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Screening characteristics of stillage.

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SCREENING CHARACTERISTICS OF STILLAGE

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ABSTRACT

The problem of recovering valuable distillers' dried grains from stillage which results from the production of whisky and alcohol from grain, is a difficult one. This investigation is particularly concerned with the factors influencing the screening of stillage--the primary operation in the manufacture of distillers' dried grains and the one most commonly used in all distilleries. As a preface to this, a brief study was made of the physical properties of stillage. The results are represented both by tables and curves.

It was found that whole stillage resembles water in boiling point, specific heat, and density, the last being slightly higher at 20°C than water and slightly lower at 90°C. Here the similarity ends for the apparent viscosity of stillage is much higher than water, but approaching the values of water at 100°C. At 20°C the viscosity of stillage is about 36 centipoises.

The data, obtained in studying the screening characteristics of stillage, were correlated in three ways. The first was a calculation of the per cent suspended solids retained in screening, which gives a picture of the total amount recovered compared with the total amount possible to recover under various operating conditions. The second was a calculation of the percentage of the original water in the stillage that is removed by the screening operations. The third was the actual quality or solids content of the screenings.

The screening study was conducted on a hand-made vibratory screen with a reciprocating type motion.

It was found that stillage containing a high concentration of suspended solids screened with comparatively good retention, poor dewatering, and a high concentration of solids in the screenings.

Efficient dewatering is usually accompanied by poor retention and vice versa.

The screening angle is the controlling factor in "blinding" and indicates whether good retention or dewatering will prevail.

Lowering particle-time will decrease the dewatering effect and increase the degree of retention.

The frequency of vibration, the amplitude of vibration, and the screening angle--the three most important variables--cannot be considered independently. It will always be a combination of these that will give the desired results of effective dewatering, capacity, and good retention.

The techniques and correlating methods derived by this research have practical applications. They can be adapted to any mechanical dewatering devices whether it be a screen, press, filter, or centrifuge and will give a comparative picture of which can do the job best.

INTRODUCTION

In the production of whisky and alcohol from grain, valuable by-products are obtained from the stillage or spent mash. These by-products are marketed as "Distillers' Light Grain", "Distillers' Dark Grain", and "Distillers' Solubles".

Although the stillage is recovered economically at present with the use of such unit operations equipment as screens, presses, evaporators and driers, the process is not beyond improvement from an engineering and economic viewpoint. To this end Joseph E. Seagrams and Sons, Inc., instituted a program of research study in the Chemical Engineering Department of the University of Louisville. This study has been conducted in an attempt to learn more of the factors influencing the recovery of the stillage and to establish, wherever possible, optimum conditions.

The study of screening, the primary operation in the manufacture of Distillers' Dried Grains and the one most commonly used in all distilleries, was decided upon as the first problem to be studied under this new plan. As a prelude to this study, it was felt that something about the physical characteristics of stillage should be known to aid in the calculations of material and heat balances. Consequently the problem resolved itself into two parts:

I. A brief study of the physical properties of stillage, executed by determinations of density, apparent viscosity, specific heat, boiling point, particle size distribution, moisture content, dissolved solids content, and suspended solids content.

II. A study of the screening characteristics of stillage on a vibrating screen showing the effect of the following variables:

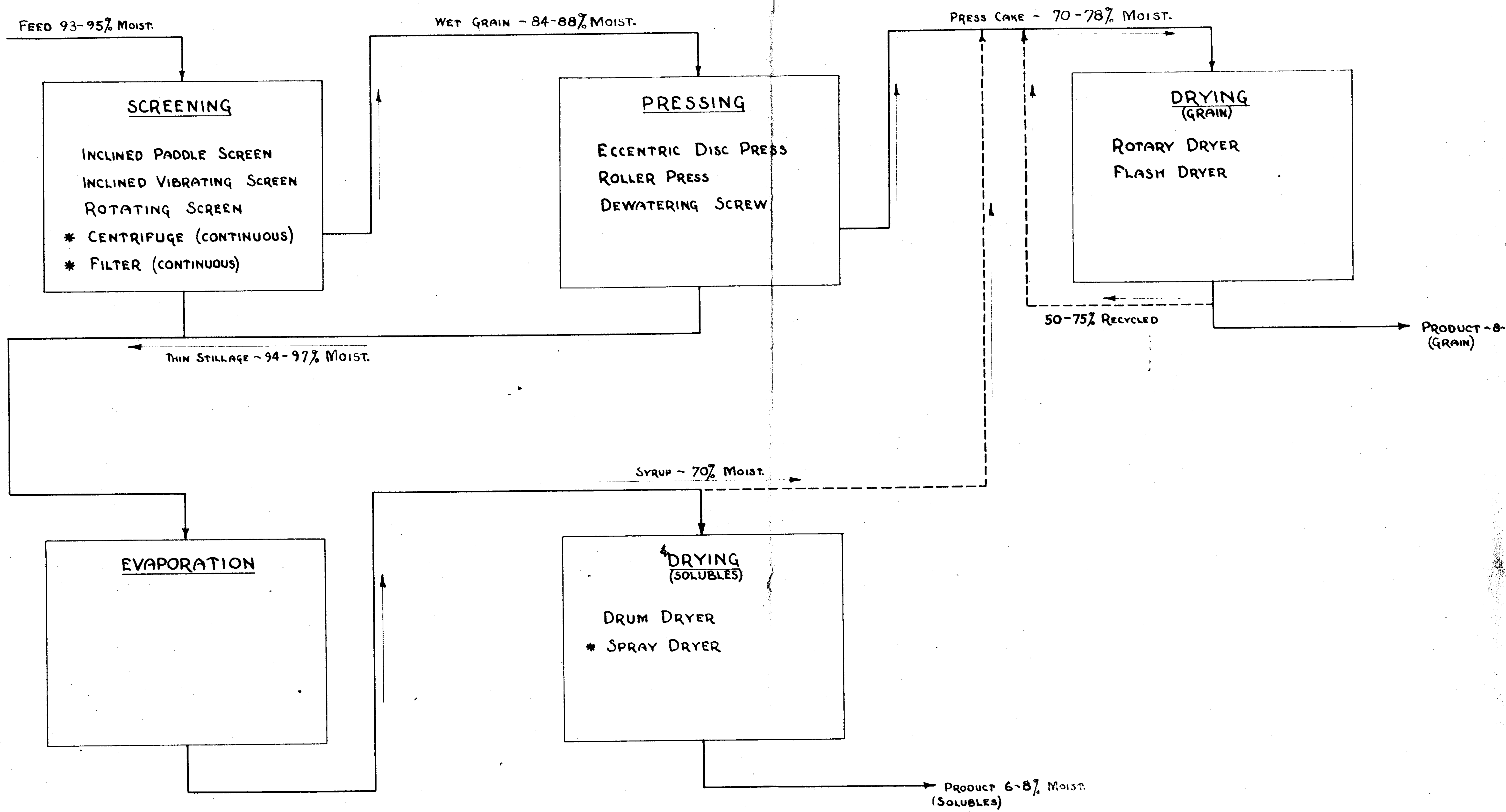
1. Quality of the feed, i.e. percentage of suspended solids in the feed.
2. Rate of feed.
3. Slope of screen.
4. Amplitude of vibration or length of stroke.
5. Frequency or number of vibrations per unit time.
6. Temperature of the feed.
7. Types of screens with varying size openings.
    (a) Woven wire.
    (b) Punched plate.
8. Mash composition.

HISTORICAL

Of the several by-products of the distilling industry -- carbon dioxide, grain oils, and stock food or distillers' dried grain -- the most important at present is distillers' dried grain.

In the past all distilleries disposed of the liquid stillage, commonly referred to as "distillery slop", by selling it directly to farmers as cattle feed. This practice, although still carried on in many small plants, was unsatisfactory because the demands for the material as feed were not sufficiently uniform. To avoid the disposal problems encountered by a non-uniform demand, methods of preparing dried stillage were instituted. Several of these methods are indicated in Figures 1, 2, and 3.

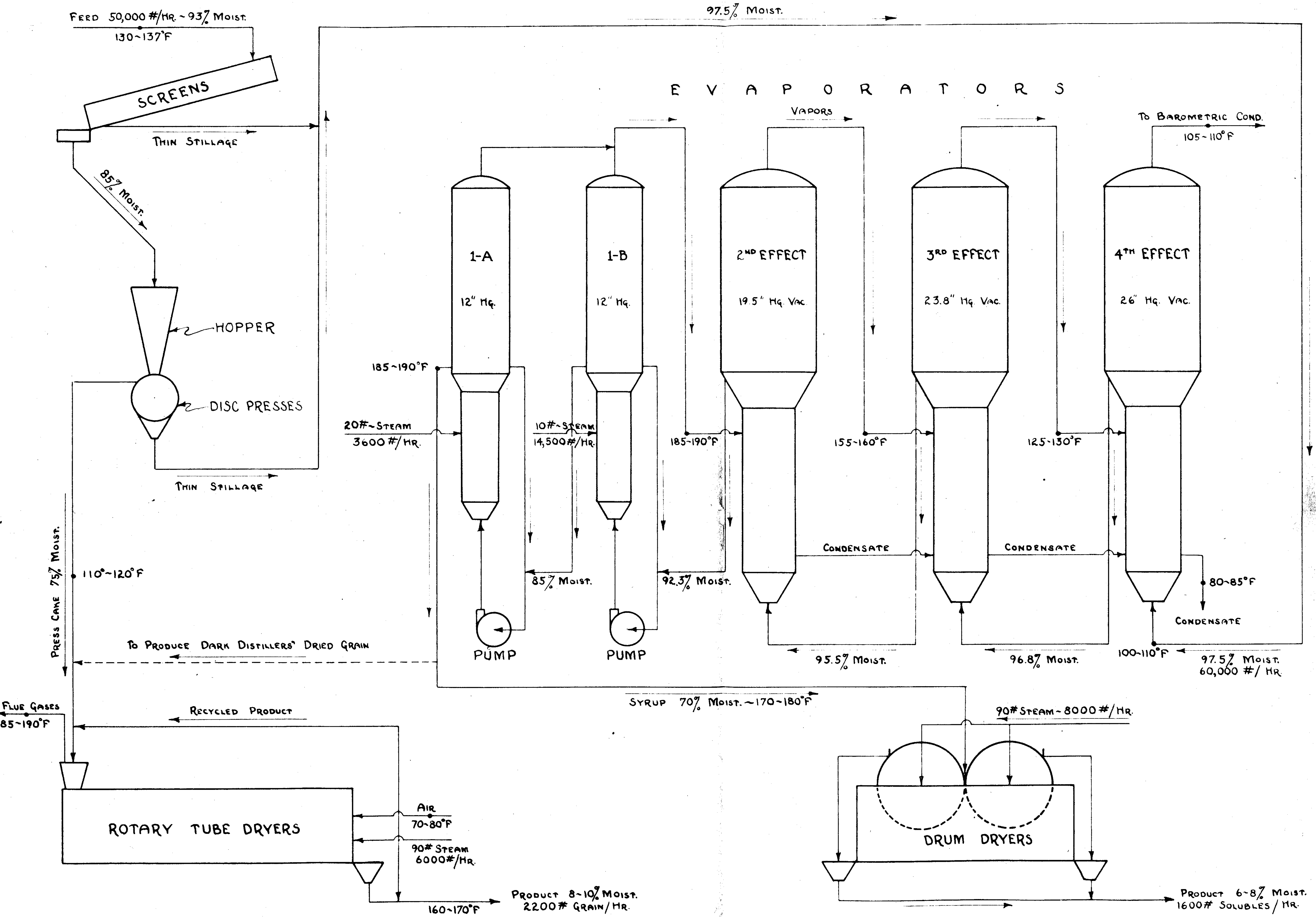
The production of distillers' dark grain was the first process devised. It consisted of screening the whole stillage (93-95 per cent water), pressing the screenings (84-88 per cent water) to form a wet press cake (70-78 per cent water), and concentrating the thin stillage in a multiple-effect evaporator from 94-97 per cent water to a syrup of 70 per cent water. This syrup was then sprayed at a constant rate onto the wet press cake, and the mixture was passed through a rotary dryer, the product having a moisture content of 8-10 per cent. In order to keep the water content of the mixture entering the dryer below 70 per cent, 50 to 75 per cent of the final product was recycled. The product, valued at approximately $45.00 per ton, was sold chiefly as stock feed because of its high bulk, protein, fat content, and total digestible nutrients. "No other concentrate on the market contains yeast-protein, essential amino-acids, vitamin G, vegetable oils, and essential minerals in so well-balanced a combination and at a price possible for use in economical production of livestock and dairy products."(1)



NOTES:

Without Using Thin Stillage Dryer ---------
Total Actual Yield — 18 #/Bu. Mashed
Total Theoretical Yield — 22 #/Bu. Mashed
Not Being Used At Present — *

FIGURE 1 - GENERAL FLOW SHEET OF DISTILLERS' BY-PRODUCT RECOVERY



Feed 50,000 #/Hr. ~ 93% Moist.
130~137°F
Screens
Thin Stillage
85% Moist.
Hopper
Disc Presses
Thin Stillage
Press Cake 75% Moist.
110°~120°F
97.5% Moist.
EVAPORATORS
Vapors
To Barometric Cond.
105~110°F
1-A
12" Hg.
1-B
12" Hg.
2nd Effect
19.5" Hg. Vac.
3rd Effect
23.8" Hg. Vac.
4th Effect
26" Hg. Vac.
185~190°F
20# ~ Steam
3600 #/Hr.
10# ~ Steam
14,500 #/Hr.
185~190°F
155~160°F
125~130°F
Condensate
Condensate
85% Moist.
92.3% Moist.
80~85°F
Condensate
Pump
Pump
95.5% Moist.
96.8% Moist.
100~110°F
97.5% Moist.
60,000 #/Hr.
To Produce Dark Distillers' Dried Grain
Syrup 70% Moist. ~ 170~180°F
Flue Gases
85~190°F
Recycled Product
90# Steam ~ 8000 #/Hr.
Rotary Tube Dryers
Air
70~80°F
90# Steam
6000 #/Hr.
Drum Dryers
Product 8~10% Moist.
2200 # Grain/Hr.
160~170°F
Product 6~8% Moist.
1600 # Solubles/Hr.

In spite of the usefulness and high quality of the distillers' dark grain, it was realized that it would be better to produce two separate products, that is, distillers' light grain and distillers' dried solubles, since they could always be mixed, in proper quantities, to yield a product similar to distillers' dark grain. Their use as separate products also could be realized.

