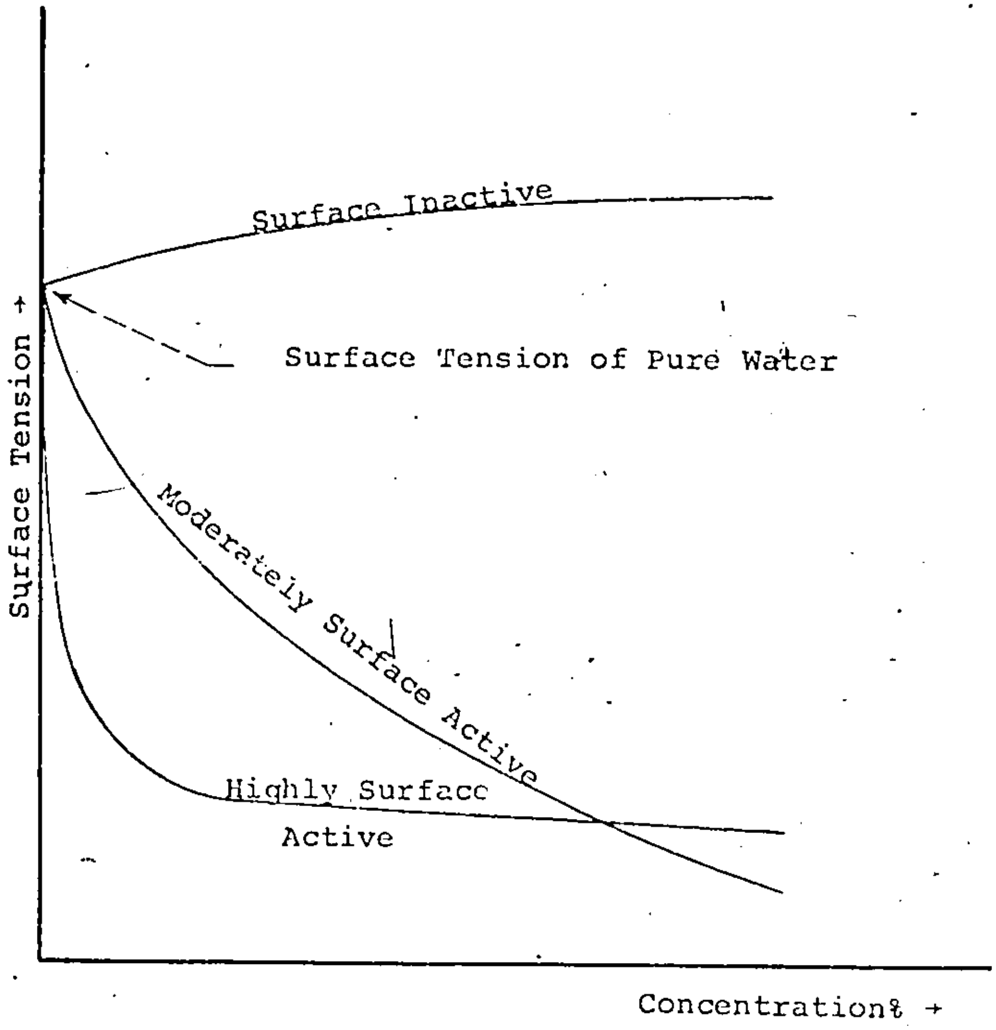


FIG. 2.3 Variation of Surface Tension With Solution Concentration

The equation from which the preceeding qualitative descriptions are derived is the Gibbs adsorption equation. [5] Gibbs' equation which has never completely achieved experimental verification is formulated from thermodynamic considerations.

Although a solution comprises but a single phase, it is convenient to think of it as having two parts:

(1) a surface layer surmounting
(2) the solution bulk.

The surface layer is of "molecular" depth and may, depending on the nature of the system, differ in composition from the interior of the solution.

The equation relates the equilibrium amount of any component adsorbed at the surface to the change in surface tension of the solution produced by that component.

The surface adsorption of the solute in a binary dilute solution at constant temperature is given by:

$$\Gamma = -\frac{c}{RT}\left(\frac{d\gamma}{dc}\right)$$

where

Γ = surface excess of the solute
c = solute concentration
R = gas constant in appropriate units

T = absolute temperature

γ = surface tension of the solute

"Surface excess" (Γ) of the solute refers to the difference in its concentration between the surface layer and the solution bulk.

Another way of stating the Gibbs adsorption theorem is to say that the concentration of the solute in the surface layer will always change in such a way as to decrease the surface tension. Thus, if further addition of the solute to the solution decreases the surface tension, it will be adsorbed and concentrate in the surface layer. If continued solute addition increases the surface tension, it will be negatively adsorbed and the surface layer will be more dilute than the interior of the solution.

2.4.2.7 Foam bubble size

The size of bubbles in a foam are related to the stability of the foam. This was first noticed by Plateau, [9] who, however, did not study the problem in a quantitative manner. In later experiments, it was found that the persistence was (roughly) inversely proportional to the square of the bubble diameter. [6]

It is believed that when persistence increases with concentration of the solute, the bubble size decreases at the same time. The use of a highly surface-active solute therefore indicates smaller bubble size in the increasing range of the persistence-concentration curve shown in Figure 2.2. The highest persistence and the smallest size bubbles are achieved at the optimum concentration for that solute. Since the bubble size is critical in the production of gypsum board, the choice of the concentration becomes a critical factor. Beating or whipping operations of a fine and rigid foam will promote a reduction in bubble size making the foam more stable. The effect is completely different if the foam being whipped is a coarse fluid foam of uneven structure since whipping such a foam would promote foam destruction.

2.5 AVAILABLE MECHANICAL FOAM GENERATORS

Although there is a wide application for such a system in and outside the gypsum board industry, the available systems are very few. In the gypsum board industry, the trend has been that each company utilizes a homemade system to the extent that different plants within the same company, at different geographical locations, may have different systems. Available findings on mechanical foam generators are kept within the individual companies and the subject has not evidenced any organized published research.

The following is the description and evaluation of a commercially available foam generator which is based on the same theory as the generator presented in this report, but utilizing a different design.

2.5.1 The Waukesha Foam Generator

The Waukesha Foam Generator consists of a metering pump, a specially designed gear pump, and a "foam conditioner", which is an expansion chamber. The generator is shown in Figure 2.4.

Foam is generated as the feed pump injects the foaming agent solution into the special gear pump where air is sucked from the atmosphere through a separate inlet. The solution enters the pump through an opening in the drive shaft and passes through tiny openings in the idler rotor. The fast-moving motor elements churn the air and liquid mixture into foam. Foam is produced in less than one revolution of the mixing gear pump and is directed out of the generator through a hose or conduit to the foam conditioner. The mixing gear pump operates at 2,500 RPM. The solution consumption is 5 IGPM to give a foam output of 100 IGPM. Normal pumping distance is 20 feet using a 1½" Dia. hose.

This system is incapable of generating the sought quality foam. This system requires a solution concentration of 2.75%, the generated foam is of very low density 2-3 lb/cu. ft., and the bubble size is comparatively quite large. The

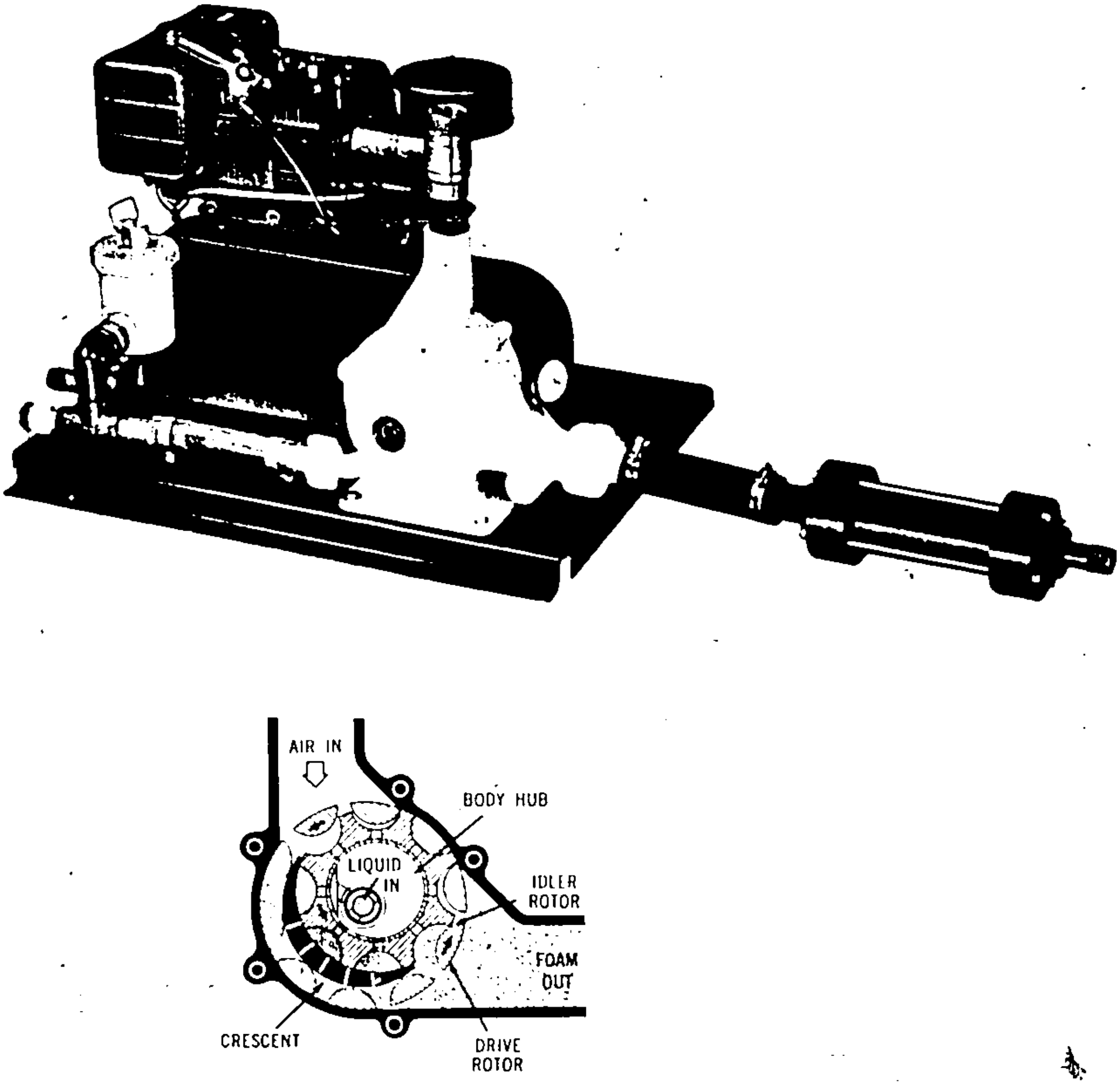


FIG. 2.4 The Waukesha Foam Generator

system as designed, does not offer a variable flow range nor a control over the density of the generated foam.

CHAPTER III

THE GENERATING SYSTEM

CHAPTER III

THE GENERATING SYSTEM

3.1 PRINCIPLE OF OPERATION, LAYOUT AND CONTROLS

The generating system is a two-stage system, each stage comprising:

1) a centrifugal pump rotated at high speed and fitted with a large diameter open impeller and

2) a pressure regulating valve.

The foaming agent solution is fed into the first centrifugal pump, from one of the batching tanks of the batching system, at the required flow rate, via a metering pump. The required air flow rate is supplied to this centrifugal pump through a separate air line. Ahead of the pump the solution and air mix, together in a 'mixing chamber'. The pump is chosen so as to create the greatest possible shearing action and is therefore oversized with respect to the required flow rate and head. In order to prevent the pump from 'hunting' and to make possible the foam generation, each pump is throttled, thus allowing the pumps to operate flooded with a maximum shearing action (beating or whipping) imparted to the solution. Since the extent to which the pumps are throttled may vary according to the solution flow rate and the density desired, pressure regulating valves are used to supply the desired back pressure. The pressure regulating valves serve a second purpose since as the foam passes across each valve it expands generating more foam through further entrainment of the remaining unentrained air (similar to what happens from a shaving cream can). The second stage of the system serves two purposes:

1) further foam generation, and
2) controlling bubble size

As explained in Section 2.4.2.7 whipping of a fine and rigid foam - generated in the first stage - promotes a reduction in bubble size which in this case is an essential foam quality requirement. The reduction in bubble size has the benefit of making the foam more stable which is another essential requirement. Although fine rigid foam is generated in the first stage of the system, it does not have the fine qualities desired and the one stage system has a low uneconomic foam generating efficiency.

The addition of the second stage improved the foam generating capability of the system; which is the ratio of the flow rate of the generated foam to the flow rate of the solution; by approximately 60%. The bubble size was reduced and the stability improved. Although experiments to calculate the percentage of foam generated in the pumps by whipping versus across the pressure regulators by expansion are not possible; since without the regulators in line the pumps hunt and foam generation is sporadic; it is estimated that with the regulators in line the major portion (80%) of the foam generated is generated in the pumps while the remaining 20% is generated across the regulators.

Centrifugal pumps are used rather than inline mixers because it is also necessary to pump the foam from the generating point to where it is utilized.

The method of air introduction will be explained in detail, in Section 3.3.3, and is a very important feature of this system. The effect of the variation of the back pressure, applied on the pumps, on foam density, will be discussed in Section 3.3.4.

Figure 3.1 is a layout of the generating system. The following components and controls are shown in Figure 3.1 and in Section BB of Figure 3.2:

Item No. 1 - Metering Pumps

One for process and one standby. Each is fed by a line from the batching system. Each pump is drivon by a variable speed drive. The desired range of flow rates is supplied by each pump by changing its rotational speed through the varispeed drive.

A description of how the metering pumps operate, their specifications and the sizing of pumps and drives are included in Appendix A1.1. Fig. 3.1 shows two pumps and drives connected in parallel. Only one pump is operational at any time. The other pump is provided as a standby pump.

Item No. 2 - End Suction Centrifugal Pumps

These provide the shearing action necessary for foam generation, with air being fed into the first centrifugal pump. Pump specifications, dimensions and sizing are included in Appendix A1.2.

Item No. 4 - Rotameter Type Flowmeter

Calibrated in IGPM.

Item No. 5 - Needle Point Valve in Air Line

Normally open.

Item No. 6 - Valve

Check valve to prevent back flow in air line.