Distillers' dried solubles did not appear on the market until late 1941 and sold for approximately $75.00 per ton. This production was made possible, at the time, by the use of drum-dryers. The process was similar to that for distillers' dark grain with one exception: Instead of the syrup from the evaporators being mixed with the press cake, it was fed to drum dryers and dried to approximately 6-8 per cent moisture. The product obtained was in the form of a thin sheet, about 0.02 inches thick, which was broken on a flaking machine. This product, because of its flakiness, was slightly bulkier than distillers' light grain. The dark grain had a bushel weight of approximately thirty-three pounds, while the light grain had a bushel weight of approximately forty-four pounds.(1)

Distillers' light grain, valued at approximately $25.00 per ton, is the product obtained from the rotary dryers when the syrup is not mixed with the wet press cake; that is, when it is either fed to the drum dryers or disposed of as waste.

A typical process for producing distillers' light grain and distillers' dried solubles is shown in Fig. 2. The distillers' dried grains are used primarily in stock and poultry feeds. The compositions of these products are shown in Table I.

Table I. Compositions of Distillers' Dried Grains (2)

	Distillers' Dark Grain	Distillers' Light Grain	Distillers' Dried Solubles
H_2O	8-10%	8-10%	5-7%
Crude Protein	27-30%	20-25%	30-33%
Crude Fat	10%	8%(Min.)	10-12%
Crude Fiber	3%	14%(Max.)	3-4%
Ash	3-4%	1-2%	6-7%

For a complete recovery of two distinct products, the process breaks down into three main unit operations for the production of distillers' light grain, and into four main unit operations for the production of distillers' dried solubles. As shown in the Fig. 1, the first two operations of each process, pressing and screening, are common to both schemes, and as a result a total of five steps are obtained: (1) screening, (2) pressing, (3) evaporation, (4) press cake drying, and (5) syrup drying.

Screening whole stillage from approximately 93-95 per cent water to 84-88 per cent water is the primary operation. At present, only three types of screens have been used commercially: inclined paddle screens, inclined vibrating screens, and rotating screens.

The inclined paddle screens are approximately 24 feet by 5 feet and are inclined at 19°-20°. The stillage is usually introduced at the top of the screens and moved over the surface of the screen by wooden paddles attached to two chain drives. The thin stillage passes through the screen, is collected in a trough, and then piped to a stillage tank where it is stored prior to further treatment in evaporators.(2)

The vibrating or gyratory screens are approximately 10 by 5 feet and are inclined from 5^{0} to 20^{0}, so that the material is moved down the screen by the vibrating action. The frequencies used range from 400 to 3600 vibrations per minute with amplitudes of stroke ranging from 0.001 inch to 2 inches.

The rotating screens are similar in their action to trommels. The stillage is fed to the inside of a slightly inclined, revolving cyclinder with a screening surface.

The thin stillage passes through the screen into a trough, while the screenings travel to the lowered end into some type of conveyor.

There are three types of pressing equipment in general use today for reducing the water content of the screenings from 84-88 per cent to 70-78 per cent: the dewatering screw, the roller press, and the eccentric disc type press. The effluent from this operation is added to that from the screens and the mixture sent to the evaporators. The solid material, or so called press cake, is moved on to the final drying operation.

The roller press consists of sheets of copper screening backed by metal plates which act as stiffeners and are hinged together to form a continuous belt. Hexagonal reels turn the belt which is slowly drawn between several pairs of rolls placed directly over one another. The screenings are fed onto the belts, carried between the rolls which squeeze excess liquid from the solids, and discharge a press cake into a conveyor leading to a dryer.

The eccentric disc press consists of two conical copper screening discs rotating at an angle to each other. The material to be pressed is fed by a hopper and falls between the rotating discs. The material is squeezed between the discs as they turn and falls free into a conveyor below. The liquid passes through the discs and is transported away.

The dewatering screw usually consists of a metal, close-fitting cone inside a cylinder made of copper screen. A screw conveyor forces the screenings between the cone and the cylinder causing the material to be squeezed.

In order to concentrate the thin stillage, most distillers use some type of multiple-effect evaporator, usually a vertical tube type. A typical evaporator set-up is shown in Fig. 2, wherein the water content of the thin stillage is reduced from 94-97 per cent to approximately 70 per cent.

By batch centrifuging the thin stillage from screens with 40 inch diameter solid bronze baskets, Hiram Walker and Sons, Incorporated, found that a small percentage of material could be removed, leaving a clarified effluent in such condition that its viscosity, when evaporated to about 50 per cent solids, was not greatly different from that of screen effluent evaporated to 25 per cent solids, but without centrifuging. (3)

Drying, in by-product recovery, naturally separates itself into two distinct types: Drying material in which the solid phase predominates, that is press cake; and drying material which is in solution or suspension, that is, syrup.

Two types of dryers are used for handling wet grain: rotary dryers, the most common type; and flash dryers, a recent innovation to distillery practices. The material to be handled in both must be granular, bulky, dry enough to be handled by conveyors, and not sticky enough to build up on the walls of the equipment. Wet press cake fits this condition almost perfectly.

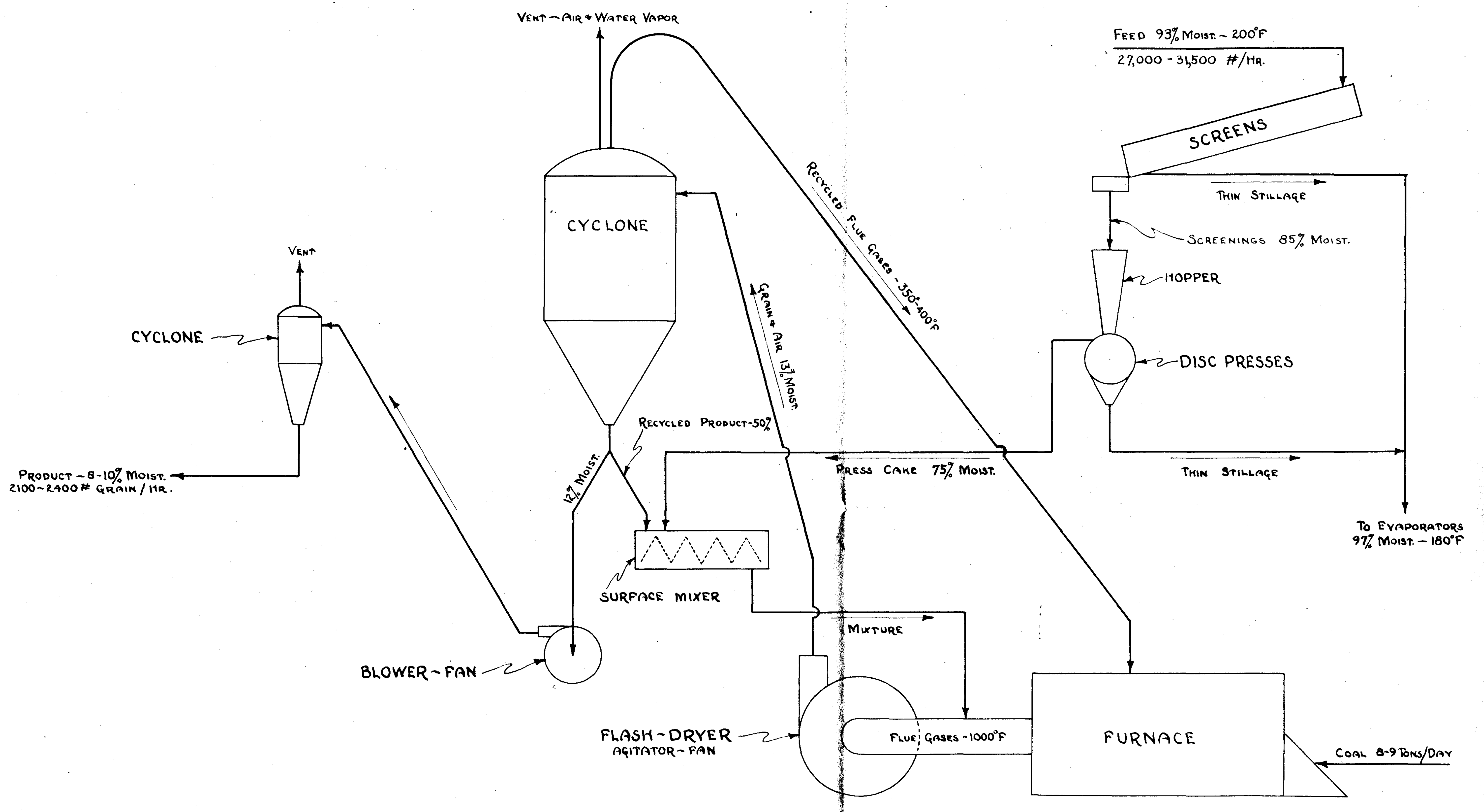


FIGURE 3 - FLOW SHEET SIMULATING SEAGRAM'S DANT & DANT PLANT

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The rotary steam tube dryers are about 50 feet long, are inclined at an angle of about 0.5 degree and are rotated at a speed of about 4 RPM. The dryer is heated by the passage of steam into a double row of tubes which extend the full length of the dryer. The steam flow is countercurrent to the flow of material and maintained at a maximum pressure of 90 pounds to prevent overheating of the grain and to prevent injury to the equipment. The grain is carried through the dryer by the rotating action and the inclination of the shell.

Flash drying (4), or the use of a flash dryer, although mentioned only occasionally in the literature, is not new and has been utilized for several years in chemical industries. This type of equipment is designed to produce optimum drying conditions, that is, exposure of a large surface area, material agitation, high vapor pressure potential, and high air velocity.

Fig. 3 shows a typical flash drying installation and illustrates how these four principles were put into operation. The wet press cake, after being mixed with previously dried grain, is dropped into a high temperature stream, approximately 1000°F, and is then carried into a large agitator fan -- termed "flash dryer" -- where its surface is enormously increased, and it is violently agitated in direct contact with the hot flue gases. These factors--surface increase, agitation, and high air velocity--greatly reduce the thickness of the moisture film next to the particles and permit ready diffusion of the moisture to the surface and into the air stream. From the high-powered fan, the material is carried suspended in the air to a large cyclone separator, where it is separated from the air. Most of this air, or flue gases, is recycled to the furnace, and approximately

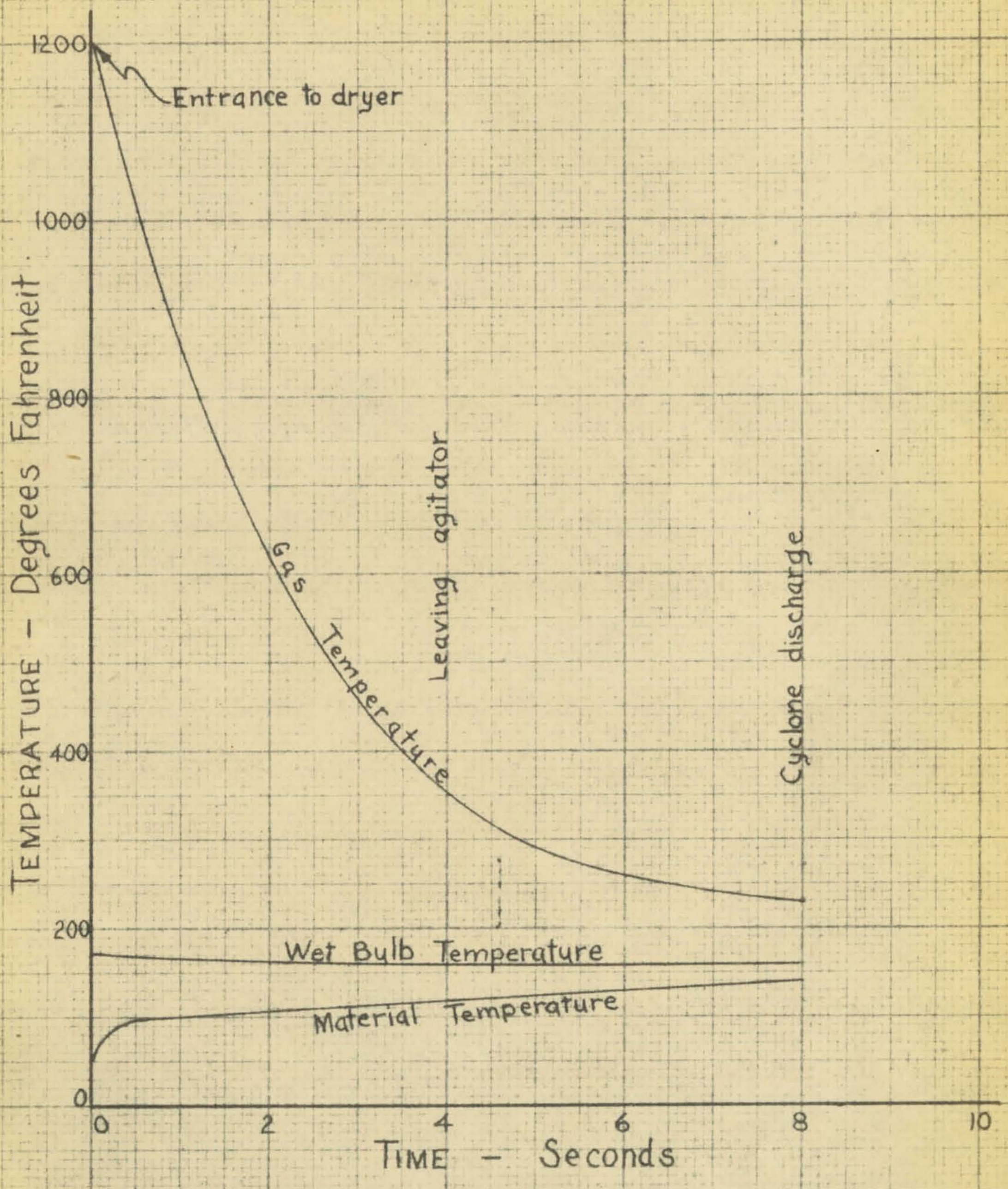

FIG. 4 – DIAGRAM PORTRAYING TYPICAL TEMPERATURE CONDITIONS OF MATERIAL AND DRYING AIR AS DRYING PROCEEDS (4).

50 per cent of the dried grain is recycled by mixing it with the wet press cake. The remaining 50 per cent is passed through a smaller blower into another smaller cyclone. The material leaving this smaller cyclone with a water content of 8-10 per cent, is the final product. Although exposed to a high temperature, the grain will not become heat damaged, because, as shown in Figure 4, the temperature of the material to be dried rarely goes above the wet-bulb temperature of the air.(4)

This type of equipment has some distinct advantages. Since the grain remains in the process only two to twelve seconds, definite control can be maintained over the final moisture content and the maximum rise in material temperature. It is possible to use inlet gas temperatures of 1000°-1200°F without increasing the temperature of the grain to more than 175°F. "With a well-insulated system, thermal efficiencies of 1,750-1,500 BTU per pound of water are common."(4)

The drying of syrup requires a type of equipment quite different from those previously discussed. Only one type, the rotary drum dryer, has been used extensively on a commercial basis.

Atmospheric rotary drum drying (5) is dependent on several variables: Steam pressure, which governs the temperature of the drum surface; speed of rotation, which determines the time of contact between the film and the preheated surface; thickness of the film, which may be governed by the distance between the drums; and the concentration, viscosity and temperature at which the solution to be dried reaches the drums.