Item No. 7 - Solenoid Air Valve

Connected to first centrifugal pump's motor. The valve opens when the motor starts.

Item No. 8 - Pressure Reducing Valves

Two pressure reducing and regulating valves for air pressure.

Item No. 10 - Plastic Hose

To convey the generated foam to the pin mixer.

Item No. 11 - Pressure Regulating Valves

Two pressure regulating valves to control the back pressure applied to the centrifugal pumps.

Item No. 12 - Steel Base for Generating System

Detail drawing shown in Appendix A1.4.

Item No. 14 - Check Valves

Four check valves.

3.2 GAGING POINTS AND INSTRUMENTS

In order to adjust the rate of flow of the foaming agent solution a rotameter is installed in the line after the metering pump. The rotameter is equipped with a pneumatic transmitter connected to a 24-hour circular chart recorder which furnishes a daily record of foam solution usage.

The various important pressures are measured by pressure gages. Figure 3.1 and Section BB of Figure 3.2, show the locations:

Item No. 3 - Pressure at Outlet

Indicates the pressure at the outlet of the metering pump.

Item No. 13 - Air Pressure

Indicates the air pressure at the inlet to the first centrifugal pump. (PGI)

Item No. 9 - Pressure gages

Indicates four pressure gages to measure:

(1) the back pressure on the first centrifugal pump (PG2)

(2) the inlet pressure to the second centrifugal pump (PG3)

(3) the back pressure on the second centrifugal pump (PG4)

(4) The inlet pressure to the hose.

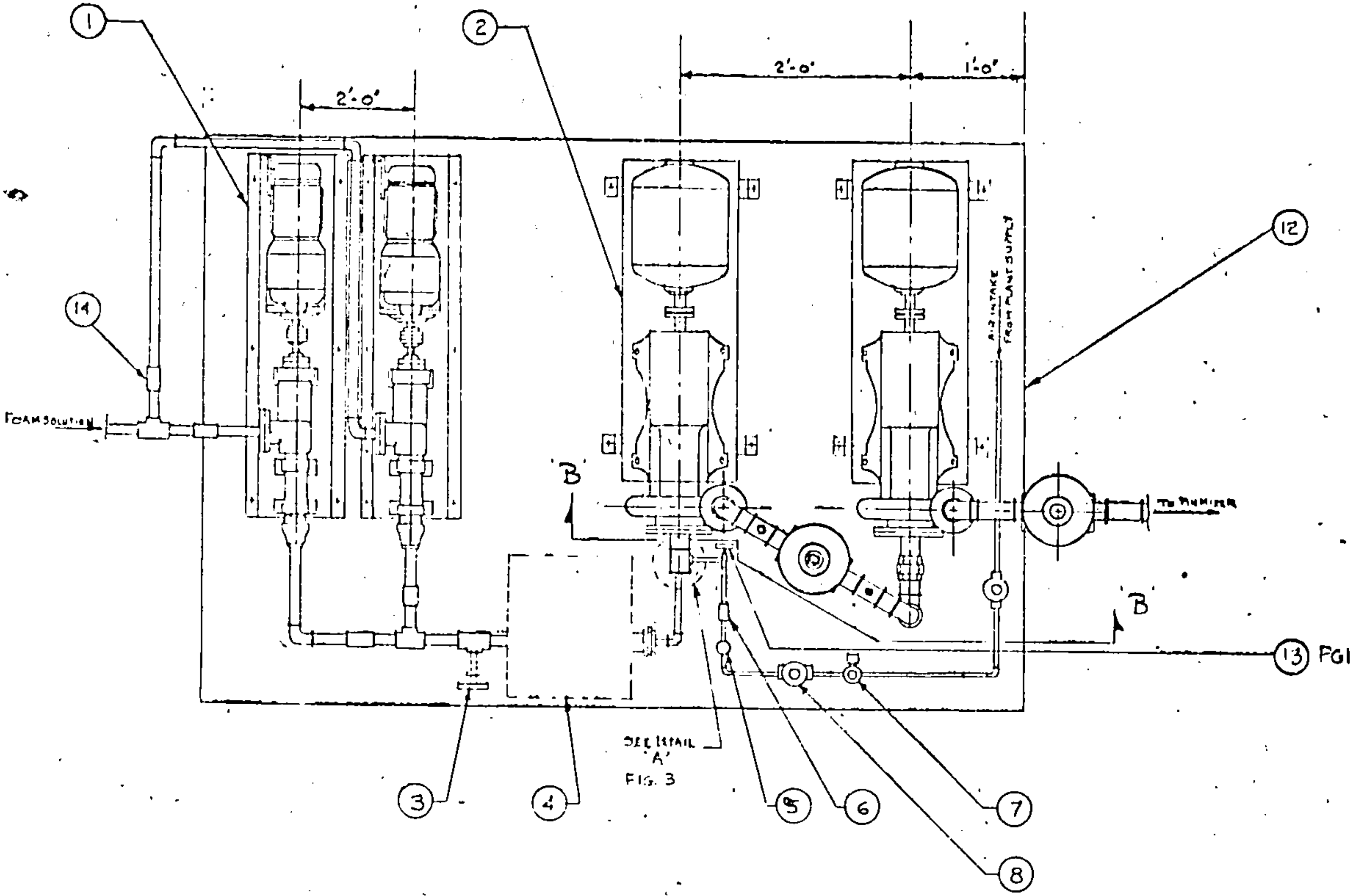
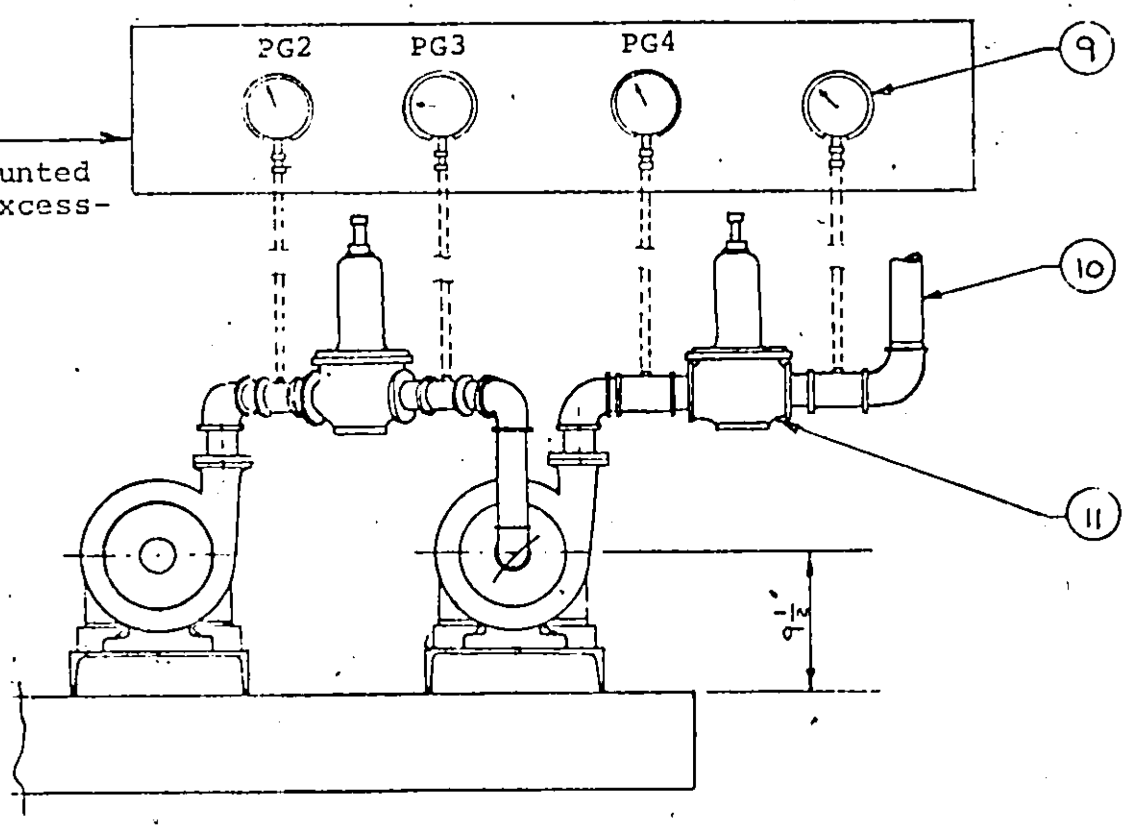


FIG. 3.1 Generating System Layout



All pressure gages to be mounted on panel on wall to avoid excessive vibrations on system

SECTION B-B

FIG. 3.2 Generating System Layout - Section B-B

In the following Section 3.3, the factors which affect the performance of the system will be discussed. The instruments presented in Section 3.2, are a measure of the adjustable factors in the system. They permit the comparison of the effect of each variable on the density and stability of the generated foam, as will be demonstrated in Section 3.4, which presents the results of the important experiments carried out.

3.3 FACTORS EFFECTING THE PERFORMANCE OF THE GENERATING SYSTEM

There are a number of factors which affect the density and stability of the foam generated by this system. Some of these factors are common to any generating system, e.g., the rate of solution flow, while others pertain to this system and were arrived at by analysing the results of the experiments carried out. The performance of the system is judged by measuring the density and stability of the generated foam and by the size of the air bubbles in the foam. The factors which affect performance, presented in the flow sequence, will be discussed in the following subsections.

3.3.1 The Type of Foaming Agent and the Concentration of the Solution

The foaming agents used are commercially available synthetic foaming agents manufactured for a wide variety of applications. They differ in their ability to foam at equivalent concentrations and in the density and stability of the generated foam. The foaming agents are supplied in either liquid or powder form. Two foaming agents were tested; Ultrawet DS Surfactant, which is supplied in powder form and Millifoam which is supplied as a solution. Ultrawet DS is an alkyl benzene sulfonate having a linear secondary alkyl side chain with an average carbon content ranging from 8.5 to 10.5 and a maximum carbon number spread of 8 carbon atoms. [7] The chemical composition of Millifoam is sodium alkylethoxysulphate.

The same quality foam may be obtained under the same governing conditions by using different strength solutions of different foaming agents, in which case, the governing factors for the choice become economical ones, since the higher the concentration of the solution, the higher the cost. It is therefore an objective to use low strength solutions. The final selection of foaming agent is according to its performance in the experiments. The foaming agents tested demonstrated that at constant solution feed rate and pressure conditions, the higher the concentration of the solution the lower is the density of the generated foam. This is illustrated in the results of the experiments Graph 2.

3.3.2 The Feed Rate of the Solution at Constant Concentration

The density of the generated foam increased with the increase in solution flow rate. Since at the higher flow rate the solution passes through the pumps quicker it is subjected for a lower interval to the shearing action of the impellers and thus foams less leading to a higher density foam. This result is illustrated in Graph 5.

3.3.3 The Air Pressure, The Air Introduction Method and the Length of the 'Mixing Chamber'

Since the primary use of foam in the board is weight reduction through replacing stucco volume by minute evenly distributed air bubbles in the core, it is necessary to introduce a constant flow of air into the solution. The introduced air increases the generation of foam, and controls its density. The higher the air pressure (air flow) the lower is the density of the generated foam, as is illustrated in Graph 1.

Because the presence of large air bubbles in the foam weakens the board core and produces voids in the board, controlling the size of the air bubbles (less than 1/64" Dia.) is very important. The method and location of air introduction in this system is a very important feature and is shown in Figure 3.3. In order to avoid producing large air bubbles, the air is not introduced directly into the solution but is fed around the solution feed pipe into a 'mixing chamber' where the air and solution mix together. The location of the air introduction is just before the suction inlet of the first centrifugal pump which allows the solution air mixture to be aspirated into the pump for direct foam generation. Although this design for air introduction prevents the formation of large air bubbles, there are limits to the air pressure which can be used. Decreasing the foam density cannot be achieved by just increasing the air pressure, but by a combination of the controlling factors presented in Section 3.3 to achieve the desired low density and the desired size of air bubbles.

Experiments carried out illustrate that the length of the 'mixing chamber' is a very critical factor in controlling the density of the generated foam. The length of this mixing chamber had to be increased from the original 3 in. dimension to 4 inches, to arrive at the required foam density. This is considered to be a further indication of the importance of this special design, and its dimensions in the success of the system. Experiments were carried out after each incremental increase of 1/4 in. until the desired foam qualities were achieved.

Due to the practical nature of this project no further research was carried out to improve the air-solution mixing beyond the success achieved, but it is an area which can be further studied. Suggestions are presented in Chapter 5. It is expected that there is an optimum length for the mixing chamber because if the solution is introduced too far away from the pump inlet, the aspiration effect into the pump will be decreased.

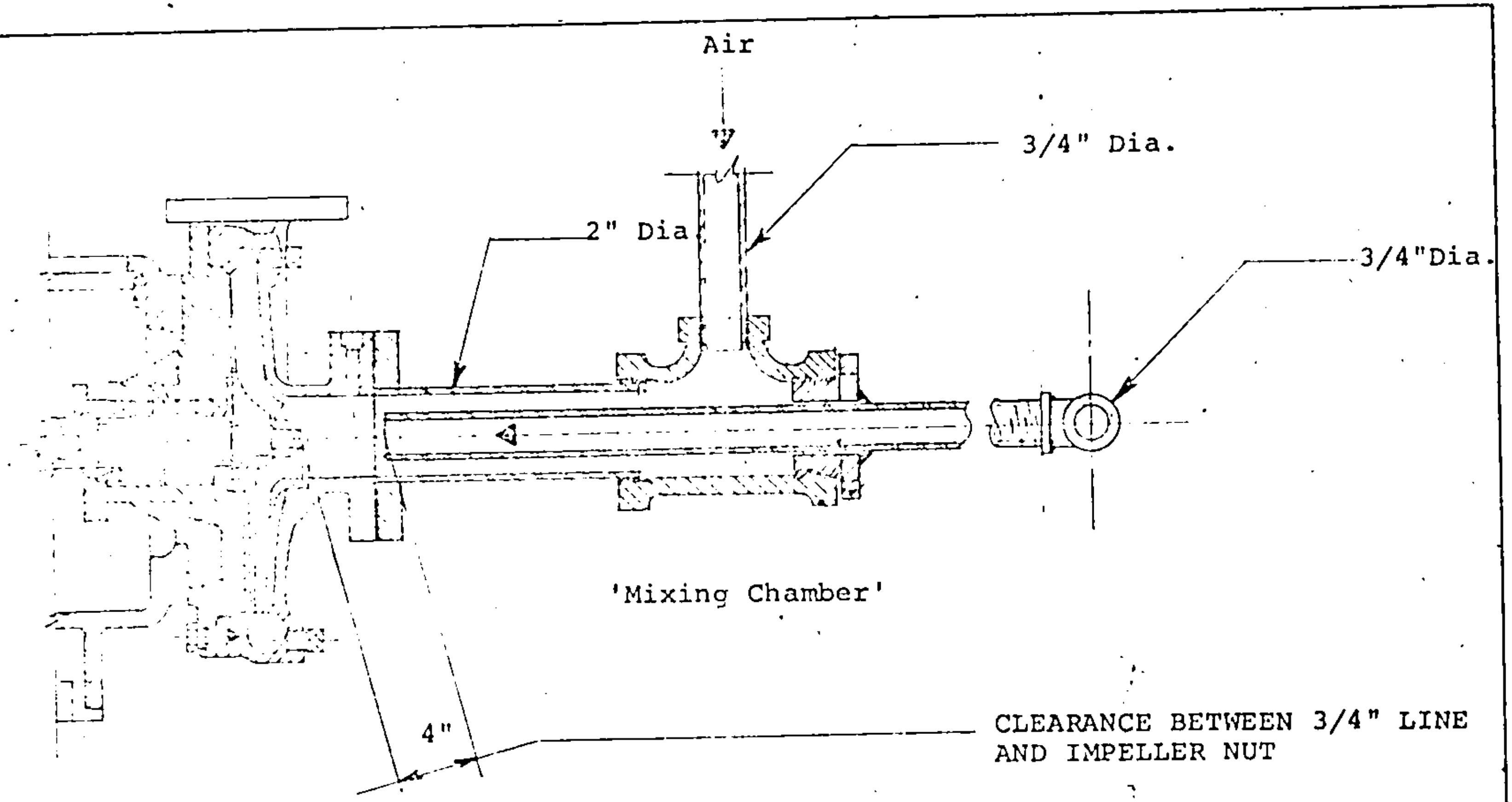


FIG. 3.3 The 'Mixing Chamber'

3.3.4 The Back Pressure Applied to the Centrifugal Pumps

A pressure regulating valve is placed in the line downstream of each pump, as shown in Figure 3.2, Section BB. These regulators apply a back pressure to each pump. By means of adjusting the back pressure, the density of the generated foam can be controlled.

When the back pressure is increased with all other variables remaining constant, the density of the foam decreases as is illustrated in Graph 3.

The following section details all the experiments carried out and their results with illustrating graphs. The graphs drawn to experiment readings highlight the relations between the factors governing the performance of the generating system and together with the experiment findings, lead to a final conclusion on the system setting and performance.

3.4 EXPERIMENTS AND RESULTS

Experiments were carried out to select the foaming agent, the solution strength, and to determine the settings of the factors affecting the performance of the generating system outlined in Chapter 3, Section 3.3, that would fulfill the requirements of the new system as outlined in Chapter 1, Section 1.4. Presented in this Section are the results of the most important experiments which lead to the finalized design and to the individual values of the governing factors necessary to generate the required foam.

In order to have a standard system at all plants the requirements of the new system dictate that the system has to be capable of generating a stable foam in the density range of 8-14 lb/cu.ft. when using a solution flow rate in the broad range of 2-8 IGPM. This broad flow range is specified because each plant has three different production speeds and because these speeds differ from plant to plant. In the following experiments the objective is to generate the required density foam in the flow rate range specified with a constant solution concentration because in this system the solution is made in batches and a plant cannot change the concentration of the batched solution each time it changes its production speed.

In order to understand the logic of the sequence of the presented experiments it must be understood that the most stringent requirement is generating the 8 lb/cu.ft. density foam at the 8 IGPM flow rate, i.e., the lowest density at the highest flow rate. This is because a low density foam is more difficult to generate (a higher density foam means more liquid and less air) and because this difficulty increases with the increase in solution flow rate since the density of the generated foam increases with the increase in the generation rate. The logic followed is therefore to assure that the system can generate the 8 lb/cu.ft. density foam when using a 2 IGPM solution flow rate (experiments 1,2 and 3) then to proceed to the 8 IGPM test (experiment 4). The generated foam must also meet the specified requirements for the size of the air bubbles and stability. Stability, which is the measure of the breakdown of the generated foam into liquid and air in a specific time period, was measured by collecting the generated foam in a 1,000 ml. graduated beaker and measuring the liquid at the beaker bottom after an interval of 5 minutes. The objective is to generate a highly stable foam which would not exceed a breakdown of more than 3% in the specified time period, i.e., 30 ml/5 min.

The experiments were carried out in one of the plants, the set-up and gauging points are shown in Figure 3.4. In order to prepare the solution batches a 45 gallon drum was used. A small 1/8 H.P. Lightning Mixer was used to dissolve and mix the foaming agents. Instead of installing a flow meter, the metering pump was calibrated and the speed setting on the variable speed drive equivalent to 2,4 and 8 IGPM were marked.

The air bubbles were visually inspected during the experiments. Samples of the finished board were inspected at the Domtar Research Centre at Senneville, by using a

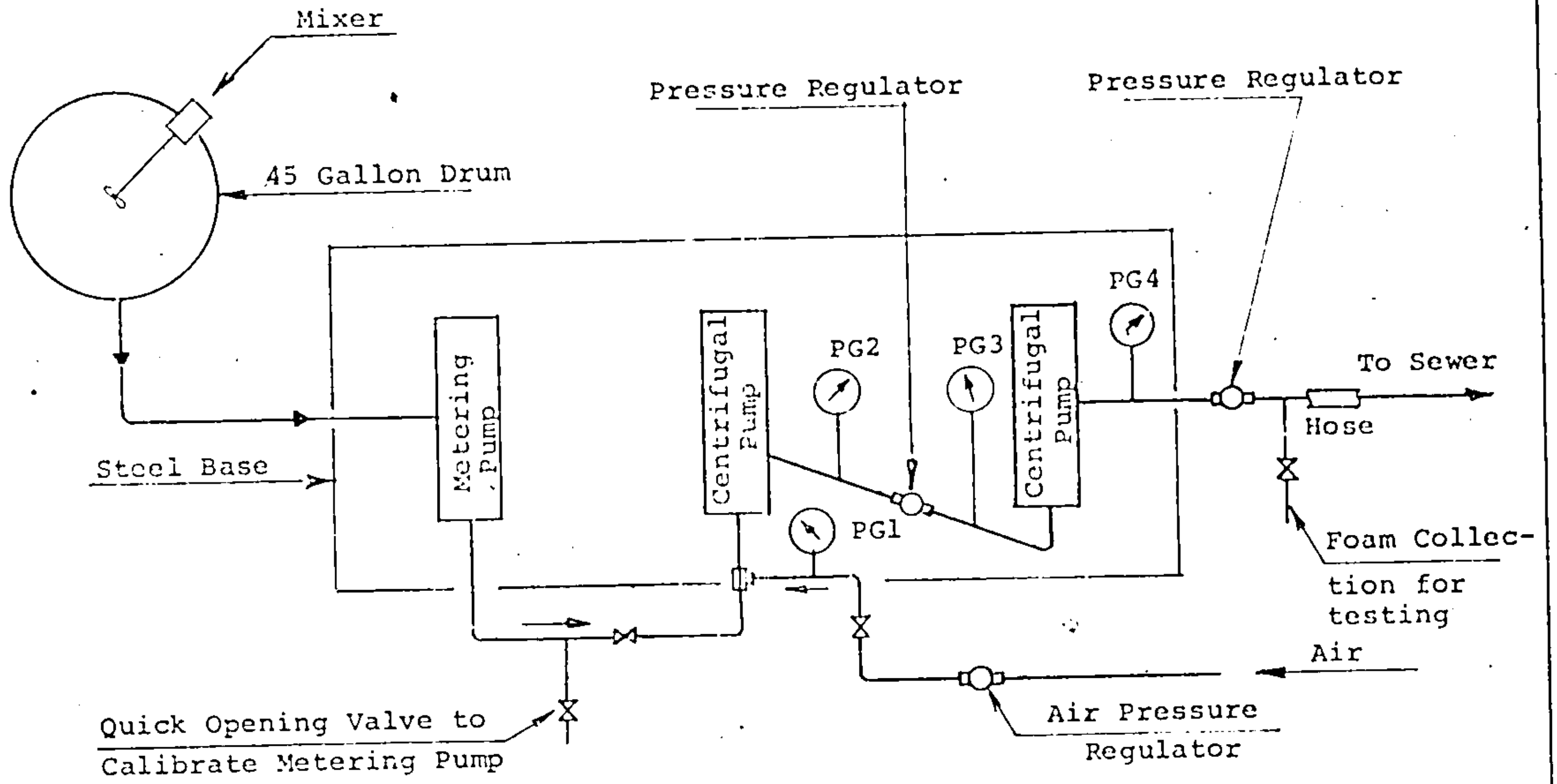


FIG. 3.4 Experiments' Set-Up and Gauging Points

scanning electron microscope.

3.4.1 Experiment 1

The foaming agent utilized in this experiment was Ultrawet (powder form). Three different solution strengths 0.2%, 0.5% and 1.0% by weight, were prepared and tested at a flow rate of 2 IGPM; the results are listed in Table 1A, Table 1B and Table 1C, respectively. The length of the mixing chamber was set at 3 inches.

3.4.1.1 Observations

Graph 1 is drawn to the readings obtained from experiment 1B and presents the relation between the density of the generated foam and the air pressure. The graph shows that the density of the generated foam decreases by increasing the air pressure (flow).

Graph 2 is drawn to the readings obtained from experiments 1B and 1C and presents the relation between the concentration of the foaming agent solution and the density of the generated foam. It shows that increasing the concentration decreases the density of the generated foam for the same air pressure. These two curves are, however, not drawn to the same pump back pressures, the densities for the 1.0% concentration curve would have been much lower if drawn to the same back pressures, as the 0.5% concentration curve. Graph 2 also shows that for the same air pressure

(6 psi) the density of the generated foam is the same using either concentrations but that much lower back pressure was needed with the higher concentration to produce the same density.

3.4.1.2 Conclusion of Experiment 1

With a 3 inch long mixing chamber and a flow of 2 IGPM Ultrawet Solution:

Experiment 1A:	It is not possible to generate an 8 lb/cu.ft. density foam using a solution strength of 0.2%.
Experiment 1B:	It is possible to generate an 8 lb/cu.ft. density foam using a solution strength of 0.5% but the generated foam had large air bubbles attributed to high air pressure and insufficient air - solution mixing. The foam stability is acceptable.
Experiment 1C:	The 8 lb/cu.ft. foam generated using a 1.0% solution strength also had large air bubbles, although at higher concentrations less air pressure is required to produce the same density foam. The foam stability is acceptable.

TABLE 3.1A EXPERIMENT 1A

Foaming Agent: Ultrawet
% Concentration: 0.2%
Solution Flow: 2 IGPM

	PRESSURES				DENSITY	STABILITY
	Air PG1 psig	Outlet of First Pump PG2 psig	Inlet of Second Pump PG3 psig	Outlet of Second Pump PG4 psig	lb/cu.ft.	ml/5 min.
(1)	6	14	0	15	17	20
(2)	18	20	15	17	11.75	23
(3)	19	30	10	30	10.5	32
(4)	19	35	9	35	10.25	43
Solution Flow: 4 IGPM						
(5)	18	39	8	40	12.25	50

TABLE 3.1B <u>EXPERIMENT 1B</u>

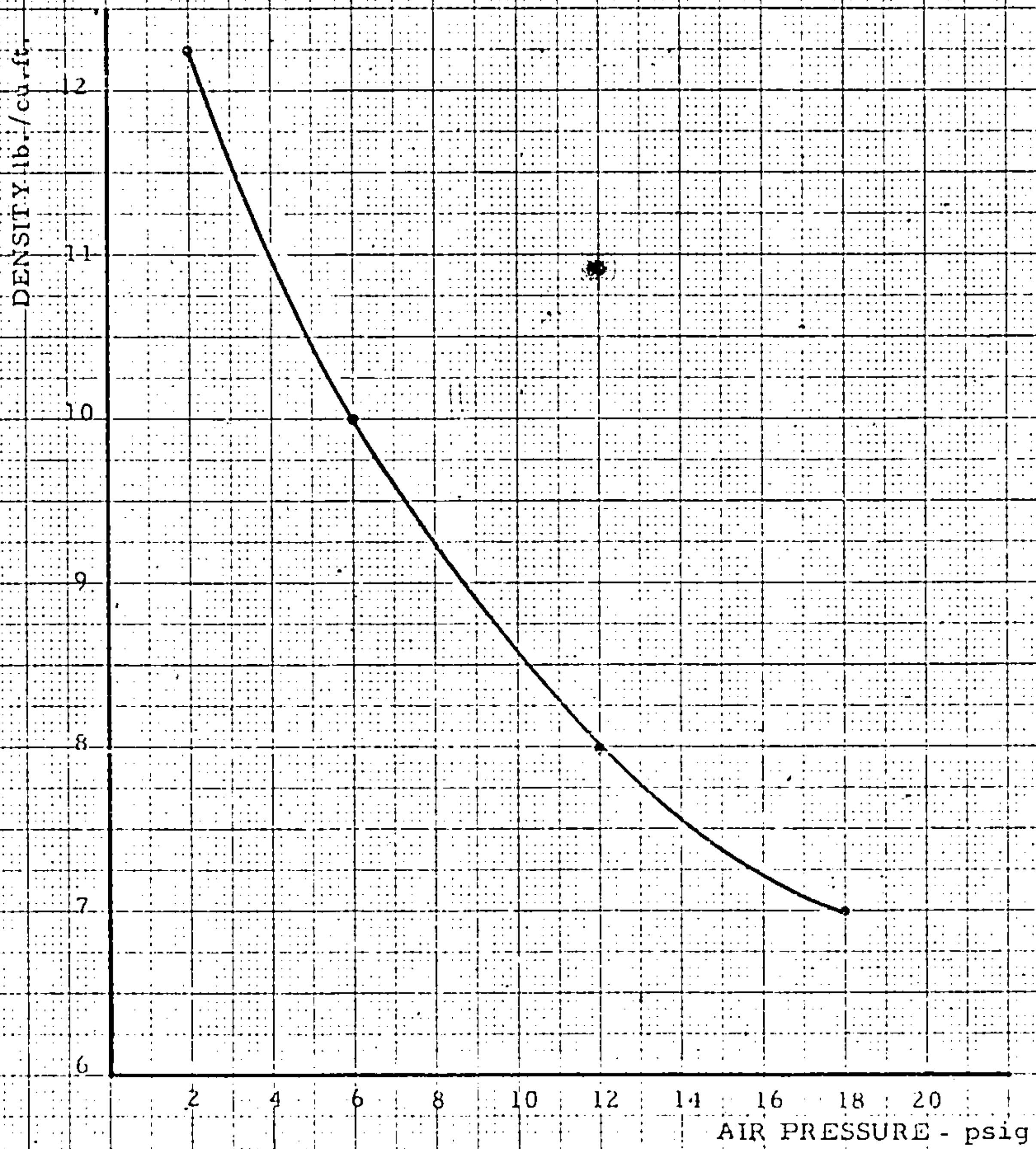
Foaming Agent: Ultrawet
% Concentration: 0.5%
Solution Flow: 2 IGPM