Drum dryers are made up of two hollow steel drums which are heated internally by steam. The syrup is fed into the "V" portion between the drums forming a thin film of syrup as the drums rotate toward each other and downward at a speed of 2 to 4 RPM with a clearance of about 0.03 inch. By the time the drums have made three-quarters of a revolution, the sheet is dry and is removed from the drum by a steel knife. The resulting sheet of dried syrup is continuous; and after being cooled with an air stream, it is sent to a flaker where it is pulverized to the proper size for marketing.

THEORY

In distillery practices, three items are desirable in mechanical dewatering devices:

1. Effective dewatering
   a. High Per Cent Dewatered
   b. High Concentration of Solids in the Screenings
2. High capacity
3. High retention (Low Suspended Solids Content in Effluent)

High retention is more of a limitation than a desire, as it is known that solids in the screening and pressing effluent many times results in poor evaporator operation and in many cases causes complete shut-downs resultive from plugging of evaporator tubes.

Effective dewatering means the increasing of the concentration of total solids in the whole stillage to a point where it can be handled easily by some standard type of dryer.

Capacity, as herein used, indicates the maximum quantity per unit time that can be effectively dewatered by the screening process for a given feed. Factors controlling dewatering capacity and retention are feed temperature, screening angle, frequency of vibration, amplitude of vibration, and the type of screening surface.

Efficient dewatering frequently is accompanied by poor retention. The extent to which this happens can be lessened by proper selection of the controlling factors. It is impossible to attain the three desirables at the same time.

An important factor in the capacity of a screen is the ability of the screening device to prevent "blinding". Blinding can be diminished by the proper combination of screening angle, frequency of vibrations, and amplitude of vibration.

For any type slurry, grain or otherwise, the dewatering process can be measured as a function of the amount of water removed per unit time, i.e., the total amount of water removed divided by the original quantity of water and multiplied by 100 will result in the percentage of original water in the stillage removed by the screening operation. This percentage will be referred to as the Per Cent Dewatered.

Considering rates of feed (R_f), screenings (R_s), and effluent (R_e), a simple material balance on the screen can be made:

$$R_f = R_s + R_e \quad \text{(Wet Basis)} \tag{1}$$

Equation (1) can be converted to a bone-dry basis by knowing the concentration of total solids in the feed, screenings, and effluent.

Thus:

$$FR_f = SR_s + ER_e \quad \text{(Dry Basis)} \tag{2}$$

Where F is per cent total solids in the feed, S the per cent total solids in the screenings, and E the per cent total solids in the effluent.

Substituting $R_e = R_f - R_s$ into Eq. (2)

$$FR_f = SR_s + E\ (R_f - R_s)$$

Simplifying,

$$FR_f = R_s\ (S - E) + ER_f$$

$$R_s = R_f \times \frac{F - E}{S - E} \tag{3}$$

Similarly, by substituting $R_s = R_f - R_e$ into Eq. (2)

$$R_e = R_f \times \frac{F - S}{E - S} = R_f \times \frac{S - F}{S - E} \tag{4}$$

The pounds of water in feed per minute is $(100-F)R_f$ and in the screenings is $(100-S)R_s$.

Thus:

$$A = \frac{(100-F)R_f}{FR_f} = \frac{100-F}{F} = \frac{\text{lbs. water in Feed}}{\text{lbs. B.D. solids in Feed}} \quad (5)$$

and,

$$B = \frac{(100-S)R_s}{FR_f} = \frac{\text{lbs. water in the Screenings}}{\text{lbs. B.D. solids in Feed}} \quad (6)$$

but,

$$R_s = R_f \times \frac{F-E}{S-E}$$

Hence,

$$B = \frac{(100-S)(R_f)(F-E)}{FR_f(S-E)}$$

$$= \frac{(100-S)(F-E)}{F(S-E)} \quad (7)$$

Since A and B are on the same basis, they can be subtracted to give the amount of water removed per pound of solids (bone-dry) in the feed.

Thus:

$$A-B = \frac{100-F}{F} - \frac{(100-S)(F-E)}{F(S-E)} = \frac{\text{lbs. of water removed}}{\text{lb. of B.D. solids in feed}}$$

Hence,

$$\text{Per Cent Dewatered} = \frac{A-B}{A} \times 100 = \frac{\frac{100-F}{F} - \frac{(100-S)(F-E)}{F(S-E)}}{\frac{100-F}{F}} \times 100 \quad (8)$$

Simplifying Eq. (8) by dividing through by $\frac{100-F}{F}$,

$$\text{Per Cent Dewatered} = \left[1 - \frac{(100-S)(F-E)}{(100-F)(S-E)}\right] 100 \quad (9)$$

It should be noted that Eq. (9) is independent of the feed rate and data necessary for its determination are readily obtainable.

Similar to Per cent Dewatered an expression representing retention can be derived. Stillage contains dissolved as well as suspended solids.

Since the dissolved solids can not be retained by screen except in what remains in the screenings, only the suspended solids will be considered in calculating the Per Cent Retained by the Screen. A low per cent retained indicates that the concentration of solids in the effluent is above normal.

The per cent of suspended solids in the effluent is $E - D_e$ where D_e is the per cent dissolved solids in the effluent, and in the feed is $F - D_f$ where D_f is the per cent dissolved solids in the feed–i.e., the difference between the amount of total solids and dissolved solids is the amount of suspended solids.

Hence,

$$T_e = (E-D_e)R_e = \text{ lbs. susp. solids in effluent per min.} \quad (10)$$

and

$$T_f = (F-D_f)R_f = \text{ lbs. susp. solids in feed per min.} \quad (11)$$

Substituting Eq. 4 into Eq. 10

$$T_e = \frac{(E-D_e)R_f(S-F)}{S-E} \quad (12)$$

The pounds of suspended solids retained by the screen is $T_f - T_e$, and the Per Cent Retained $= \frac{T_f - T_e}{T_f} \times 100 = (1 - \frac{T_e}{T_f})\ 100$ (13)

Hence,

$$\text{Per Cent Retained} = \left[1 - \frac{\frac{(E-D_e)(S-F)R_f}{S-E}}{(F-D_f)R_f} \right] 100 \quad (14)$$

Simplified, Eq. 14 resolves into an expression devoid of the feed rate,

$$\text{Per Cent Retained} = \left[1 - \frac{(S-F)(E-D_e)}{(S-E)(F-D_f)} \right] 100 \quad (15)$$

Where $\frac{(S-F)(E-D_e)}{(S-E)(F-D_f)}$ is the fraction of the suspended solids in the feed that passes through the screen.

Analytically, it is difficult to determine D_f or D_e, directly, but if the feed or effluent is centrifuged and the dissolved solid content of the centrifuged mother liquor is used, an indirect determination can be made. Let M_f and M_e equal the per cent of dissolved solids in the feed and effluent mother liquor, respectively. Then, on the basis of 100 pounds of mother liquor,

$$\frac{M_f}{(100-M_f)} = \frac{\text{lbs. of dissolved solids in centrifuged mother liquor}}{\text{lb. of water}}$$

On the basis of 100 pounds of feed,

$$\frac{D_f}{100-F} = \frac{\text{lbs. of dissolved solids}}{\text{lb. of water}}$$

Therefore

$$\frac{D_f}{100-F} = \frac{M_f}{100-M_f} \qquad (16)$$

and

$$D_f = \frac{M_f(100-F)}{100-M_f} \qquad (17)$$

Similarly,

$$D_e = \frac{M_e(100-E)}{100-M_e} \qquad (18)$$

MATERIALS

Stillage, the residue from a beer-still, is a grain slurry. Factors controlling the physical characteristics of stillage are:

1. Percentage and type of grains used in cooking process.
2. Mashing-ratio.
3. Type of grind.
4. Cooking Temperature and Pressure.
5. Distillation Temperature and Pressure.

A number of grains may be used to produce the original mash, such as corn, sorghum, wheat, rye, and malt. Combinations of grains frequently used are (1) 45-70% wheat, 20-45% corn, and 10% malt; (2) 60-65% wheat, 24-29% rye, and 11% malt; (3) 90% wheat and 10% malt. In making these slurries, different mashing ratios, i.e., the number of gallons of water used per bushel of ground grain, may be used. The mashing ratios may vary from 34-48 gallons of water per bushel of meal. The grain is ground to a meal before it is mashed, and the type of grind used in this process is very important. After mashing, the meal is cooked, either atmospherically, at 100°C., or under pressure, 145 to 360°C. The temperature of stillage leaving the stills is 91-95°C. if atmospheric distillation is employed, and 54-58°C. for vacuum distillation.

The following is a classification of samples and barrels of stillage taken from Seagram plants:

<u>Sample No. 1 and 3</u> — <u>Dant & Dant Plant - Jan. 14, 1944</u>

Mash Bill - 51% Wheat
39% Milo (Sorghum)
10% Barley Malt

Total Solids -- 4.3-5.5%

Cooking Pressure - 60#/sq.in.
Cooking Temperature - 146°C.
Distillation - Atmospheric
Screening Temperature - 91°C.

Sample No. 5 and 8	Louisville Plant - Jan. 15, 1944
Mash Bill - 51% Wheat	Cooking Pressure - 160#/sq.in.
39% Milo (Sorghum)	Cooking Temperature - 182°C.
10% Barley Malt	Distillation - Vacuum
	Screening Temperature - 55.5°C.
Total Solids -- 6.2-6.5%	

Sample No. 10	Dant & Dant Plant - Feb. 9, 1944
Mash Bill - 46% Wheat	Cooking Pressure - 46#/sq.in.
44% Milo (Sorghum)	Cooking Temperature - 146°C.
10% Barley Malt	Distillation - Atmospheric
	Screening Temperature - 91-95°C.
Total Solids -- 5.1%	

Barrel No. 1 and 2	Louisville Plant - May 15,20, 1944
Mash Bill - 70% Wheat	Cooking Pressure - 160#/sq.in.
20% Milo (Sorghum)	Cooking Temperature - 182°C.
10% Barley Malt	Distillation - Vacuum
	Screening Temperature - 54-58°C.
Total Solids - 6.7%	
Dissolved Solids- 2.7%	

Barrel No. 3	Louisville Plant - August 4, 1944
Mash Bill - 90% Wheat	Cooking Pressure - 160#/sq.in.
10% Malt	Cooking Temperature - 182°C.
	Distillation - Vacuum
	Screening Temperature - 54-58°C.
Total Solids - 7.0%	
Dissolved Solids- 3.3%	

Barrel No. 4 and 5	Louisville Plant - Sept. 13,20, 1944
Mash Bill - 64% Wheat	Cooking Pressure - 160#/sq.in.
25% Rye	Cooking Temperature - 182°C.
11% Barley Malt	Distillation - Vacuum
	Screening Temperature - 54-58°C.
Total Solids - 4.9%	
Dissolved Solids- 2.3%	

Barrel No. 6	Louisville Plant - Oct. 25, 1944
Mash Bill - 60% Wheat	Cooking Pressure - 160#/sq.in.
30% Milo (Sorghum)	Cooking Temperature - 182°C.
10% Barley Malt	Distillation - Vacuum
	Screening Temperature - 54-58°C.
Total Solids - 6.7%	
Dissolved Solids- 2.7%	

Hereinafter, stillage from Barrel No. 1, 2, and 6 will be referred to as Mash Type No. 1; stillage from Barrel No. 3 as Mash Type No. 2; and Barrel No. 4 and 5 classified as Mash Type No. 3.

Sample No. 10 was used in the Boiling Point, and Apparent Viscosity determinations and the Specific Heat of Sample Nos. 1, 3, 5, 8 and 10 were determined. The Density runs were made with Sample No. 3. Stillage from Barrel No. 6 was used for determining the Particle Size Distribution.

The Shaking Screen runs were made with Mash Type Nos. 1, 2, and3 and distributed as follows:

Item Investigated	Mash Type No. Used
Quality of Feed	1, 3
Feed Rate	1, 3
Temperature	1, 2
Screen Angle	1
Screen Type	2
Frequency of Vibration	2
Amplitude of Vibration	2, 3
Reproducibility of Results	1

PHYSICAL PROPERTIES OF STILLAGE

Stillage can be described as a grain slurry, containing 93-95 per cent water, 2.5-3.5 per cent dissolved solids, and 2.5-3.5 per cent suspended solids. The physical properties of such a material are necessary for the calculation of material and heat balances on unit operation equipment, and to gain an understanding of its usually peculiar actions in various types of equipment.

No references were found in the literature pertaining to apparent viscosity, density, specific heat, boiling point, and particle size distribution of whole stillage. Accordingly, representative samples of stillage were obtained from the Louisville Plant and the Dant & Dant plant of Joseph E. Seagram & Sons, Incorporated, to be used in determining the above-mentioned properties as well as water content, dissolved solids content, and suspended solids content.

It should be noted that the physical properties of stillage are intrinsically tied-up with the percentages of grains cooked, types of grain used, type of grinding used, cooking methods, and type of still used.