	PRESSURES				DENSITY	STABILITY
	Air PG1 psig	Outlet of First Pump PG2 psig	Inlet of Second Pump PG3 psig	Outlet of Second Pump PG4 psig	lb/cu.ft.	ml/5 min.
(1)	2	14	-8	14	12.25	35
(2)	6	25	0	25	10	25
(3)	6	30	-5	30	9.75	25
(4)	6	40	-2	40	9.5	50
(5)	12	40	4	40	8	27
(6)	18	40	8	40	7	19

TABLE 3.1C EXPERIMENT 1C

Foaming Agent: Ultrawet
% Concentration: 1.0%
Solution Flow: 2 IGPM

	PRESSURES				DENSITY	STABILITY
	Air PG1 psig	Outlet of First Pump PG2 psig	Inlet of Second Pump PG3 psig	Outlet of Second Pump PG4 psig	lb/cu.ft.	ml/5 min.
(1)	2	14	-8	14	11.5	27
(2)	4	16	-7	13	11.75	27
(3)	6	16	-2	14	10	26
(4)	10	16	4	16	7.75	15
(5)	12	18	8	17	6.75	



GRAPH 1

Results of Experiment 1B

Effect of the Inlet Air Pressure on
the Density of the Generated
Foam

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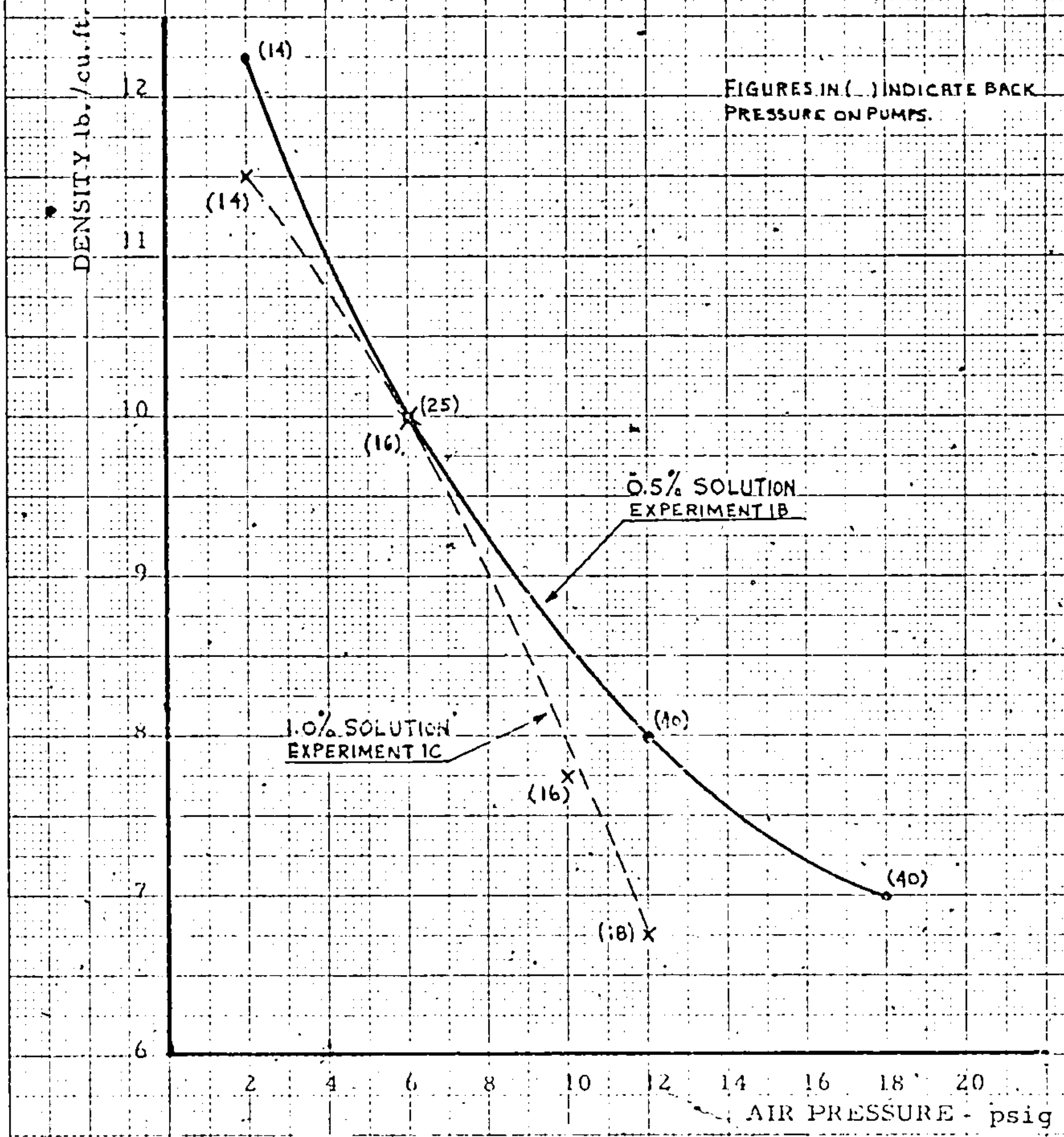


GRAPH 2

Results of Experiments 1B and 1C

Effect of the Concentration of the Foaming Agent Solution on the Density of the Generated Foam

3.4.1.3 Following Action

To investigate the behaviour of another foaming agent.

3.4.2 Experiment 2

The foaming agent utilized in this experiment was Millifoam (liquid form). Four different solution strengths, 0.3%, 0.5%, 1.0% and 2.0% by weight, were prepared and tested at a flow rate of 2 IGPM, the results are listed in Table 3.2A, Table 3.2B, Table 3.2C and Table 3.2D, respectively. The length of the mixing chamber was set at 3 inches.

3.4.2.1 Conclusions of Experiment 2

With a 3 inch long mixing chamber and a flow of 2 IGPM Millifoam solution:

Experiments 2A and 2B:	It is not possible to generate an 8 lb/cu.ft. foam using a solution strength of 0.3%.
Experiments 2C and 2D:	It is possible to generate an 8 lb/cu.ft. foam but the high breakdown and large size of air bubbles are not acceptable.

Comparing generated foam of the same density using the two different agents tested in Experiments 1 and 2, it is apparent that higher air and pump pressures are required when using the Millifoam solution. Higher concentrations are also necessary. For all the above reasons all further experiments were carried out using Ultrawet foaming agent.

3.4.2.2 Following Action

To improve the air-solution mixing by increasing the length of the mixing chamber. With improved mixing, the air entrainment efficiency will increase allowing the use of lower air pressure to generate the required density foam. Decreasing the air pressure will reduce the size of the air bubbles in the generated foam. The next experiment presents the results with the mixing chamber length set at 4 inches.

The efficiency of air entrainment in the mixing chamber appears to be low because high air inlet pressures are required to provide enough air volume to produce the desired low density foam. At the high pressures, part of the air passed without mixing through the system and appeared as large bubbles in the generated foam.

3.4.3 Experiment 3

The foaming agent utilized in this experiment was Ultrawet at a solution strength of 0.5% by weight at a flow rate of 2 IGPM. The results are listed in Table 3.3. The length of the mixing chamber was set at 4 inches.

TABLE 3.2A EXPERIMENT 2A

Foaming Agent: Millifoam
% Concentration: .3%
Solution Flow: 2 IGPM

	PRESSURES				DENSITY	STABILITY
	Air PG1 psig	Outlet of First Pump PG2 psig	Inlet of Second Pump PG3 psig	Outlet of Second Pump PG4 psig	lb/cu.ft.	ml/5 min.
(1)	2	14	-6	14	20.75	no measurable breakdown
(2)	4	14	-3	14	19.75	"
(3)	6	14	0	14	18.5	"
(4)	10	15	8	15	17.25	"
(5)	6	25		25	16.75	"

TABLE 3.2B **EXPERIMENT 2B**

Foaming Agent: Millifoam
% Concentration: 0.5%
Solution Flow: 2 IGPM

	PRESSURES				DENSITY	STABILITY
	Air PG1 psig	Outlet of First Pump PG2 psig	Inlet of Second Pump PG3 psig	Outlet of Second Pump PG4 psig	lb/cu.ft.	ml/5 min.
(1)	2	14		14	17 1/2	no measurable breakdown
(2)	2	23	-2	24	16	"
(3)	6	25	0	25	14.25	"
(4)	12	16	12	14	13.5	"
(5)	12	25	6	25	12	"
(6)	16	25	10	25	13.25	"
Solution Flow: 4 IGPM						
(7)	6	25	0	25	16.25	"

TABLE 3.2C <u>EXPERIMENT 2C</u>

Foaming Agent: Millifoam
% Concentration: 1.0%
Solution Flow: 2 IGPM

	PRESSURES				DENSITY	STABILITY
	Air PG1 psig	Outlet of First Pump PG2 psig	Inlet of Second Pump PG3 psig	Outlet of Second Pump PG4 psig	lb/cu.ft.	ml/5 min.
(1)	10	14	3	14	10.5	
(2)	10	25	4	25	9.5	
(3)	10	40	0	40	9.5	
(4)	12	14	5	14	9.75	
(5)	12	40	3	40	9	30
(6)	18	40	7	40	8	51
Solution Flow: 4 IGPM						
(7)	18	45	8	45	9.25	

TABLE 3.2D EXPERIMENT 2D

Foaming Agent: Millifoam
% Concentration: 2.0%
Solution Flow: 2 IGPM

	PRESSURES				DENSITY	STABILITY
	Air PG1 psig	Outlet of First Pump PG2 psig	Inlet of Second Pump PG3 psig	Outlet of Second Pump PG4 psig	lb/cu.ft.	ml/5 min.
(1)	6	14	0	14	9.5	
(2)	10	14	10	14	8.25	
(3)	12	14	13	14	7.5	
(4)	6	25	-3	25	9.25	45
(5)	10	25	0	25	8	55
(6)	10	40	5	40	7.5	
(7)						

3.4.3.1 Observations

The relation between the density of the generated foam and the back pressure applied to the centrifugal pumps is presented in Graph 3, drawn to the readings of experiment 3. The graph shows that for the same inlet air pressure, increasing the back pressure on the pumps decreases the density. It also shows that the extent of reduction in density attributed to the increase in pump pressure depends on the air pressure. At an inlet air pressure of 2 psi increasing the pump back pressure from 30 psi to 40 psi decreased the density by 1.5 lb/cu.ft. from 9.5 down to 8 lb/cu.ft. while the same increase in pump pressure at an inlet air pressure of 6 psi produced a reduction in density of .75 lb/cu.ft. from 8.5 down to 7.75 lb/cu.ft. The graph also shows that for the same pump back pressure increasing the air inlet pressure decreases the density.

Graph 4 presents the effect of changing the length of the mixing chamber on the density of the generated foam compared at the same air inlet pressure of 6 psi for a 2 IGPM flow of 0.5% Ultrawet solution. The graph shows that with all mentioned variables remaining constant, the density of the generated foam decreased with the increase in mixing chamber length due to increased air entrainment in the solution a result of improved mixing efficiency.

3.4.3.2 Conclusions of Experiment 3

With a 4 inch long mixing chamber and a flow of 2 IGPM Ultrawet solution at a concentration of 0.5%:

> It is possible to generate the full range of densities required. The generated foam had the required small air bubbles and met the stability requirements. The inlet air pressure required is quite low and the pump back pressures are reasonable.

Success of this experiment is attributed to the increased air entrainment.

3.4.3.3 Following Action

Since the system has been proven to be capable of generating the required foam at a flow rate of 2 IGPM, the next step is to test the system at the maximum flow rate of 8 IGPM.

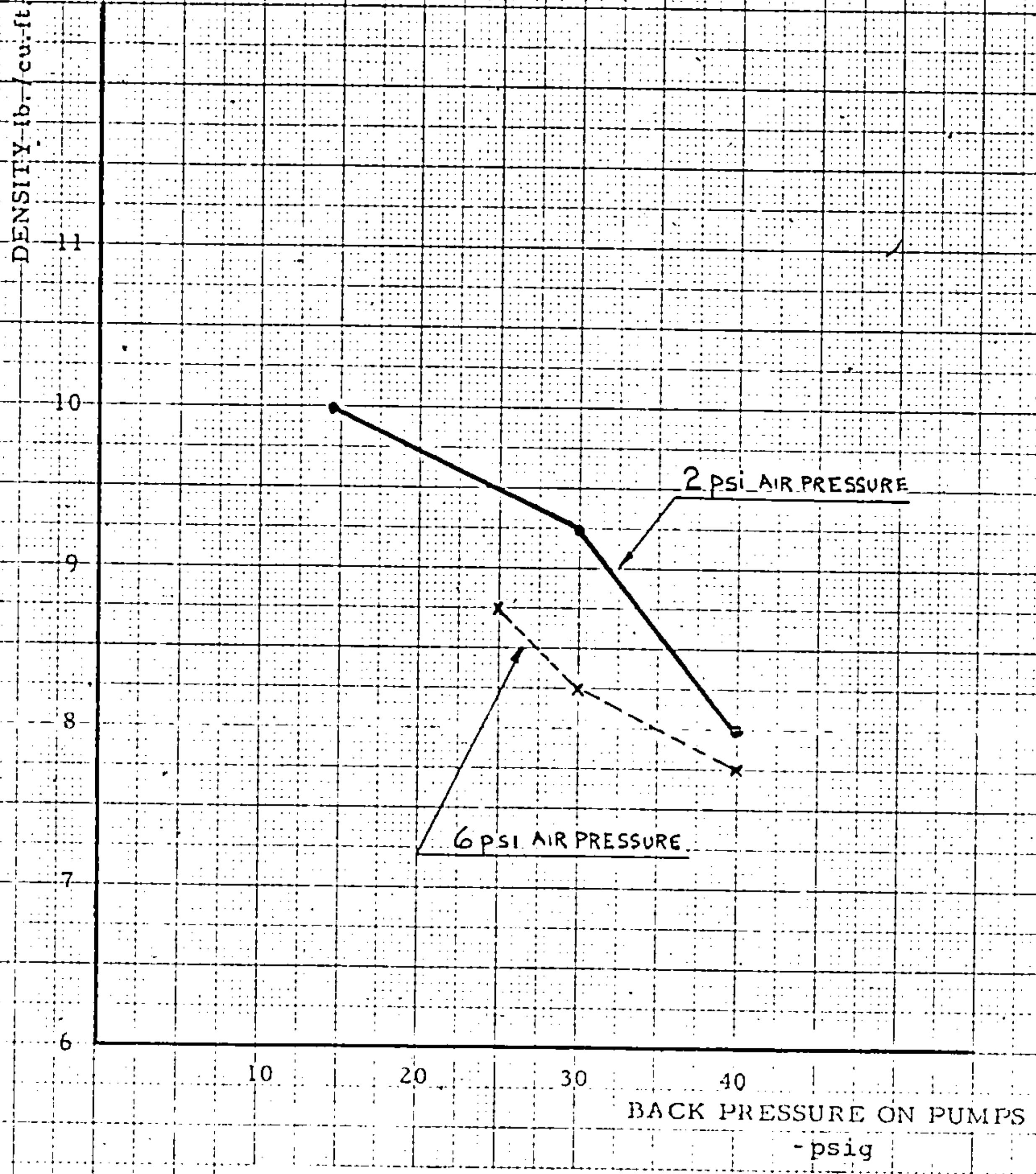
3.4.4 Experiment 4

The foaming agent utilized in this experiment was Ultrawet at a solution strength of 0.5% at a flow rate of 8 IGPM. The results are listed in Table 4. The length of the mixing chamber set at 4 inches.

TABLE 3.3 <u>EXPERIMENT 3</u>

Foaming Agent: Ultrawet
% Concentration: 0.5%
Solution Flow: 2 IGPM

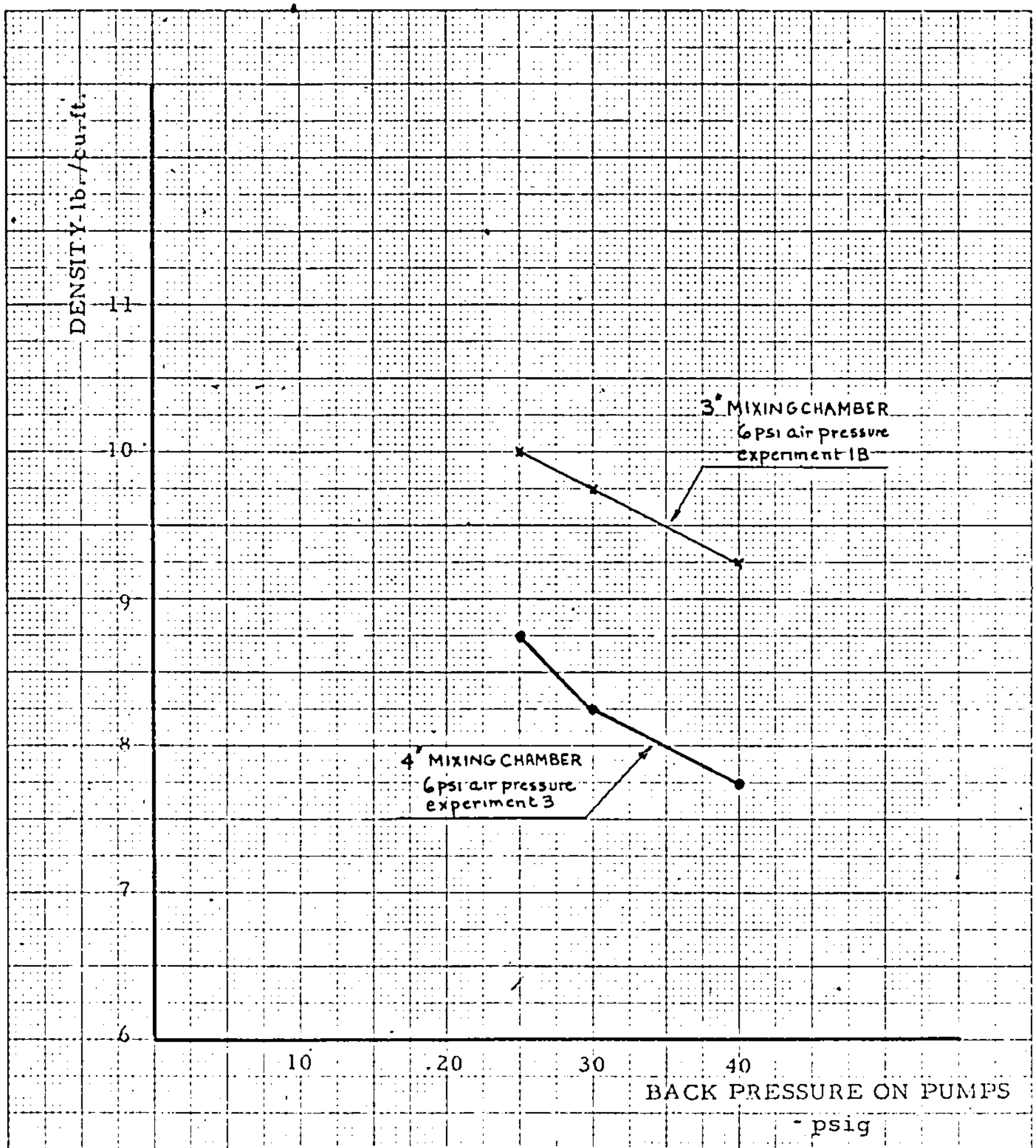
	PRESSURES				DENSITY	STABILITY
	Air PG1 psig	Outlet of First Pump PG2 psig	Inlet of Second Pump PG3 psig	Outlet of Second Pump PG4 psig	lb/cu.ft.	ml/5 min.
(1)	1	5	-9	5	14	20
(2)	2	14	-6	14	10	25
(3)	2	30	-4	30	9.25	23
(4)	2	40	5	40	8	27
(5)	6	25	-4	25	8.75	
(6)	6	30	0	30	8.25	
(7)	6	40	4	40	7.75	
(8)	12	40	8	40	5.25	



GRAPH 3

Results of Experiment 3

Effect of Pump Back Pressure on the Density of the Generated Foam



GRAPH 4

Results of Experiments 1B and 3

Effect of 'Mixing Chamber' Length on the Density of the Generated Foam

3.4.4.1 Observations

The relation between density and solution flow rate is presented in Graph 5. The graph is drawn to the results of experiments 3 and 4. It shows that at the same solution concentration, air inlet pressure and the same back pressure on the pumps, the density of the generated foam increases with the increase in solution flow rate. The graph also shows that to generate the same density foam using a higher solution flow rate higher air inlet pressure and higher pump back pressure are needed.

3.4.4.2 Conclusions of Experiment 4

With a 4 inch long mixing chamber and a flow of 8 IGPM Ultrawet solution at a concentration of 0.5%:

It is possible to generate the full range of densities required. The generated foam had the required small sized air bubbles and confirmed with the stability requirements.

TABLE 3.4 EXPERIMENT 4

Foaming Agent: Ultrawet
% Concentration: .5%
Solution Flow: 8 IGPM

	PRESSURES				DENSITY	STABILITY
	Air PG1 psig	Outlet of First Pump PG2 psig	Inlet of Second Pump PG3 psig	Outlet of Second Pump PG4 psig	lb/cu.ft.	ml/5 min.
(1)	2	14	-3	14	20	
(2)	2	30	0	30	17	
(3)	2	40	6	40	16	
(4)	4	30	3	30	14	17
(5)	4	40	6	40	12.5	
(6)	6	30	7	30	10.75	20
(7)	6	40	10	40	10.25	20
(8)	8	30	11	30	9.25	25
(9)	9	40	14	40	8	29

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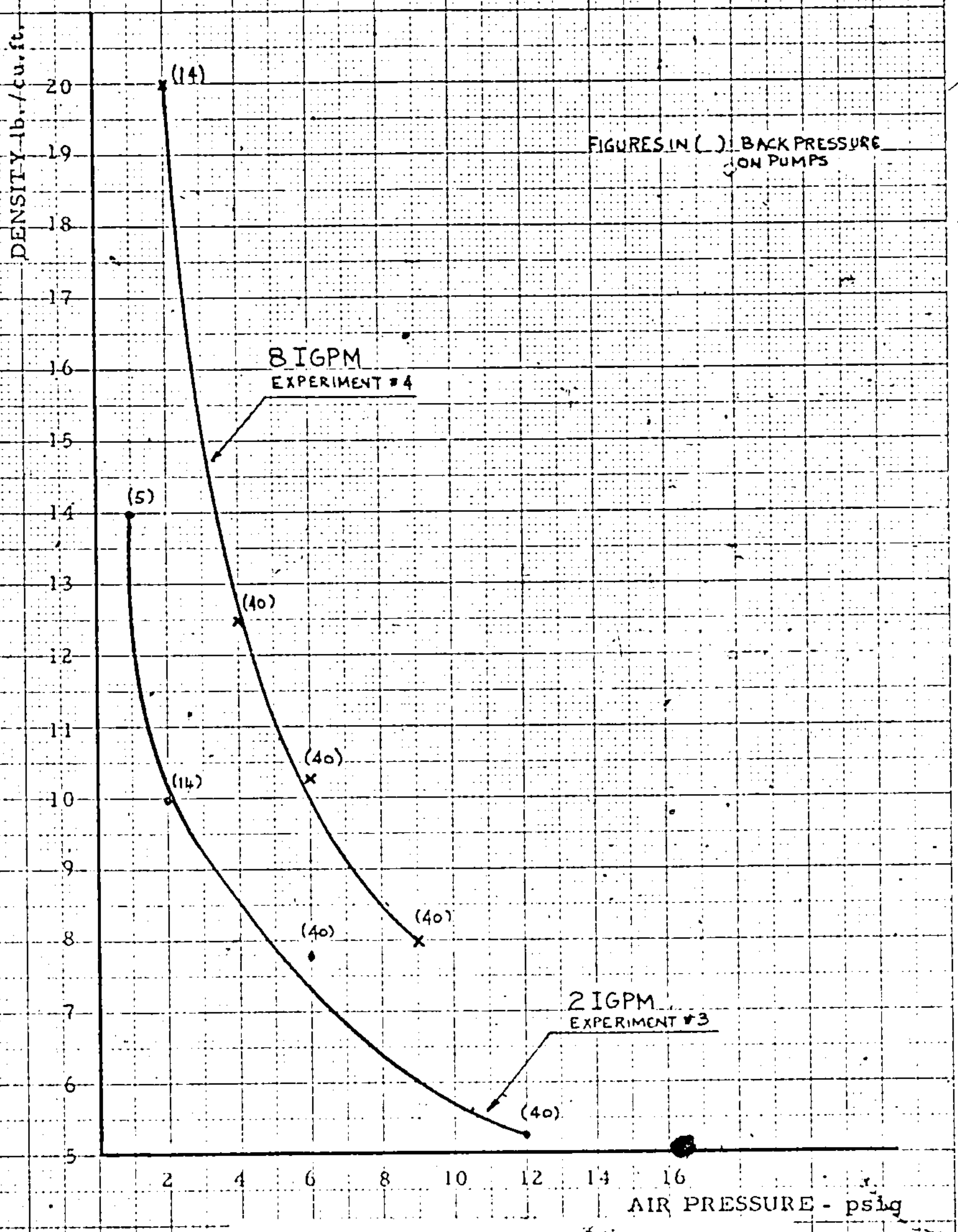
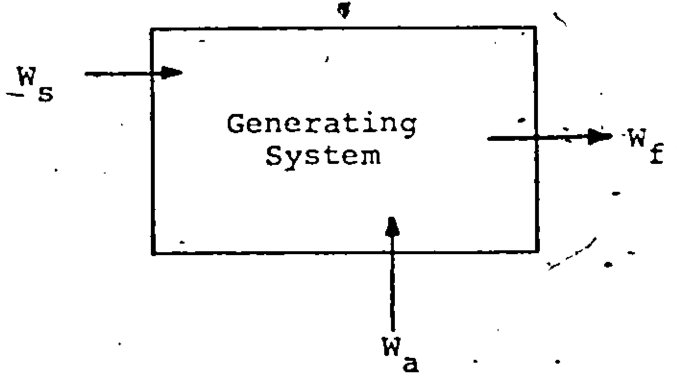


GRAPH 5

Results of Experiments 3 and 4

Effect of Solution Flow Rate on the Density of the Generated Foam

3.5 MATERIAL BALANCE - GENERATING SYSTEM



For the generating system:

$$W_s + W_a = W_f$$

where

W_s = solution mass flow rate - lb/min.
W_a = air mass flow rate - lb/min.
W_f = foam mass flow rate - lb/min.

In order to carry out a material balance, a rotameter was put in the air line just ahead of the 'Mixing Chamber', air flows and pressures were recorded to arrive at the air mass flow rate. In this section, the predicted and actual measured mass flow rates are compared.

When generating a constant density foam at different solution flow rates, it was noticed that the difference between the predicted and actual air mass flow rates decreased as the solution mass flow rate increased, i.e., quite near predicted air mass flow rates were required at the higher solution flow rates indicating that the air entrainment improved at the higher solution flows. This is illustrated in Table 3.5 and Graph 6.

Material balance calculations are included in Appendix A1.5.

3.6 CONCLUSION

The system satisfies all the requirements listed in Chapter 1, Section 1.4, as follows:

(1) The new system is capable of producing a foam with the required stability in the density range of 8-14 lb/cu.ft., when using a solution flow rate in the range of 2-8 IGPM.