Boiling Point

Procedure - Approximately 755 grams of stillage, obtained from, Sample No. 10, a mash of 44 per cent milo, 46 per cent wheat, 10 per cent malt, were distilled in an ordinary distilling flask with a partial reflux. The boiling point of the mixture was recorded at 0, 100, 200, 300, 400, 450, 500, 525 cc of distillate. This resulted in a change of water content from 94.9 per cent to 82.5 per cent. The residue at the latter moisture content

TABLE II - BOILING POINT OF STILLAGE

Weight of Original Sample No. 10 - 755.2 grams

cc. of Distillate	Per Cent Water	B.P. °C
0	94.9	100.85
100	94.2	100.9
200	93.1	100.9
300	91.5	101.0
400	89.2	100.9
450	87.4	100.7
500	84.9	100.5
525	82.5	100.4

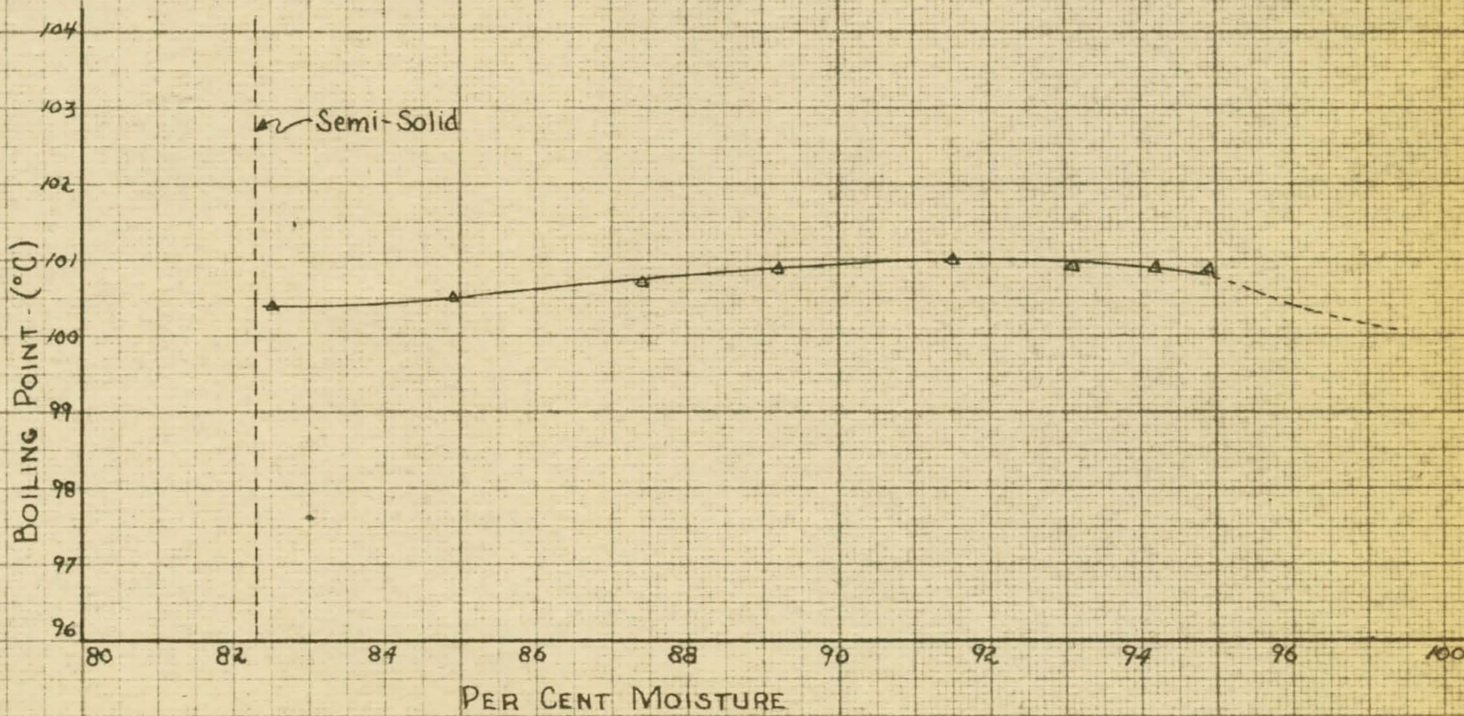

Fig. 5 - Boiling Point Of Stillage - Moisture Content

TABLE III - SPECIFIC HEAT OF STILLAGE

Sample Type	Wt. of Calo-rimeter	Calo-rimeter & Sample	Wt. Sample	Initial Temp.	Observed Final Temp.	Calo-rimeter, Hot H_2O & Sample	Wt. of Boiling H_2O Added	Specific Heat of Sample
1	398.3	607.0	208.7	21.8°C	58.3°C	798.6	191.6	0.964
3	399.2	605.7	206.5	26.8°C	60.92	796.4	190.7	0.977
5	398.7	611.5	212.8	20.6°C	57.4	806.8	195.3	0.984
8	398.9	592.6	193.7	20.2	58.3	784.0	191.4	0.995
10	398.0	599.7	201.7	21.3	59.2°C	800.1	200.4	0.987
H_2O	399.2	584.1	184.9	26.0	62.2	777.2	193.1	S=16.7 cal/deg.C

was a semi-solid mass.

Results - As shown in Fig. 5, the boiling point did not change appreciably from that of water (100.4 to 101.0°C).

Specific Heat

Procedure - Approximately 200 grams of stillage were placed in a Dewar Vacuum Bottle and approximately 200 grams of boiling water were added. The initial and final temperatures were recorded. The heat capacity of the calorimeter having been previously determined (in a similar manner), the specific heat of the stillage can be calculated from the following equation:

$$(C_H)(W_H)(t_H - t_2) = (C_s)(W_s)(t_2 - t_1) + S(t_2 - t_1)$$

Where: S = heat capacity of calorimeter, cal./deg. C.
C = specific heat, cal./(gram)(deg. C)
W = weight of material placed on calorimeter, grams
t_1 = initial temperature of stillage, deg. C
t_2 = final temperature of mixture, deg. C
t_H = temperature of hot water added, deg. C
subscript H = water
subscript S = stillage

Results - It was found that the specific heat of stillage was in the range 0.964-0.995 calories per gram per degree Centigrade at 20-26 degrees Centigrade.

Density

Procedure - A 60°F/60°F hydrometer was calibrated by placing approximately 500 cc of boiling water in a 250 ml graduate and taking temperature and hydrometer readings as the sample cooled, stirring the sample at all times.

The specific gravity of the stillage was obtained, using the same

TABLE IV - DENSITY

Figure #6 H_2O Temp. °C	Figure #6 H_2O Sp. Gr. 60°/60°Hdr.	Figure #7 Sample #3 Temp. °C	Figure #7 Sample #3 Sp. Gr. 60°/60°F
16	0.999	22	1.015
24	0.996	26	1.015
30	0.995	32	1.013
32	0.996	39	1.010
40	0.994	40	1.009
43	0.993	46	1.009
50	0.988	50	1.007
52.5	0.986	52	1.006
60	0.986	55	1.004
67	0.983	56	1.004
70	0.980	59	1.003
75	0.978	59	1.002
75	0.977	60	1.001
80	0.976	65	0.998
85	0.972	69	0.997
87	0.971	74	0.997
90	0.968	76	0.996
		78	0.993
		80	0.992
		83	0.990
		84	0.988
		85	0.986
		88	0.983

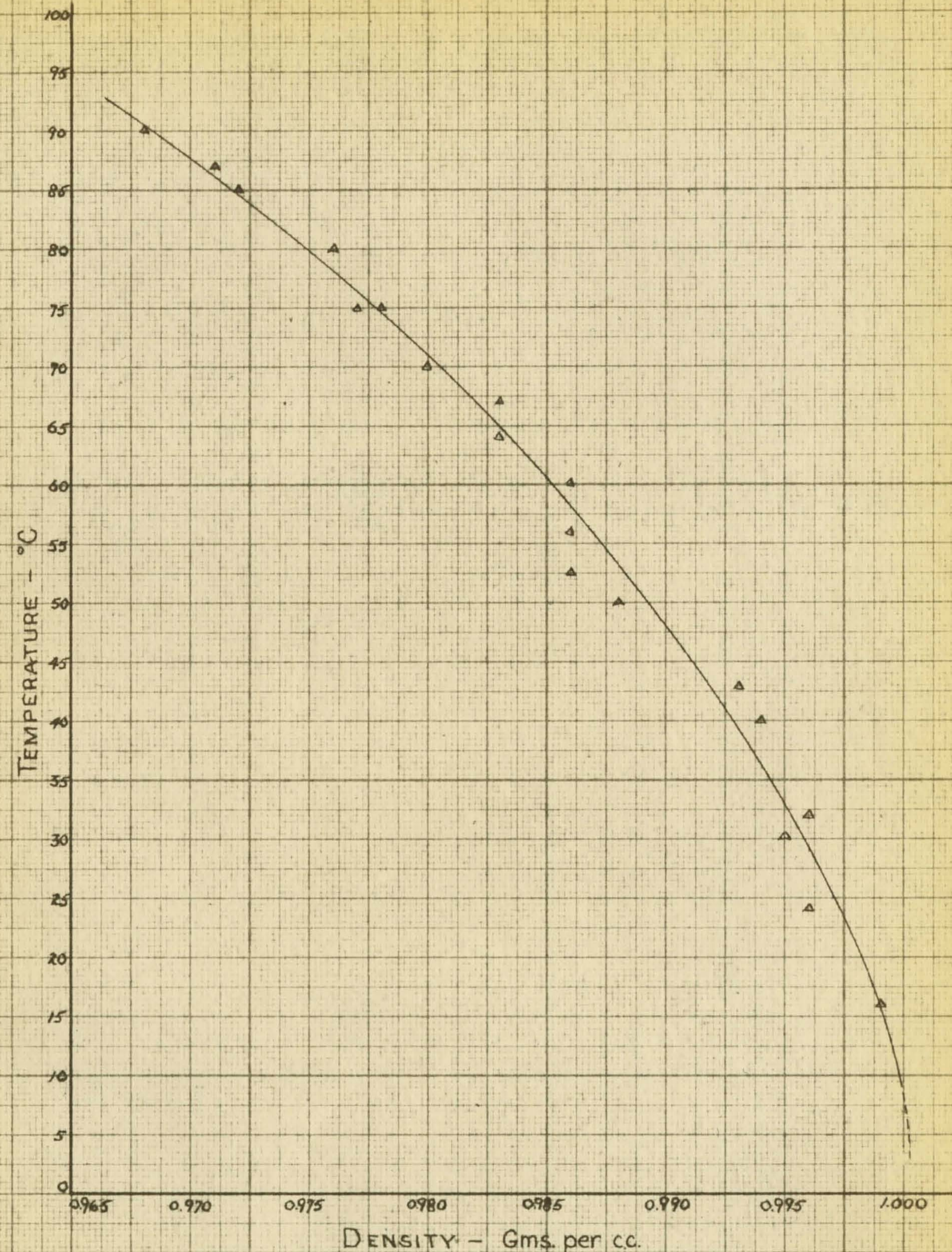

FIG. 6 - DENSITY WATER (Hydrometer) - TEMPERATURE

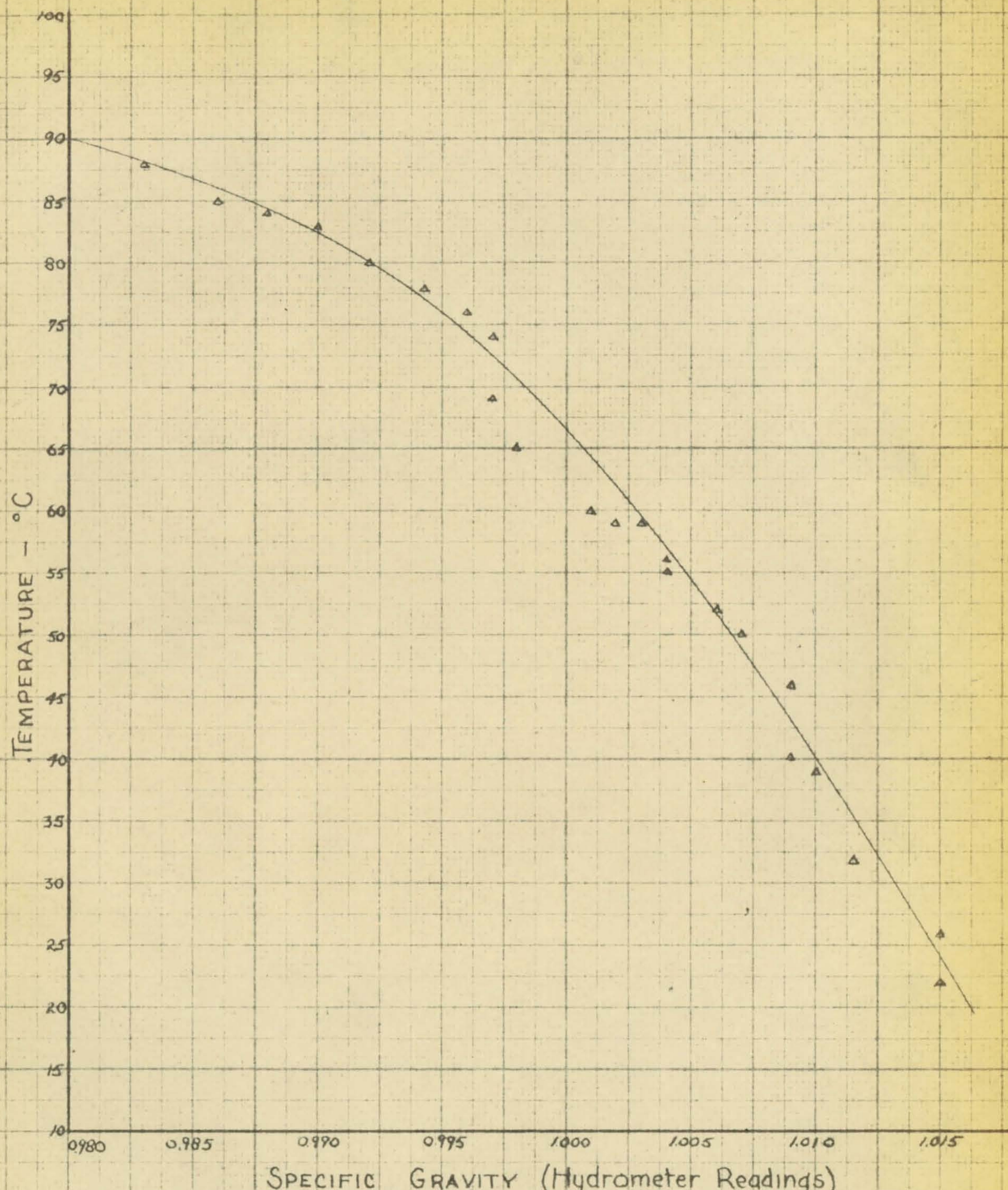

FIG. 7– SPECIFIC GRAVITY STILLAGE – TEMPERATURE

TABLE V - DENSITY (CONTINUED)

	Curve #8 Hydrometer Calibration				Curve #9
Temp. °C	Actual Density H_2O from Perry's Handbook	Density H_2O from Figure 6	Observed Sp. Gr. of Stillage From Figure 7	Corrected Sp.Gr. of Stillage by use of Figure 8	True or Calculated Density of Stillage (a)(d) gms/cc
	a	b	c	d	e
4°	1.0000	1.0003*			
20	0.9982	0.9983	1.0165	1.0185	1.0167
30	0.9958	0.9958	1.0133	1.0150	1.0106
40	0.9922	0.9928	1.0100	1.0113	1.0035
50	0.9981	0.9893	1.0065	1.0074	0.9954
60	0.9832	0.9853	1.0028	1.0025	0.9857
70	0.9778	0.9805	0.9983	0.9982	0.9760
80	0.9718	0.9750	0.9918	0.9908	0.9629
85	0.9685	0.9718	0.9870	0.9853	0.9543
90	0.9653	0.9685	0.9800	0.9774	0.9435
100	0.9584				