(2) The size of the air bubbles in the foam can be controlled to be less than 1/64" dia. by controlling the inlet air pressure, the back pressure on the pumps provides the final adjustments to produce the desired density. At higher solution flows larger air volumes (higher pressure) are needed. Large air bubbles are produced only if more air than necessary is put into the system which then passes right through the system and appears in the generated foam.

(3) The percentage concentration of the required solution by weight is 0.5%.

(4) The cost of the generating system (including a stand - by metering pump) was $4,500. The cost of the batching system was $10,000 including installation. All electrical equipment and installation included.

(5) The system does not contain any equipment that requires operator supervision.

(6) The components of the new system do not require any special maintenance skills for their repair.

TABLE 3.5

PREDICTED vs. ACTUAL AIR MASS FLOW RATES AT VARIOUS SOLUTION MASS FLOW RATES REQUIRED TO GENERATE AN 8 LB/CU.FT. DENSITY FOAM

Predicted Mass Flow Rates To Generate 8lb/cu.ft. Density Foam			Actual Mass Flow Rates To Generate 8lb/cu.ft. Density Foam		
W_s lb/min.	W_a lb/min.	$W_f = W_s + W_a$ lb/min.	W_s lb/min.	W_a lb/min.	$W_f = W_s + W_a$ lb/min.
40	7.6	47.6	40	10.0	50.0
60	11.4	71.4	60	12.8	72.8
80	15.2	95.2	80	15.6	95.6

Back pressure on pumps 40 psig.

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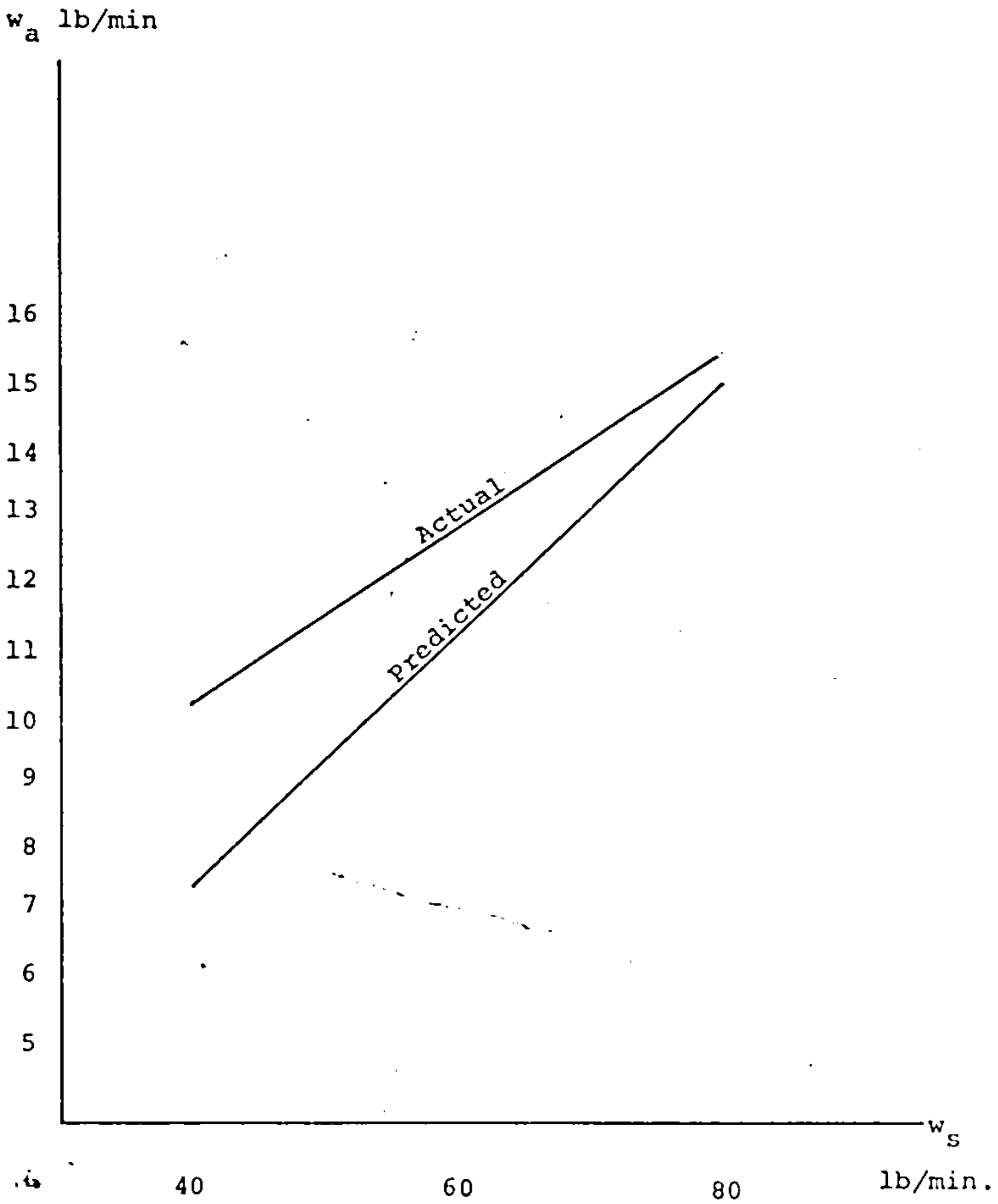

GRAPH 6

Predicted vs. Actual Air Mass Flow Rates at Various Solution Mass Flow Rates Required to Generate an 8 lb/ cu.ft. Density Foam

FIGURE 3.5

Generating System 'Assembly' Drawing

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DRAWING OF DOMTAR FOAM SYSTEM.

CHAPTER IV

THE BATCHING SYSTEM

CHAPTER IV

THE BATCHING SYSTEM

4.1 INTRODUCTION

The function of the Batching System is to prepare an aqueous dilute foaming agent solution from the concentrate foaming agent. Since board production is a continuous process requiring a continuous supply of foam, and therefore a continuous supply of foaming agent solution to the generating system, two batching tanks are necessary. While the content of one is being used, another batch is being prepared.

Since the foam solution has a corrosive nature, a material that would not corrode had to be chosen. Corrosion in the tanks would decrease their life and the rust and scale would also block the lines and Rotameter in the generating system. Three alternative materials were evaluated: - Epoxy-coated Mild Steel, Stainless Steel, and Polyethylene. On a life-cost comparison basis, the Stainless Steel, is the best choice. The system is presented in Figure 4.1, and consists mainly of two 1,000 IG batching tanks situated on the main floor and one 150 IG mixing tank situated on the mezzanine floor. Each tank is furnished with a mixer, and the mixing (top) tank is connected to both of the batching tanks which are connected to the metering

FIGURE 4.1

THE BATCHING SYSTEM

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pump of the Generating System. The 0.5% solution must be prepared without generating foam, this is an important consideration in the choice of the mixers. The various components and method of operation of the system are included in the following description of the batching method procedures to prepare the required 0.5% Ultrawet solution (see Figure 4.1).

4.2 BATCHING PROCEDURES TO PREPARE A .5% 'ULTRAWET' SOLUTION

(1) Push fill start button to actuate solenoid valve to fill mixing tank with water. The water fills to the float position (100 Imperial Gallons) which shuts the water flow by closing the solenoid valve.

(2) Pour 50 lb. (one bag full) of Ultrawet into the mixing tank.

(3) Push button to actuate mixer. After Ultrawet has dissolved shut off mixer.

(4) Open valve (A) to transfer the solution (by gravity) to the required batching tank.

(5) Push the fill start button for the batching tank being filled, this will fill the tank with water up to the float level (1,000 Imperial Gallons). The solenoid valve (C) is normally closed and is opened when the start button is pressed. When the

required level of 1,000 IG is reached the float de-energizes the solenoid valve (C) to close.

(6) Push button to actuate the mixer. After mixing is complete (15 minutes) mixer is shut off by means of a timer.

In operation one tank should be always full while the other is being used. When the one being used becomes empty the valve (E) leading to the main line going to the metering pump in the Generating System is closed and the other tank's (E) valve is opened to start using that tank. The first tank is then refilled. Before using a tank its mixer should be actuated for a period of approximately 10 minutes to avoid any settlement which may have occurred, thus insuring a homogeneous solution. The quick actuating valve (B) is normally open. It is put in line to shut off the water quickly in case of a malfunction (does not clos[illegible] the solenoid valve (C). An overflow line leading to [illegible]rain is also provided to avoid spillage. Valve (D) is normally closed. It is provided in a bypass loop to enable filling the tanks with water in case of a malfunction (does not open) of the solenoid valve (C).

4.3 MIXERS

Greey portable Lightnin mixers were installed in the mixing tank and in the batching tanks. The mixers were mounted on the sides of the tanks. The mixers had to insure proper mixing and at the same time, avoid generating foam in the tanks. Use was made of the research facilities available at Greey Mixing Equipment Ltd., in Toronto, to guarantee the performance of the mixer. The specifications of the mixers are included in Appendix A1.6.

CHAPTER V

CONCLUSIONS AND SUGGESTED FURTHER RESEARCH

CHAPTER V

CONCLUSIONS AND SUGGESTED FURTHER RESEARCH

5.1 CONCLUSION

The system is capable of generating foam which satisfies all the quality requirements of density, bubble size and stability for the designated solution flow range of 2-8 IGPM. The system also satisfies the initial cost, operating and maintenance requirements as indicated in Chapter 3, Section 3.6.

The factors affecting the quality of the generated foam are:

(a) The type of foaming agent and the solution concentration.

(b) The method and efficiency of air entrainment.

(c) The method and efficiency of foam generation.

(d) The combination of controls provided by the generating system.

The above factors were all discussed in detail in previous chapters. The success of the system is attributed to each of these factors and to their combination. Through the use of the highly surface-active Ultrawet DS foaming agent, the indirect introduction of the air into the solution to avoid creating large size bubbles, the high efficiency of air entrainment through the special design 'mixing chamber', the high efficiency of a double stage foam generating bubble size reducing combination of large diameter 'whipping' throttled pumps and 'expansion' valves and the control over the required air flow rate and degree of foam generation (through degree of throttling) provide the success of generating the required density foam through the whole flow range. The combination of these different factors make this system a highly controllable system. Several systems have been built and installed in the plants and are functioning quite satisfactorily.

In order to utilize this system to generate foam in the same density range of 8-14 lb/cu.ft., at solution flow rates higher than 8 IGPM the system would have to be scaled up. The extent of the necessary increase in the back pressure applied to the pumps is dependent on the air entrainment efficiency of the system which increases with the increase in solution flow rate as demonstrated in the material balance observations, Chapter 3, Section 3.5. The increase in the back pressure applied to the pumps will require the utilization of larger pumps and pressure regulating valves. Another alternative to scaling-up the system would be to add a third stage (pump and regulating valve) to the system.

5.2 SUGGESTED FURTHER RESEARCH

Since the system satisfied all the required objectives and due to the practical nature of the project no further research was carried out. Methods for improving the efficiency of air entrainment could be further studied. The introduction of the air in a vortex form may improve the mixing and increase the air entrainment efficiency. The installation of a perforated disc in the air-stream just downstream of the 'mixing chamber' is expected to improve the mixing and reduce the final bubble size. Perforations would be less than 1/64" dia.

APPENDIX A

APPENDIX A

A1.1 SELECTION OF METERING PUMP AND DRIVE

A Moyno pump is used to meter the solution out of the batching tanks to the generating pumps because the Moyno pump can supply a uniform feed rate without pulsation and does not create any shearing action which may generate foam within the pump. The internals of the pump are shown in Figure A1.1, the pump consists of a stator and a rotor and its operation might be compared to that of a precision screw conveyor. Figure A1.2 explains the principle of operation, as the rotor turns within the stator cavities are formed which progress toward the discharge end of the pump conveying the solution, the rotor thus exerts a positive pumping action comparable to that of a piston moving through a cylinder of infinite length. The capacity of the Moyno pump is proportional to the rotational speed of the rotor, by driving the correctly sized pump through a variable speed drive of matched range, the pump can be made to deliver the required flow. It is more desirable to run the pump at a low speed because the wear on the pump increases proportionally to the square of the rotational speed.

The chosen pump has the following designation: 1L4 CDQ which means it has one stage, a standard L-frame size 4, which delivers 1.68 IG per 100 revolutions. The pump has a cast