* Extrapolated

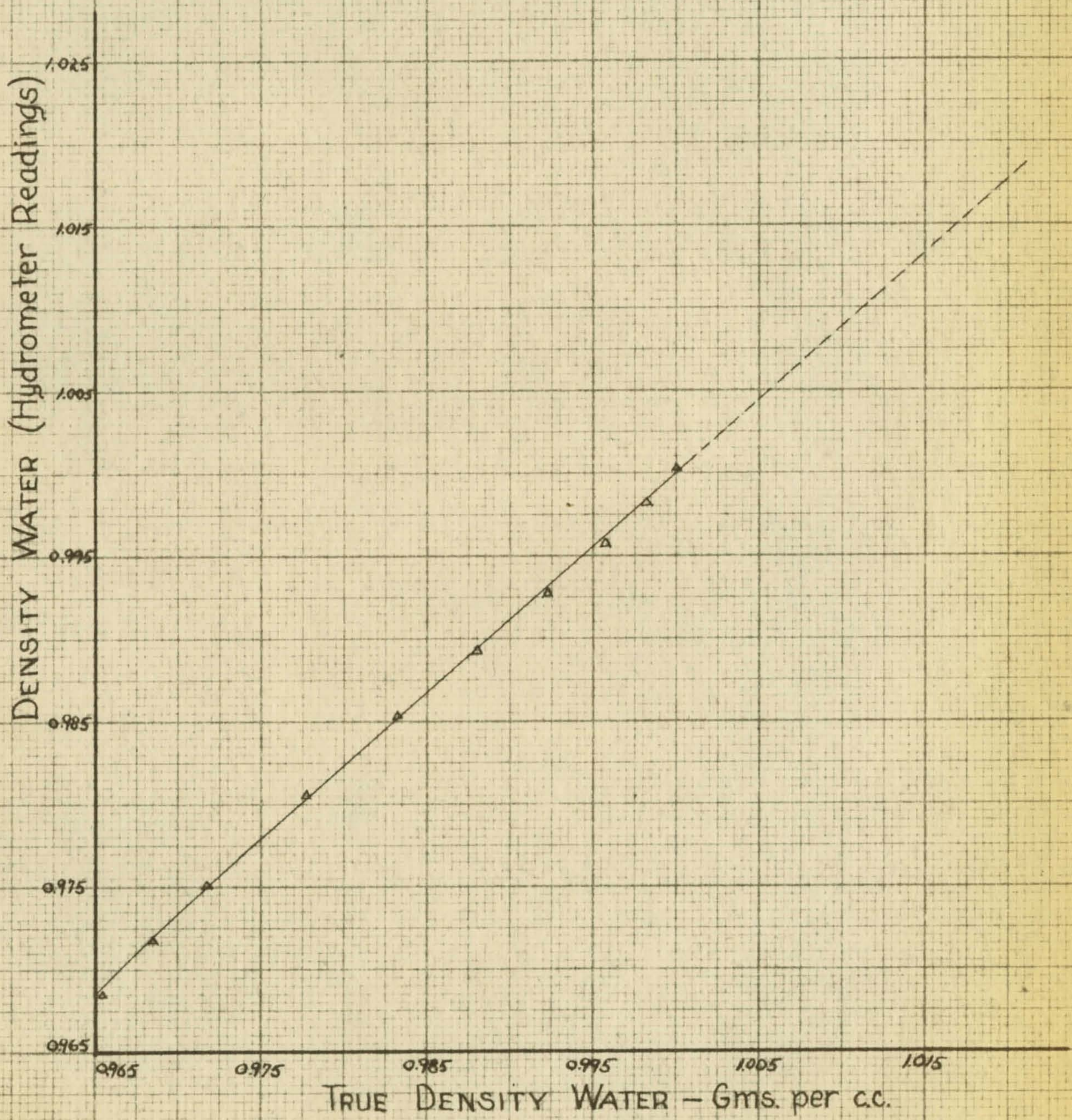

FIG. 8 – HYDROMETER CALIBRATION.

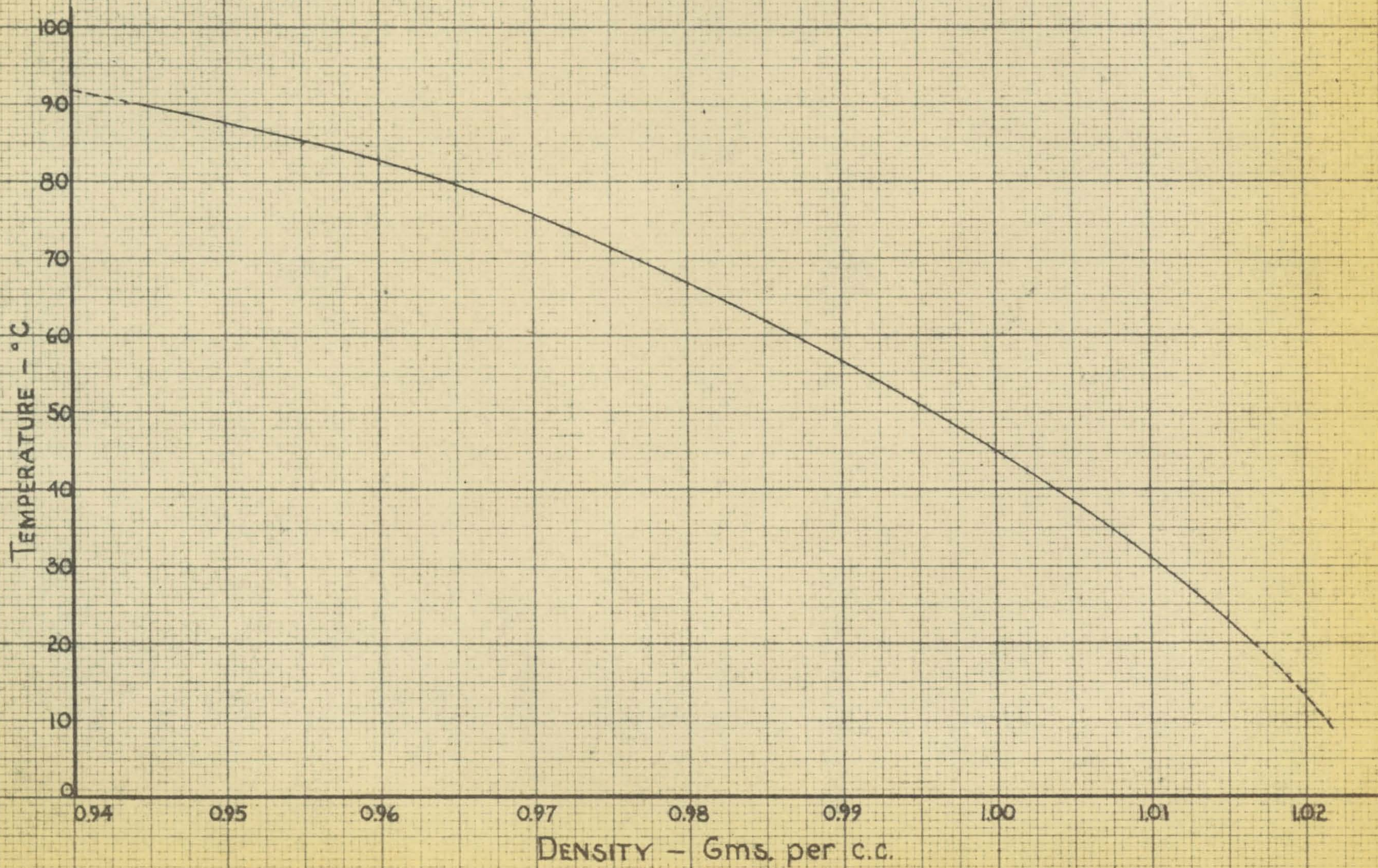

Fig. 9 — Density Stillage — Temperature

hydrometer, in a similar manner.

Results - Figures 6 and 7 depict the observed hydrometer values versus temperature for water and stillage respectively. The curves are similar in shape.

The Hydrometer Calibration Curve, Figure 8, was obtained by comparing observed water readings from Fig. 6, and the actual density of water, as given in the handbooks, at the same temperature points.

Figure 9, True Density of Stillage versus Temperature, was obtained by plotting the temperature of an observed stillage specific gravity value versus the product of the observed value, corrected by use of the Calibration Curve, and the actual density of water at the same temperature.

It was necessary to extrapolate the Calibration Curve, Fig. 8, in order to correct the stillage hydrometer readings.

Apparent Viscosity

Procedure - A modified Stormer Viscosimeter, 1931 Model, was further modified by using an oil bath for temperature control of the stillage. This oil bath was made from two cans, a half-pint can inside a quart can with the two-pronged paddle projecting into the inner one. The inner can also was fitted with a thermometer holder. Measurement of viscosity is accomplished by measuring the shear of a fluid in an annular space between concentric cylinders. This principle is carried out with the use of the two-pronged paddle which describes a cylinder as it revolves.

In order to calibrate the instrument, water was placed in the inner container and heated indirectly with linseed oil placed in the annular space between the containers. This unit was placed on the Stormer Viscosimeter

TABLE VI - APPARENT VISCOSITY OF WATER

1931 Model, Stormer Viscosimeter
Used With 20 gm. Weight and Two-Pronged Paddle

Run No. 8a -- H_2O

Temp. °C.	Time--Sec.	Temp. °C	Time--Sec.
21.5	54.4	53.9	49.6
21.5	54.6	55.0	48.6
21.5	54.2	55.0	48.6
21.5	54.6	55.0	48.8
21.5	54.4	54.6	48.6
36.1	53.2	65.5	47.0
39.2	52.6	67.0	46.4
40.8	51.8	67.5	47.0
41.8	51.6	66.4	46.2
42.0	51.0	70.2	46.8
42.1	51.4	71.0	47.4
52.2	49.8	70.6	48.0
		69.6	47.0
		68.5	47.2

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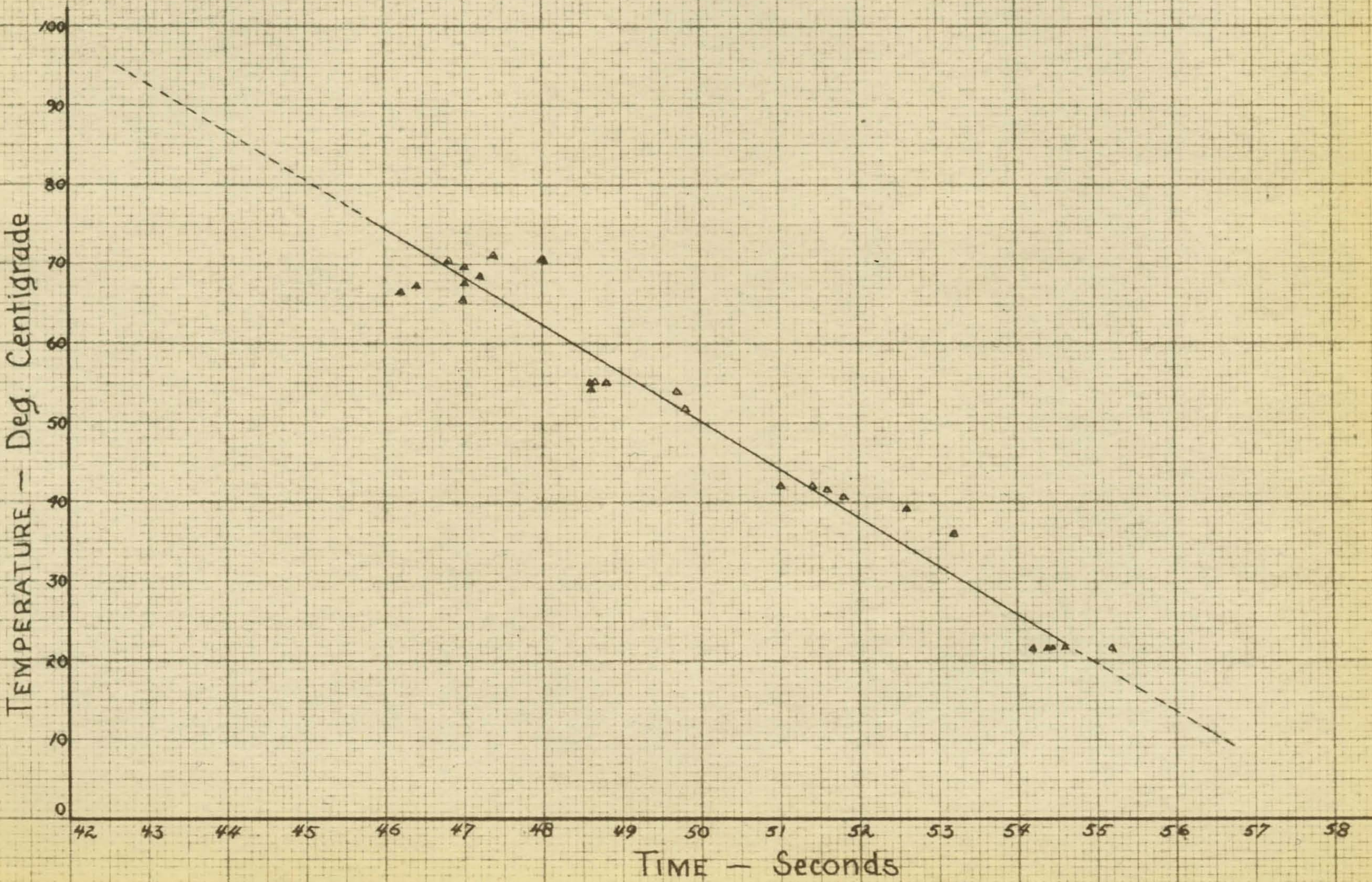


FIG. 10 — STORMER VISCOSITY WATER — TEMPERATURE

TABLE VII -- APPARENT VISCOSITY OF STILLAGE

1931 Model, Stormer Viscosimeter
Used With 20 gm. Weight and Two-Pronged Paddle

Run #10 - Temperature	Sample #10 Time-Sec. for 100 Rev.	Curve Data Av. Temp.	Curve Data Av. Time
20.5	95.0)		
20.5	98.4)	20.5	95.2
20.5	95.2)		
20.5	95.0)		
26.0	79.4)		
26.0	81.4)	26.0	81.7
26.0	84.4)		
33.0	80.8)		
33.0	80.6)	33.0	79.8
33.0	79.0)		
32.9	79.0)		
43.75	72.8)		
44.0	71.4)	44.0	71.0
43.9	70.4)		
43.5	69.4)		
52.0	69.6)		
50.0	68.4)	50.3	68.7
49.0	68.2)		
57.6	65.8)	58.5	64.8
59.5	63.8)		
63.0	64.6)		
62.5	63.0)	62.5	63.4
62.0	62.6)		
75.5	60.2)		
74.5	60.6)		
73.5	59.2)		
71.5	60.6)	72.7	59.8
73.5	60.0)		
71.75	59.2)		
70.0	59.2)		
83	59.0)		
82	58.0)	81.8	58.2
80.5	57.6)		
78.5	58.0)		

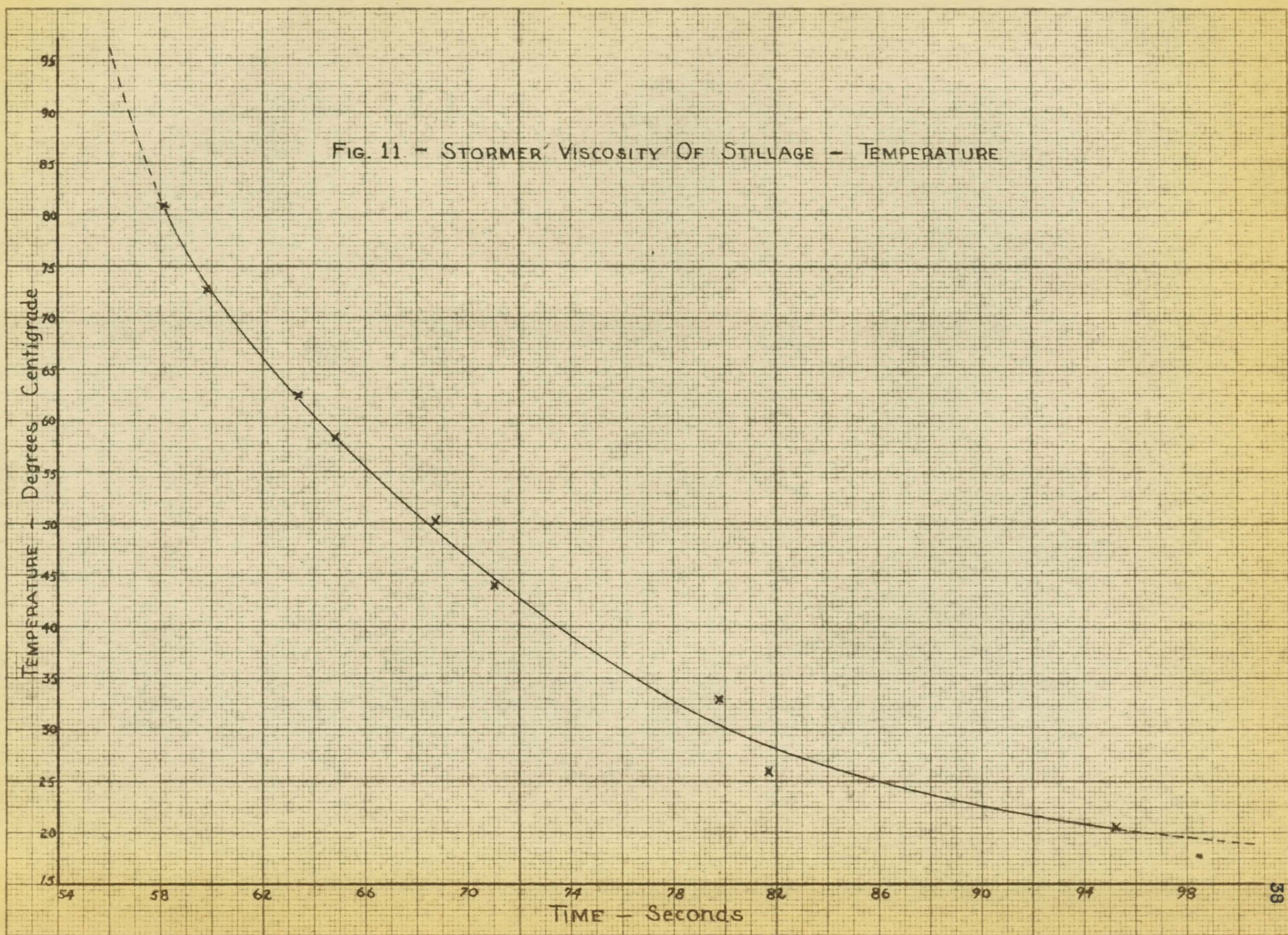


FIG. 11 - STORMER VISCOSITY OF STILLAGE - TEMPERATURE

stand and raised so that the liquid level of the water fell exactly on the paddle hair-line. A 20 gram weight was used to load the stirring device since a lighter weight would not turn the paddle in the stillage, and a heavier weight turned the paddle too rapidly in the water.

Stormer viscosity in seconds for 100 revolutions of the paddle were recorded for a temperature traverse of 20 to 71 degrees Centigrade.

A sample of stillage, equal in volume to the water used in the calibration run, was then placed in the inner container and the procedure repeated. Precautions had to be taken to minimise the loss of moisture by evaporation which would in turn change the quality of the stillage. This was attained by using a cover on the inner container at all times when not actually taking a reading.

Results - As shown by Fig. 10, the Stormer viscosity of water is a linear function of temperature in the temperature range of 20 to 71 degrees Centigrade. In this interval, the Stormer time ranged from 55.0 to 46.7 seconds. This curve was extrapolated to give a wider range.

The change on apparent viscosity of whole stillage in Stormer units with temperature is depicted in Fig. 11. Each point on this curve is the average of a number of observed values, i.e., they actually represent from three to seven observed values as shown in Table VII.

Fig. 12 represents a conversion curve from Stormer viscosity in seconds to viscosity in centipoises and is obtained by plotting, for a given temperature, the log of the actual viscosity of water in centipoises versus the log of the viscosity of water in Stormer units. This curve is a straight line in the lower temperature range, from 40 to 10 degrees centigrade,

TABLE VIII -- APPARENT VISCOSITY (CONTINUED)

Compilation of Data

Temp. °C	Viscosity of Water from Perry's Handbook Centipoises	Viscosity of H_2O Stormer Time in Sec. from Fig. 13	Viscosity of Stillage from Fig. 11 Stormer Time in Sec.	Viscosity in Centipoises from Fig. 12
0.0	1.7921	58.2		
10.0	1.3077	56.6		
19.0			100.0	49.0
19.5			98.0	43.0
20.0	1.0050	55.0	96.0	38.0
21.5			92.0	28.4
23.6			88.0	21.0
25.0			86.0	18.0
26.5			84.0	15.5
28.0			82.0	13.2
30.0	0.8007	53.4	80.1	11.8
32.8			78.0	9.4
40.0	0.6560	51.7	73.5	6.4
42.8			72.0	5.5
50.0	0.5494	50.1	68.4	4.0
55.4			66.0	3.2
60.0	0.4688	48.4	64.1	2.6
70.0	0.4061	46.7	60.6	1.8
76.0			59.0	1.5
80.0	0.3565	45.0	58.3	1.4
81.5			58.0	1.3
88.0			57.0	1.2
90.0	0.3165	43.4	56.8	1.1
96.0			56.0	1.1
100.0	0.2838			

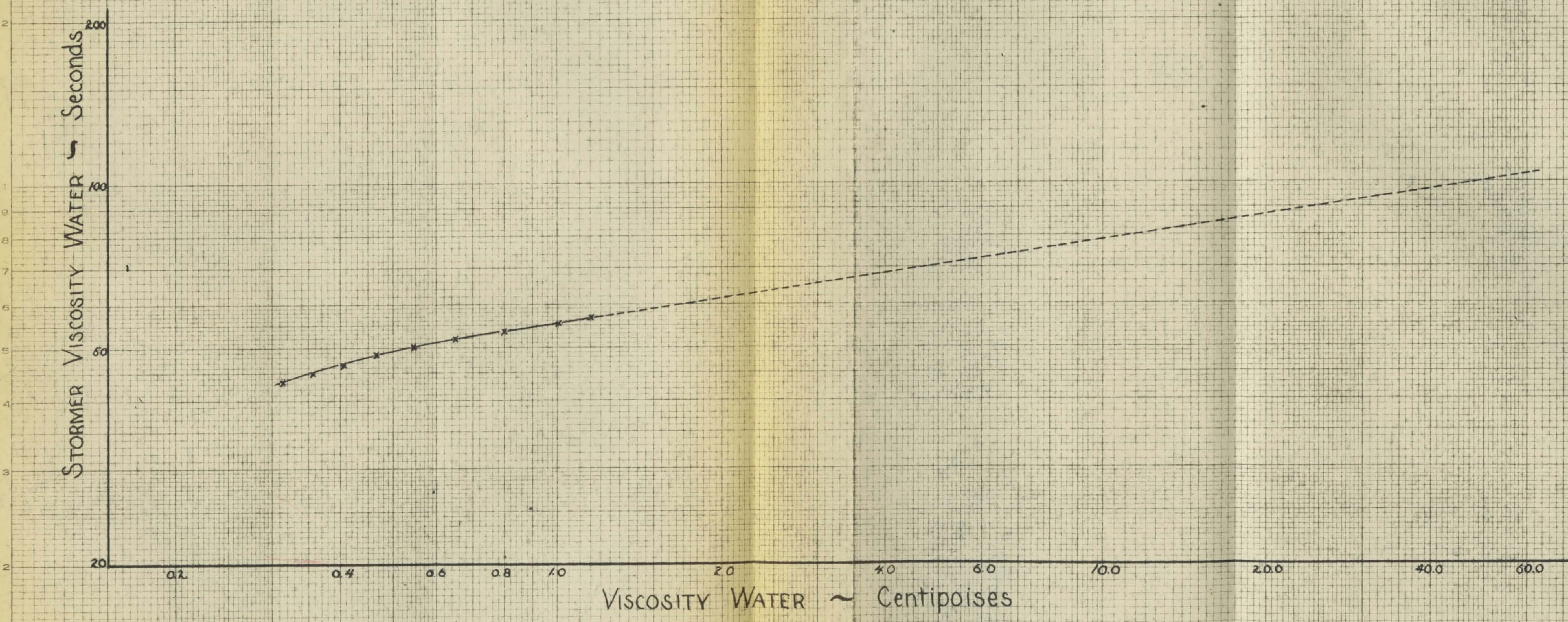


Fig. 12 - Conversion Chart of Stormer Viscosity in Seconds to Centipoises

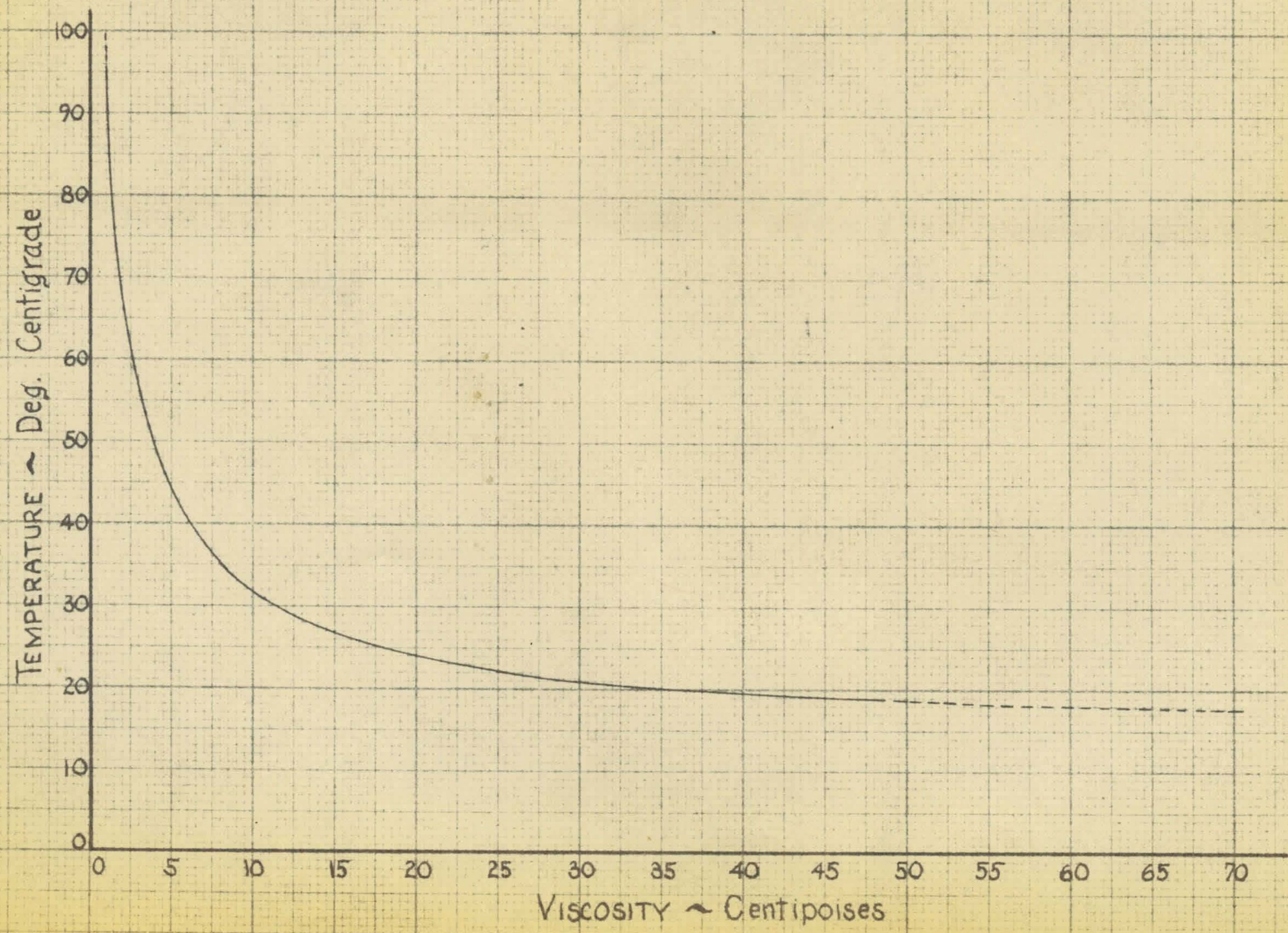


Fig. 13 – Apparent Viscosity Of Stillage — Temperature

enabling the conversion of the higher Stormer readings of stillage to centipoises by extrapolation.

Fig. 13 represents this conversion of Stormer viscosity of stillage in seconds to the standard units of centipoises. The shape of the curve is a hyperbola, showing very slight change in viscosity at 100 degrees centigrade and an extreme increase at 17 to 20 degrees Centigrade.

Per Cent Total Solids

Procedure - A 350 cc sample of stillage, whether it be whole stillage, screen effluent, or screenings, was placed in a 400 ml beaker, weighed and dried at 80-85 degrees Centigrade to dryness-usually taking two to three days.

Results - It was found that whole stillage contained from 5-7 per cent solids, screen effluent 3.5 to 6 per cent solids, and screenings 12 to 16 per cent solids.

Per Cent Dissolved Solids

Procedure - A 50 cc sample of stillage was centrifuged, the supernatant liquid was poured into a 10 ml weighing bottle, weighed, and dried completely at 80-85 degrees Centigrade. The results were obtained using Eq. 17 or 18.

Results - Whole stillage contained 2.5-3.5 per cent dissolved solids, and screen effluent contains approximately the same amount of dissolved solids as the whole stillage from which it was obtained.

Per Cent Suspended Solids

Per Cent Suspended Solids were obtained by subtracting the dissolved solids in a sample from the total solids.