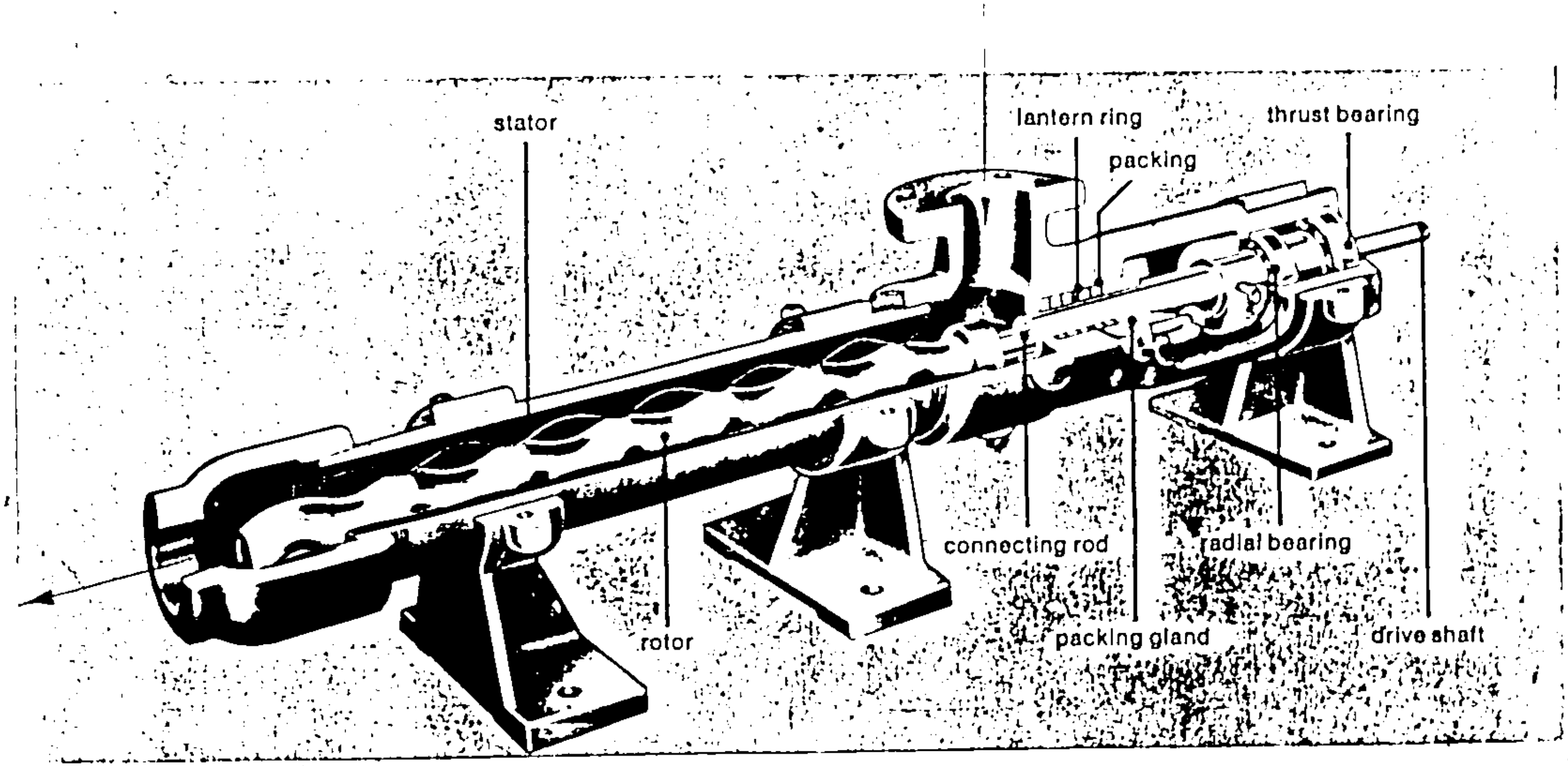
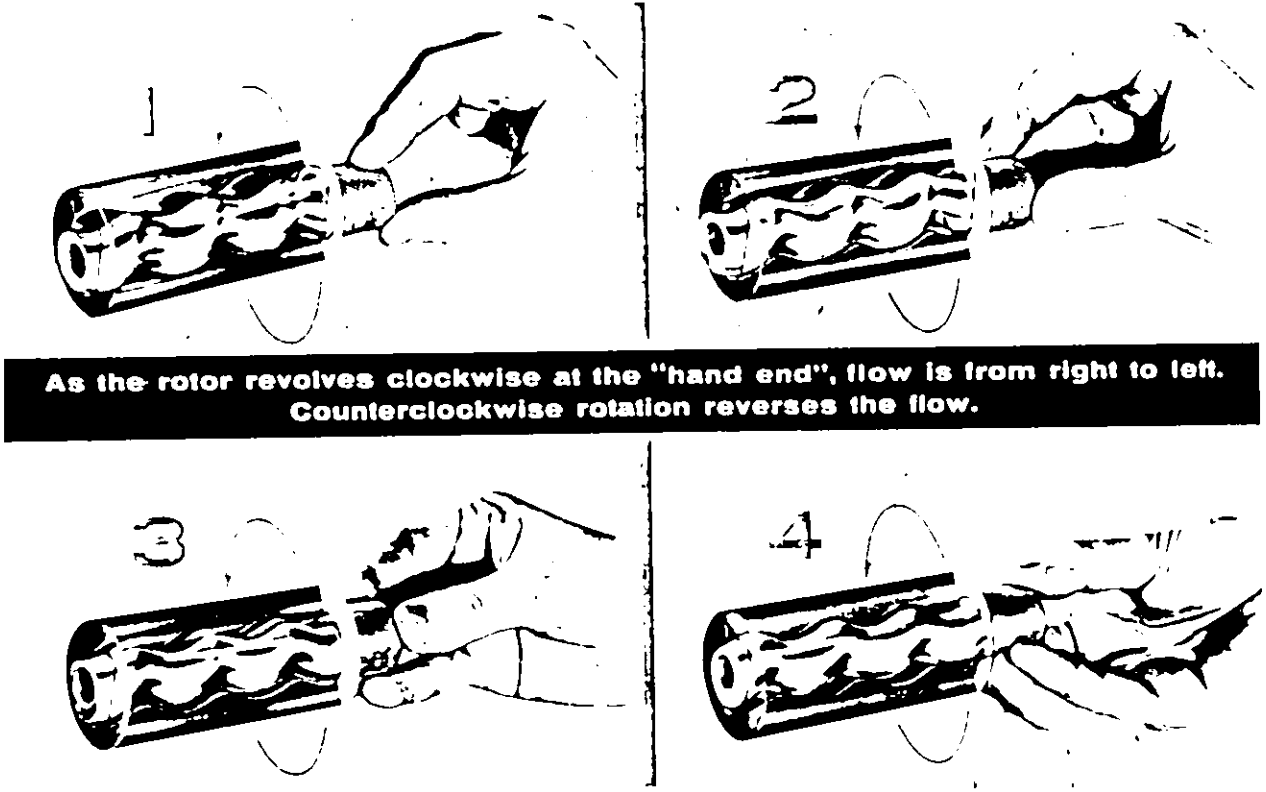


FIG. A1.1 The Moyno Pump



As the rotor revolves clockwise at the "hand end", flow is from right to left. Counterclockwise rotation reverses the flow.

FIG. A1.2 Operating Principle of The Moyno Pump iron frame 'C', the rotor is tool steel 'D' and the stator is Buna N, synthetic rubber 'Q'. The chosen mechanical speed drive is a Sterling drive and is matched with the pump to deliver a flow rate of 2-8 IGPM, the speed range of the drive is 49-500 RPM, driven by a 1 H.P. T.E.F.C. motor.

A1.2 SELECTION OF CENTRIFUGAL PUMPS

The role carried out by the centrifugal pumps in this system is different from what a centrifugal pump is designed for, since the pump is used mainly to shear and not to pump. The pumps are equipped with an open impeller because they create a better shearing action than a closed impeller. The choise of the pumps was guided not so much by the design point rating, but by the overall range of operation desired.

A1.2.1 Pump Designation

Make: Smart - Turner - Hayward
Model: 1½ GWUO
Suction: 2"
Discharge: 1½"
Max. Sphere: ¾"
Impeller Dia.: 8"

A1.2.2 Motor Designation

Make:	Westinghouse
Type:	Totally Enclosed Fan Cooled
H.P.:	10
R.P.M.:	3,600
Phase:	3
Cycle:	60
Volt:	575
Frame:	215 T

The pump and motor are supplied on a steel base and directly coupled with a flexible coupling.

A1.2.3 Pump Construction Materials

Casing:	Cast Iron
Impeller:	Bronze
Shaft:	Steel (SAE 1040)
Shaft Sleeve:	Bronze
Packing:	Graphited long fibre asbestos
Case Gaskets:	Manilla
Gland Bolt and Klip:	Stainless Steel
Lantern Gland:	Bronze
Base Plate:	Steel

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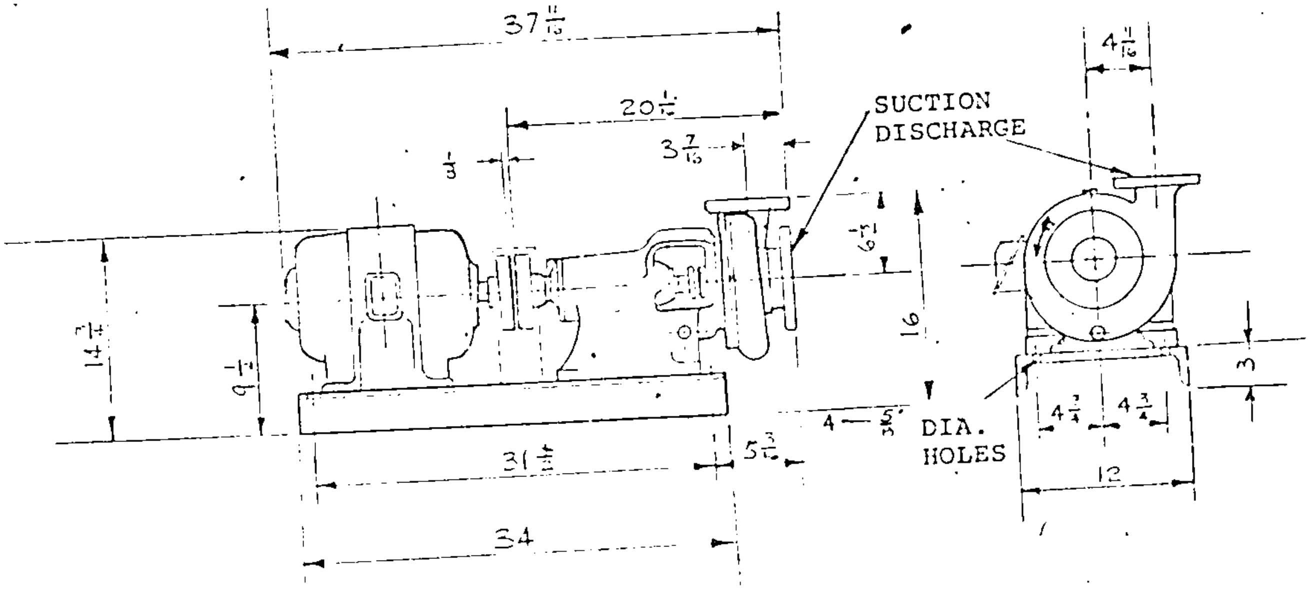

FIG. A1.3 Dimensions of Centrifugal Pump and Motor

A1.2.4 Pump Dimensions

The dimensions of the pump and motor are shown in Figure A1.3.

A1.2.5 Pump Performance Curves

The performance curves for the Smart - Turner - Hayward 1½ GWUO, are shown in Figure A1.4.

A1.3 GENERATING SYSTEM PIPING

The piping layout for the generating system is shown in Figure A1.5.

A1.4 GENERATING SYSTEM STEEL BASE

The steel base required for mounting the components of the generating system is shown in Figure A1.6.

A1.5 MATERIAL BALANCE CALCULATIONS - GENERATING SYSTEM

For a Constant Foam Density of 8 lb/cu.t.

From the measurement done at a flow of 2 IGPM:-

$$W_f = 23.8 \text{ lb/min.}$$

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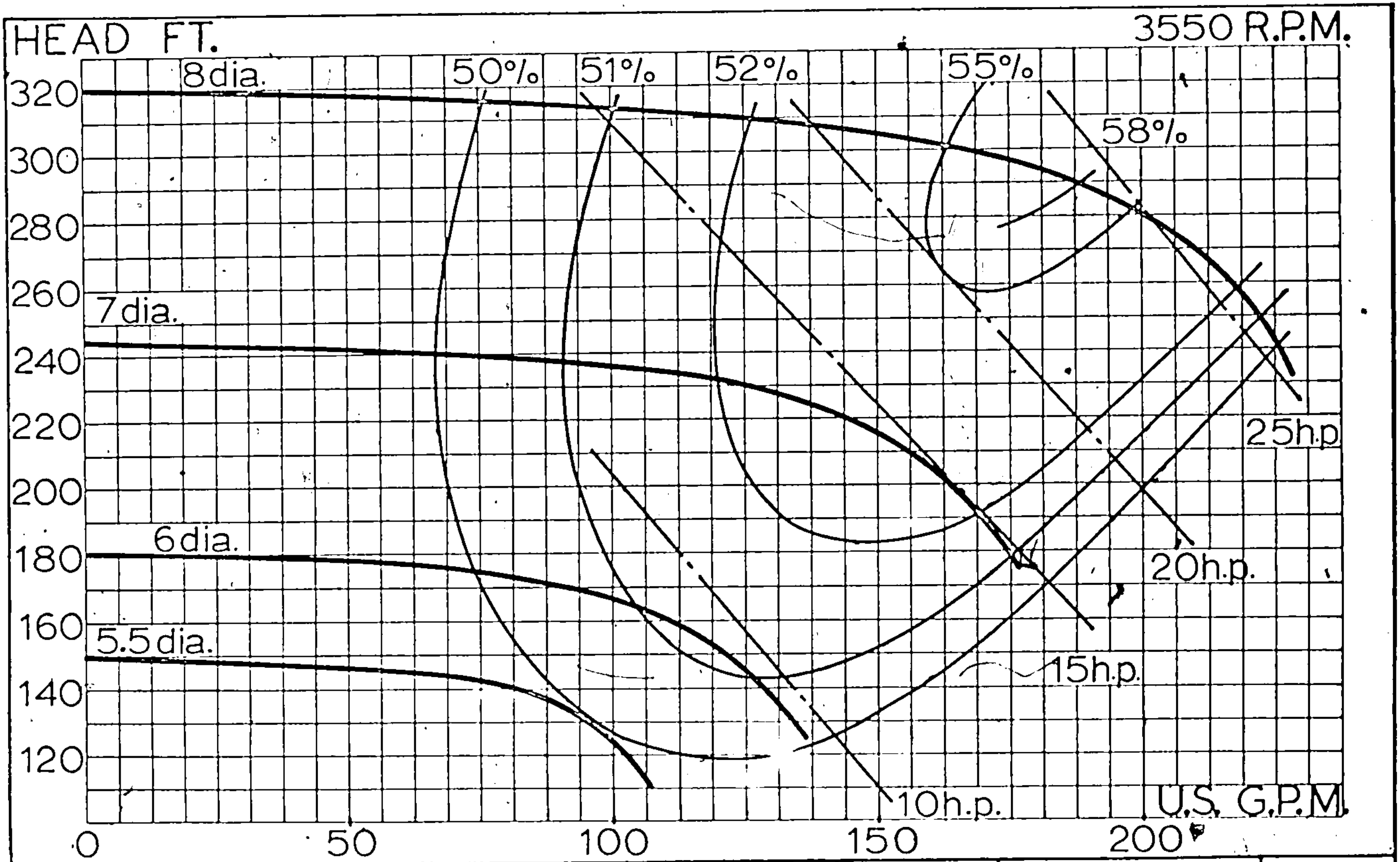
FIGURE A1.4

Graph Chart of Centrifugal Pump Performance
Curves for the Smart - Turner - Hayward
1½ GWUO



PUMP MODEL GW-O	SIZE 1½×2	IMPELLER 00071-4	MAX SPHERE ¾	DATE 27-2-70	APP'D BY	CURVE No G-6127
FREE EYE AREA 3.14sq. in.	MAX DIA 8	MIN DIA 5½	DRAWN RJ.	SMART | TURNER | HAYWARD LTD HAMILTON — CANADA		

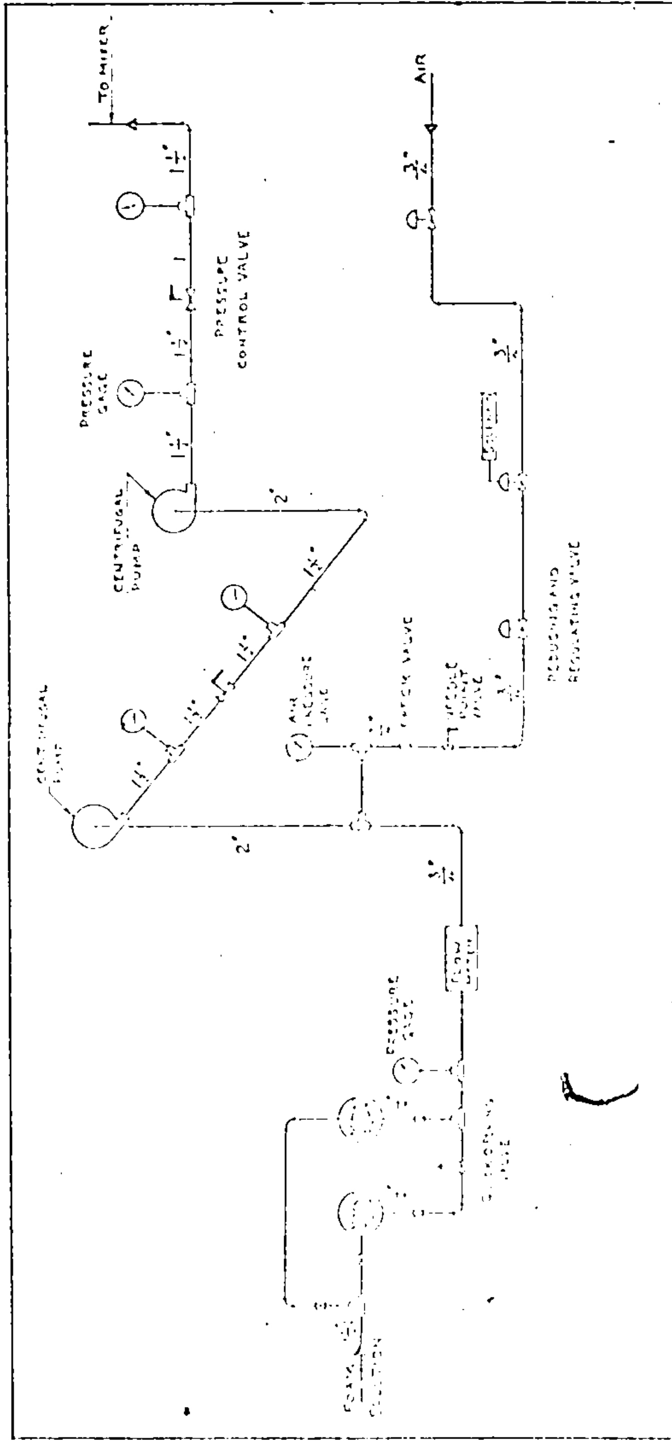


FIG. A1.5 Generating System Piping

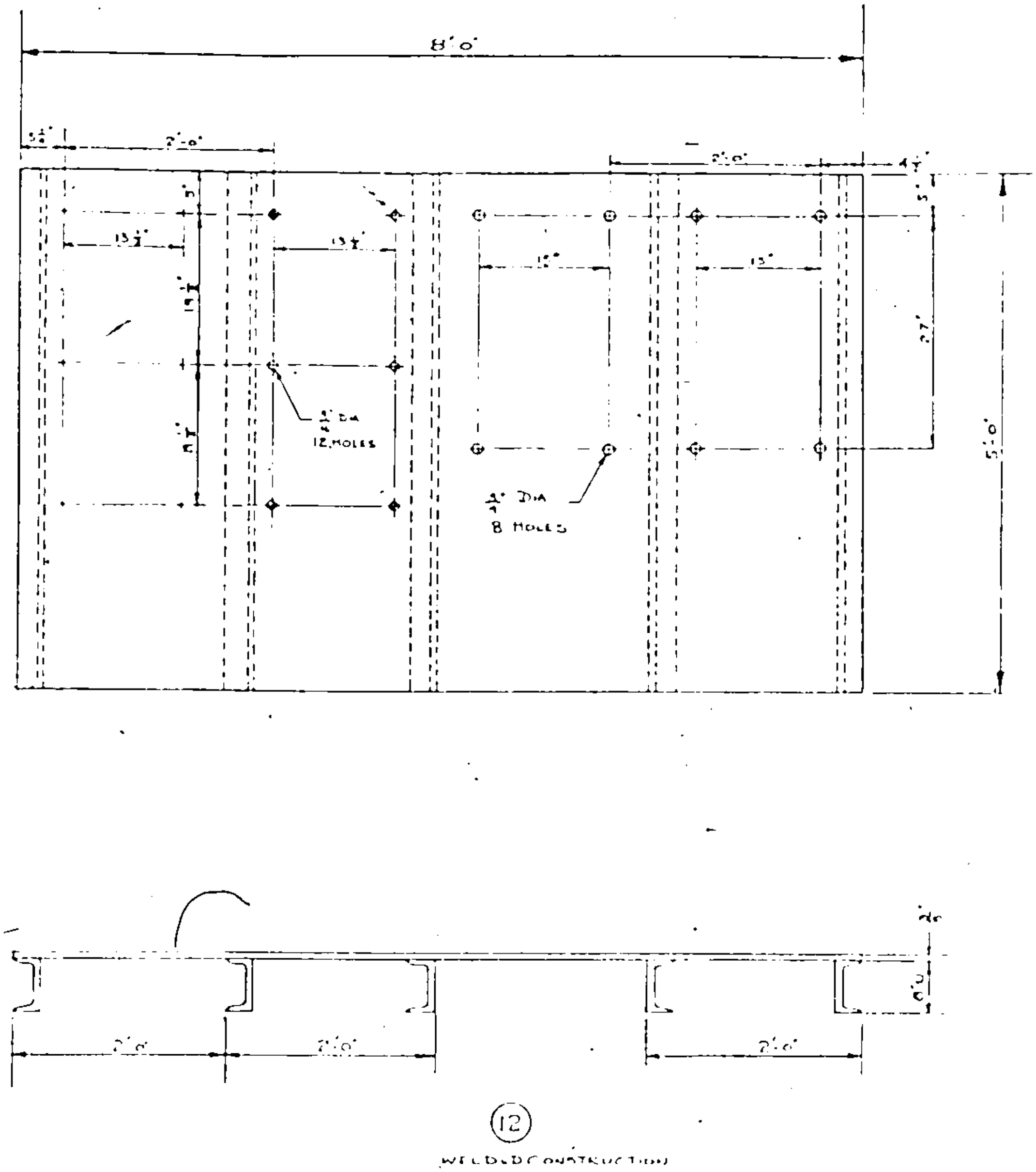


FIG. A1.6 Generating System Steel Base

$$\because \quad w_f = v_f \times d_f$$

$$\therefore \quad v_f = \frac{23.8}{8} = 2.975 \text{ cu.ft/min.}$$

$$\because \quad v_s = .32 \text{ cu.ft/min}$$

$$\therefore \quad v_f = 9.3\ v_s$$

i.e., the volume of the generated foam is 9.3 times the volume of the original solution.

Applying this relationship to the flow rate range to predict the air mass flow rate required to generate an 8 lb/cu.ft. density foam:-

(a) At a Solution Flow Rate of 4 IGPM (w_s = 40 lb/min., v_s = .64 cu.ft/min).

Applying: $v_f = 9.3\ v_s$

$$\therefore \quad v_f = 5.95 \text{ cu.ft/min.}$$

$$w_f = v_f \times d_f = 5.95 \times 8 = 47.6 \text{ lb/min.}$$

$$\therefore \quad w_a = w_f - w_s = 47.6 - 40$$

$$w_a = 7.6 \text{ lb/min.}$$

(b) At a Solution Flow Rate of 6 IGPM (w_s = 60 lb/min., v_s = .96 cu.ft/min.)

Applying: $v_f = 9.3\ v_s$

$\therefore$ v_f = 8.93 cu.ft/min.

$w_f = v_f \times d_f = 8.93 \times 8 = 71.4$ lb/min.

$\therefore$ $w_a = w_f - w_s = 71.4 - 60$

w_a = 11.4 lb/min.

(c) At a Solution Flow Rate of 8 IGPM (W_s = 80 lb/min., v_s = 1.28 cu.ft/min.)

Applying: $v_f = 9.3\ v_s$

$\therefore$ v_f = 11.9 cu.ft/min.

$w_f = v_f \times d_f = 11.9 \times 8 = 95.2$ lb/min.

$\therefore$ $w_a = w_f - w_s = 95.2 - 80$

w_a = 15.2 lb/min.

A1.6 LIGHTNIN MIXERS

A1.6.1 Mixer Specifications

Model: ND - 2A Portable, Clamp Mount, Gear Drive, Greey Lightnin Mixer.

Motor: ¾ H.P. 575/3/60 Totally enclosed chemical motor.

Unit presealed, prelubricated, suitable for continuous operation for a minimum period of 5 years. Drive supplied complete with tank clamp mount including integral vibration pad to ensure shaft stability plus ball and swivel joint for angular off-centre positioning.

A1.6.2 Shafts and Propellers

	Mixing Tank	Batching Tank
Shaft Length:	48"	70"
Number of Propellers:	2	1 equipped with stabilizing ring
Propeller Diameter:	10.5"	11.4"
Propeller Pitch Ratio:	1.5	1.5
Operating Speed:	350 RPM	350 RPM

A1.6.3 Mixer Construction Materials

Mixer Housing: Aluminum
Motor Frame: Cast Iron
Chuck Type Coupling: 316 Stainless Steel
Clamp: Aluminum
Shaft: 316 Stainless Steel
Propellers: 316 Stainless Steel

A1.6.4 Mixer Mounting

Each mixer clamped to the side of each mixing tank has its shaft swung 15° from the vertical and positioned midway between the centre and edge of the tank for strong top-to-bottom turnover with no vortexing. The mixer clamped to the side of the mixing tank has its shaft positioned to create vortexing.

A1.6.5 Mixer Components and Internal Parts

Figure A1.7 shows the mixer components and the internal gearing of the Lightnin mixers.

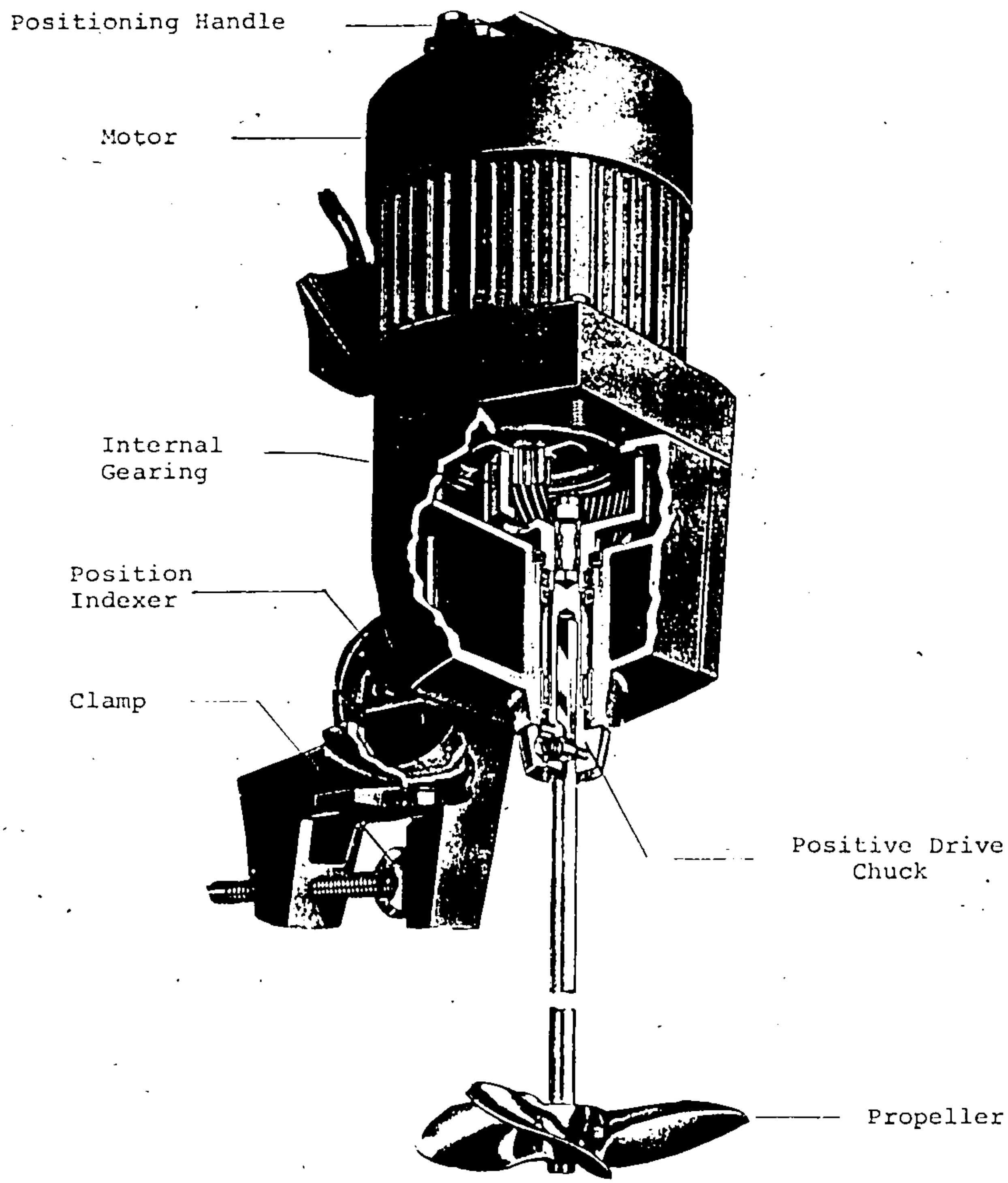


FIG. A1.7 Lightnin Mixer Components and Internal Gearing

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REFERENCES

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