Particle Size Distribution

Procedure - A set of Tyler Standard Sieves (10, 14, 20, 28, 35, and 48 mesh sieves) were used. The percentages of total and suspended solids in a 1000 gram sample of whole stillage were determined. Then, 750 grams of this sample were placed on the No. 10 Sieve, using only approximately 100 grams at a time-i.e. at no time was there more than 100 grams of the original stillage on Sieve No. 10. This 100 gram sample was washed with a small, light spray of water until, by observation, all the particles possible to pass through the No. 10 Sieve had done so. The grain remaining on the sieve was then washed into a large evaporating dish using a minimum of wash water. This procedure was repeated for the remainder of the original sample. The supernatant water was carefully decanted and the remaining grain and water weighed and dried in a 400 ml beaker at 80-85 degrees Centigrade. The same method of washing, collecting, and drying was used with the remaining sieves in order.

Results - A plot of the cummlative percentages (by weight) retained versus the size of the sieve opening in inches is shown on Fig. 14.

TABLE IX -- PARTICLE SIZE DISTRIBUTION

Sample from Barrel No. 6

Wgt. of Sample	978.0 grams
Per Cent Total Solids	6.45
Per Cent Dissolved Solids	2.76
Wgt. of Total Solids	63.0 grams
Wgt. of Dissolved Solids	27.0 grams
Wgt. of Suspended Solids	36.0 grams

Tyler Sieve No.	Openings Inches	Weight Retained On Sieve	Per Cent Suspended Solids Retained	Cumulative Per Cent By Wgt.
10	0.065	3.90 gm	10.8	10.8
14	0.046	5.10	14.2	25.0
20	0.0328	4.75	13.2	38.2
28	0.0232	2.65	7.4	45.6
35	0.0164	2.00	5.6	51.2
48	0.0116	1.30	3.6	54.6

Fig. 14 – Particle Size Distribution Of Whole Stillage

APPARATUS

The apparatus, as shown by Figures 15, 16, and 17, consisted of a 55-gallon steel Holding Tank, fitted with a two-paddle Lightning Mixer; a 10-gallon, steam and water jacketed iron kettle, used to heat the stillage to the desired feed temperature; a 2 H.P. centrifugal pump; a P.I.V. (Positive-Infinite Variable) Drive motivated by a 3 H.P. motor; a thermometer (0 - 100 degrees Centigrade); a 2 H.P. turbo-pump and a Shaking Screen.

The Shaking Screen is made up of five parts:

1. A rectangular galvanized sheet-metal Weir Box (12"x14"x8") with a 2-inch weir leading into a trough (12"x24"x1"), which itself, is attached to the Weir Box. Although the Weir Box was stationary it could be adjusted to correspond to the angle at which the Screen Frame was set.

2. The Screen Frame, made of wood and galvanized sheet metal, was used to hold the Screens.

This frame was approximately 44 inches long, 18 inches wide, 5 inches deep at the feed end, and 6 inches deep at the outlet end. There were two outlets separated by a baffle plate. One outlet, in the shape of a frustum of a rectangular pyramid, was for the screenings. An adaptation of a roof gutter with end pieces and a drop spout was used for the effluent outlet. Just above the latter outlet a sloping, almost horizontal baffle was placed to eliminate the effluent from splashing back through the screen.

The Screen Frame was hung from a wooden framework by four adjustable wooden hangers. To one of these hangers was attached an automatic counter device to give an indication of the frequency of vibration.

Fig. 15A <u>GENERAL VIEW OF SHAKING SCREEN</u>

1 - Weir Box

2 - Weir Box Trough

3 - Feeder Trough

4 - Screen Frame and Trough

5 - Effluent Outlet

6 - Screenings Outlet

7 - Adjustable Wooden Hangers

8 - Automatic Counting Device

9 - P.I.V. Drive

10 - Crank

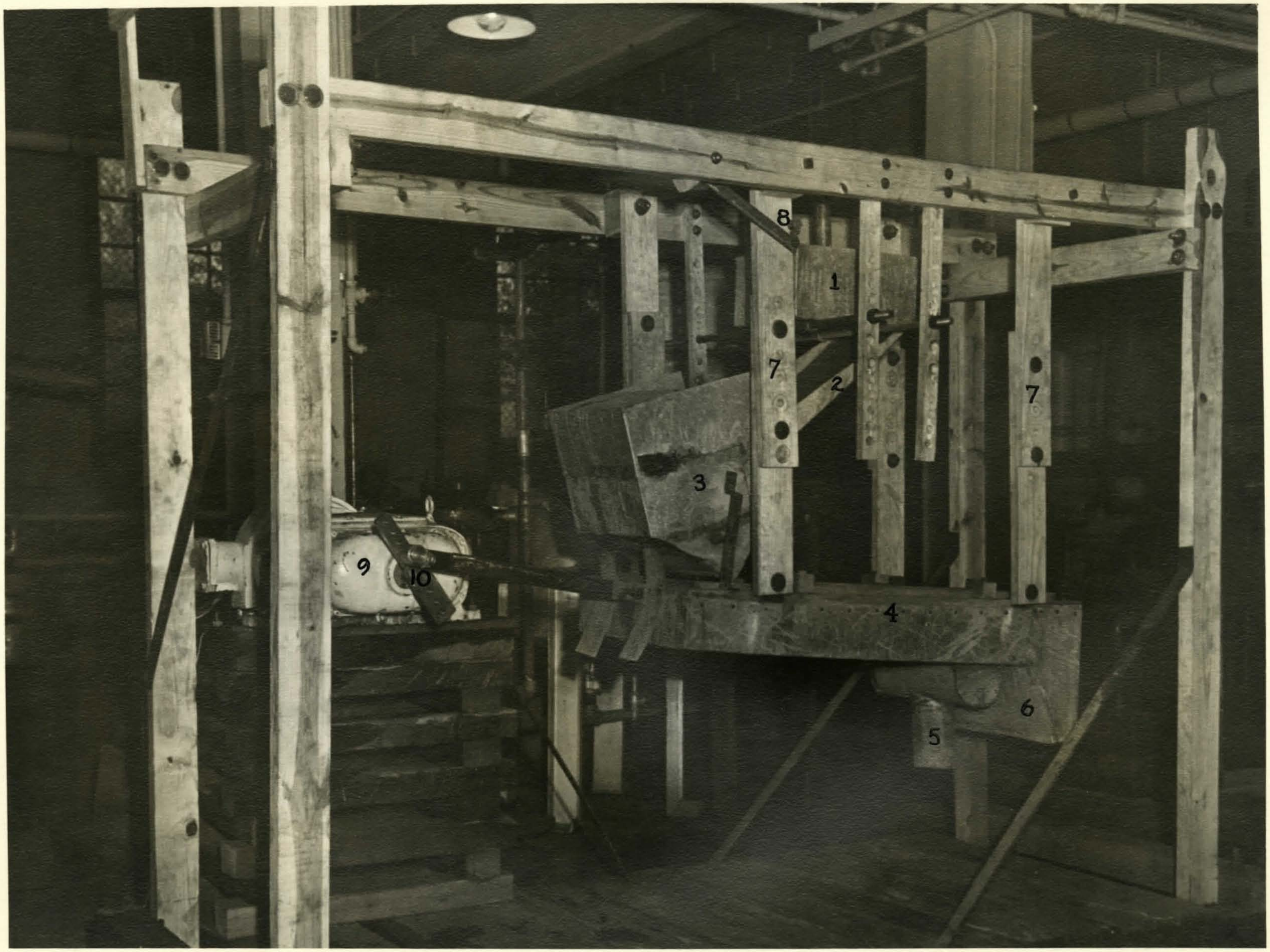


Fig. 15A GENERAL VIEW OF SHAKING SCREEN

Fig. 15B <u>FRONT VIEW OF SHAKING SCREEN</u>

1 - Weir Box

2 - Weir Box Trough

3 - Feeder Trough

4 - Screen Frame

5 - Screening Surface

6 - 3 H.P. Motor

7 - P.I.V. Drive

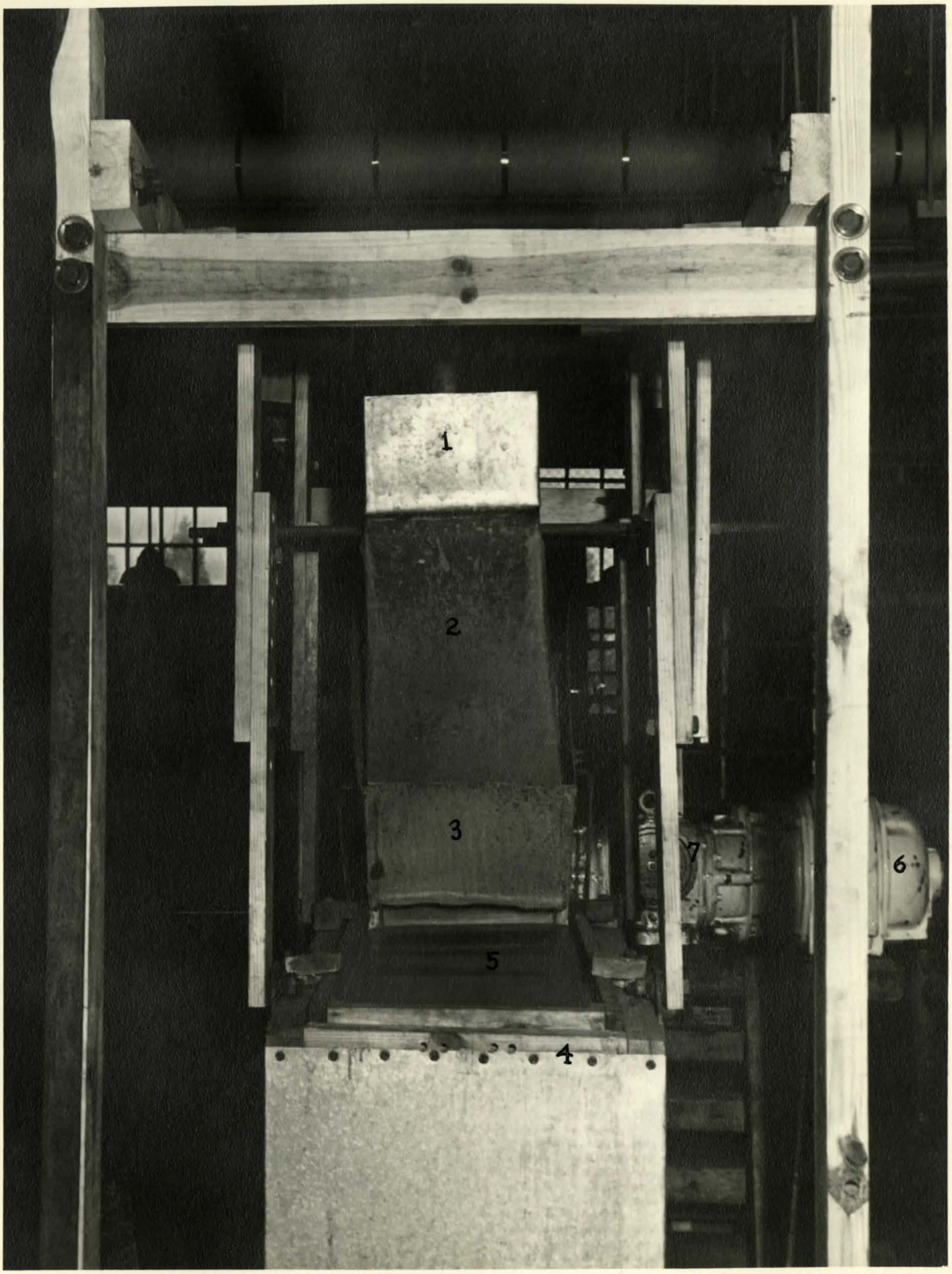


Fig. 15B FRONT VIEW OF SHAKING SCREEN

Fig. 15 C CLOSE-UP OF BAFFLING ARRANGEMENT

1 - Splash Preventing Baffle

2 - Separation Baffle

3 - Wooden Clamps

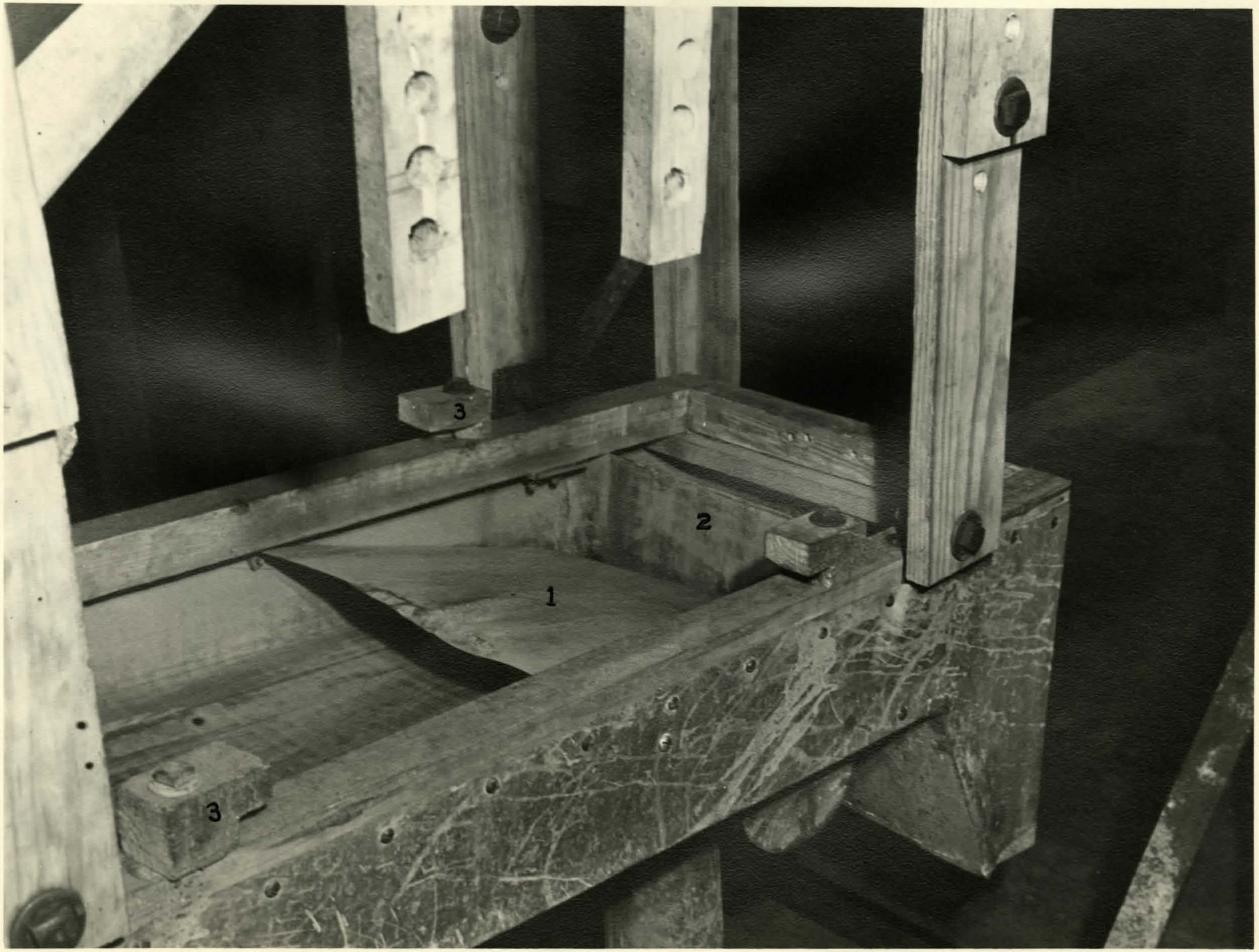


Fig. 15C <u>CLOSE-UP OF BAFFLING ARRANGEMENT</u>

3. The Feeder Trough was attached to the Screen Frame and designed to receive the feed from the Weir Box Trough as the screen vibrated for all combinations of screen angle and amplitude of vibration used. It was approximately 12 inches wide, 15 inches long, and 16 inches high.

4. The reciprocating motion of the screen was imparted by the P.I.V. drive through the use of a Crank, drilled and tapped at 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, and 5 inches from the center of the drive shaft. An adjustable connecting rod was used to link the Crank and the Screen Frame. This connecting rod was fastened at the Screen Frame end simply by means of a drilled hole and bolt with a slide fit. At the Crank end, a slip bearing was brazed on, into which a special steel shaft was placed and threaded into the holes in the Crank. This unit converted the rotary motion of the P.I.V. drive to an almost horizontal reciprocating motion.

5. The Screens, with approximately a 1 by 3 foot screening surface, were stretched taut on wooden frames which fitted into the Screen Frame and were held down by four, small wooden clamps. Thirteen screens were fabricated, seven being woven brass wire and six punched copper plate. The following is a list of these screens giving the size or mesh number, the size of the opening, and the number of holes per square inch:

Mesh or Size No.	Size of Opening (Inches)	No. of Holes Per Sq. In.
	Woven Wire	
50	0.0115	2500
35	0.0166	1225
32	0.01925	1025
28	0.0237	784
24	0.0277	576
20	0.0330	400
16	0.0395	256

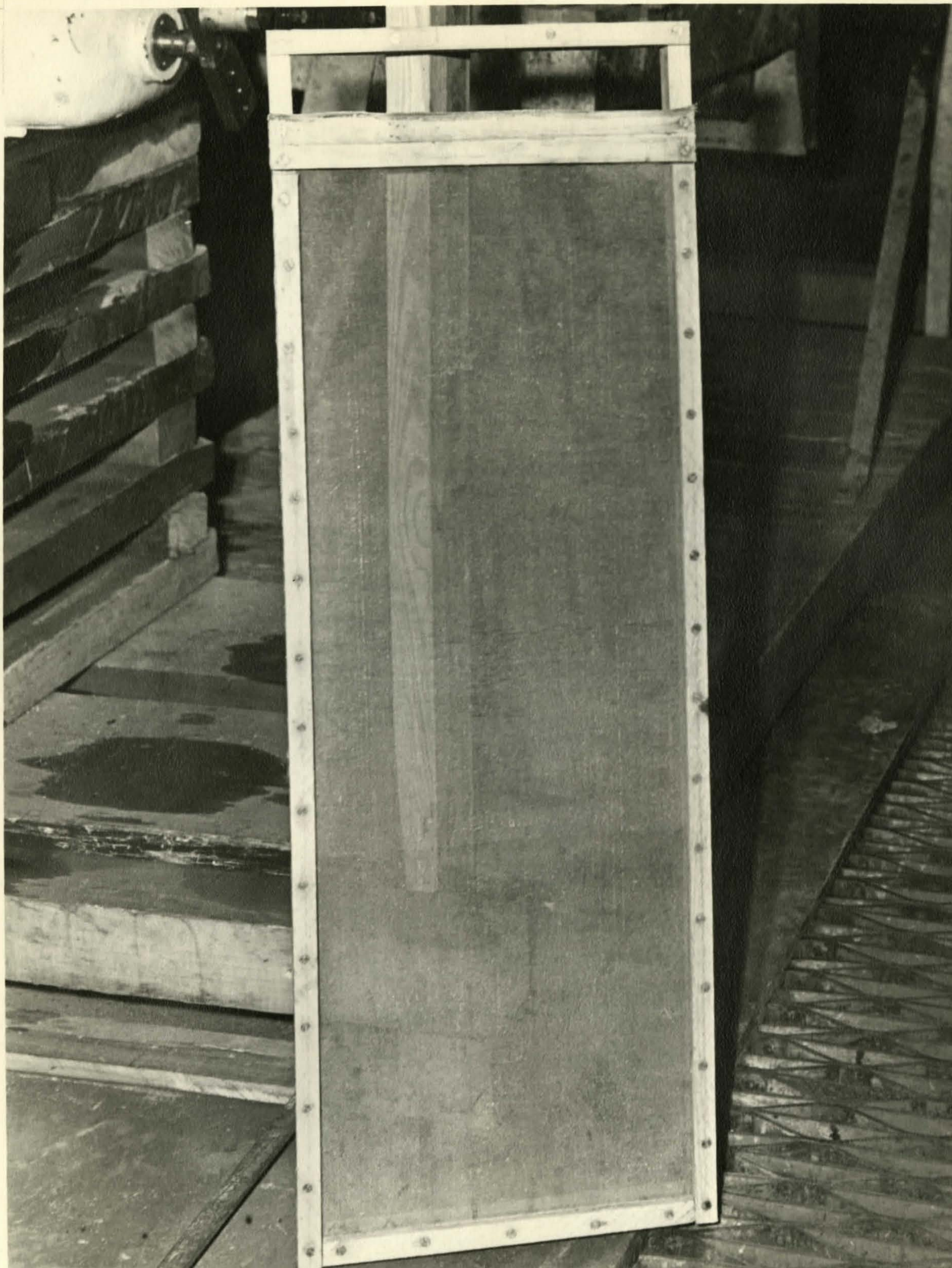


Fig. 16 WOODEN FRAMED SCREEN

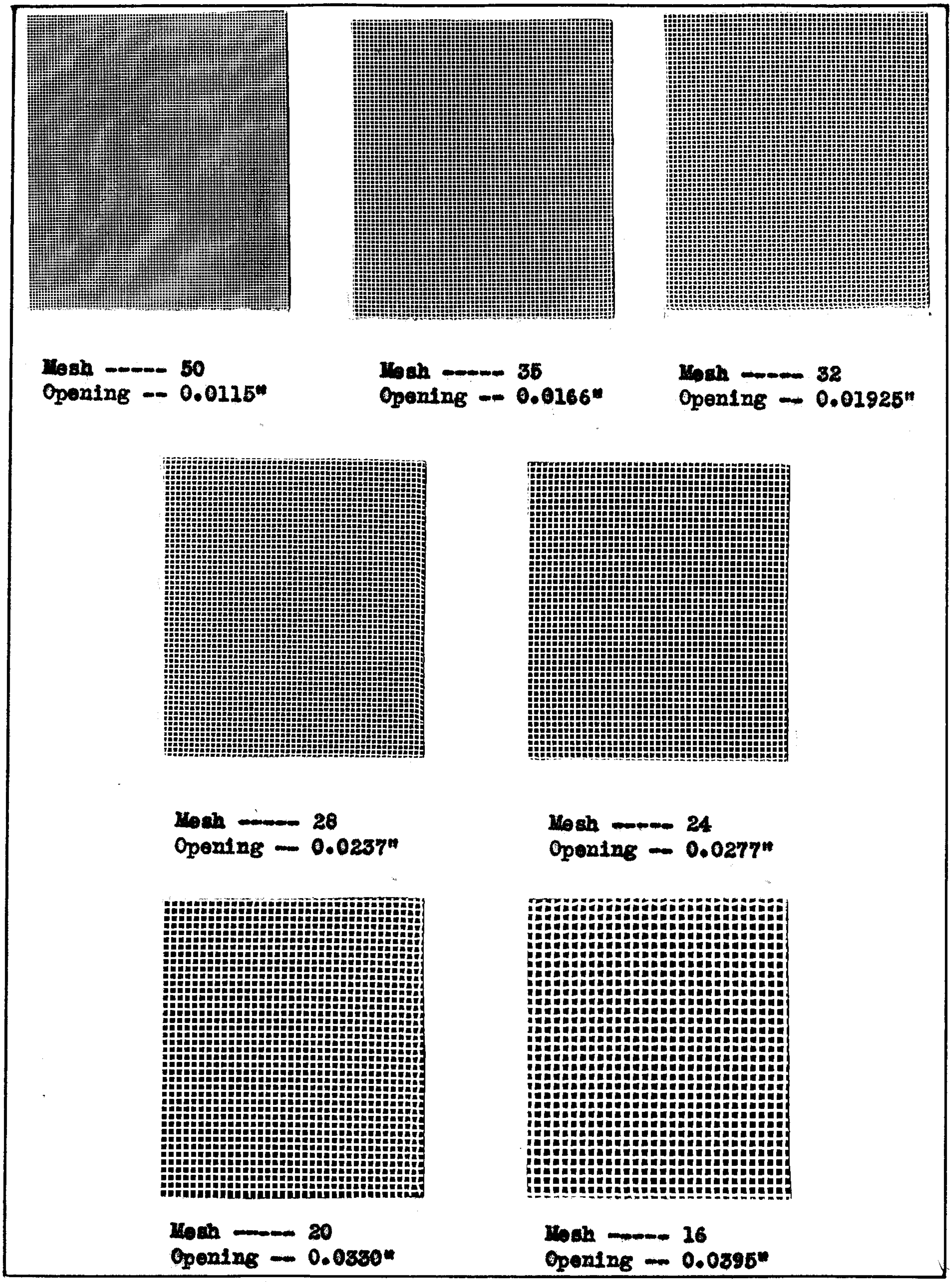
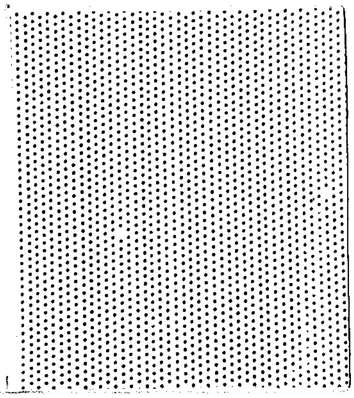
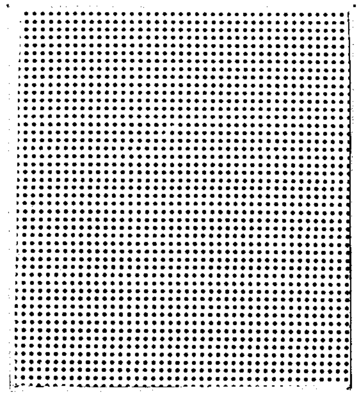


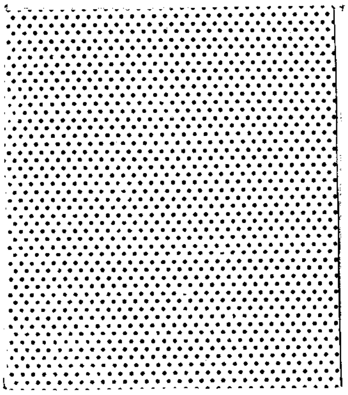
Fig. 17A - WOVEN WIRE SCREENS



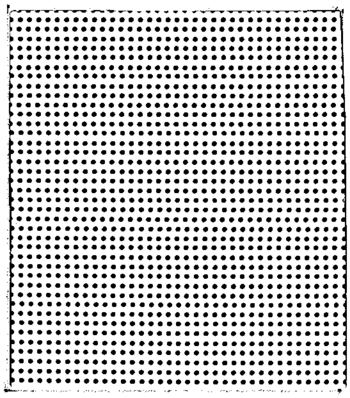
Size No. 00
Opening -- 0.020"
Holes/sq. in.-625



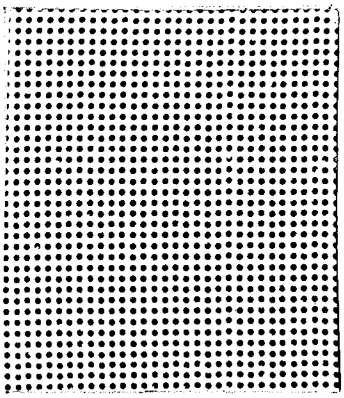
Size No. 0
Opening -- 0.023"
Holes/sq. in.-575



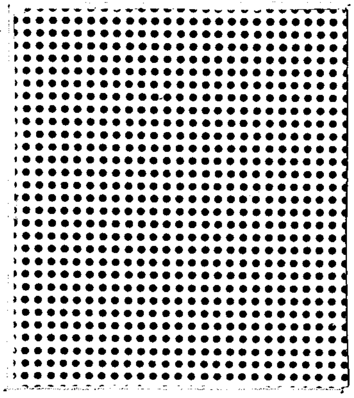
Size No. 0A
Opening -- 0.023"
Holes/sq. in.-400



Size No. 1
Opening -- 0.027"
Holes/sq. in.-400



Size No. 2
Opening -- 0.033"
Holes/sq. in.-329



Size No. 3
Opening -- 0.039"
Holes/sq. in.-225

Fig. 17B - PUNCHED PLATE SCREENS

Mesh or Size No.	Size of Opening (Inches)	No. of Holes Per Sq. In.
	Punched Plate	
00	0.020	625 (staggered)
0	0.023	575
0A	0.023	400 (staggered)
1	0.027	400
2	0.033	329
3	0.039	225

PROCEDURE

General

As shown in Fig. 18, the whole stillage as received from the Louisville Plant of Joseph E. Seagram & Sons, Incorporated, was transferred from the wooden barrels to the Holding Tank by means of a small 2-H.P. Turbo-Acting Pump. Forty-five to fifty-five gallons of stillage was pumped to the holding tank which was enough for six or seven runs. After thorough mixing to obtain uniformity about ten gallons of stillage was allowed to flow by gravity into the jacketed-kettle. The stillage was then pumped to a three-way cock - one outlet leading to the Shaking Screen, the other, fitted with a thermometer, being the recirculation line, to the Kettle. The line leading to the three-way cock contained a by-pass line into the Kettle which is used for controlling the rate of flow. The liquid coming from this line also aided in keeping the stillage in the Kettle well mixed.

The stillage was pumped through the recirculation line--i.e., the cock opening was closed to the Shaking Screen--and the valves adjusted to the desired flow conditions. The steam was turned on and the material slowly heated to the desired temperature. When this temperature was reached, a 350-375 cc sample of the feed (whole stillage) was taken. About 50 cc of this sample was then carefully poured into a centrifuging tube. The material remaining in the beaker was then weighed. These samples were used to determine the dissolved solids content and total solids content of the whole stillage as described in the Physical Properties Section.

While the stillage was heated to the proper temperature, the Shaking Screen was adjusted as to Screening Angle, Frequency of Vibration, Amplitude

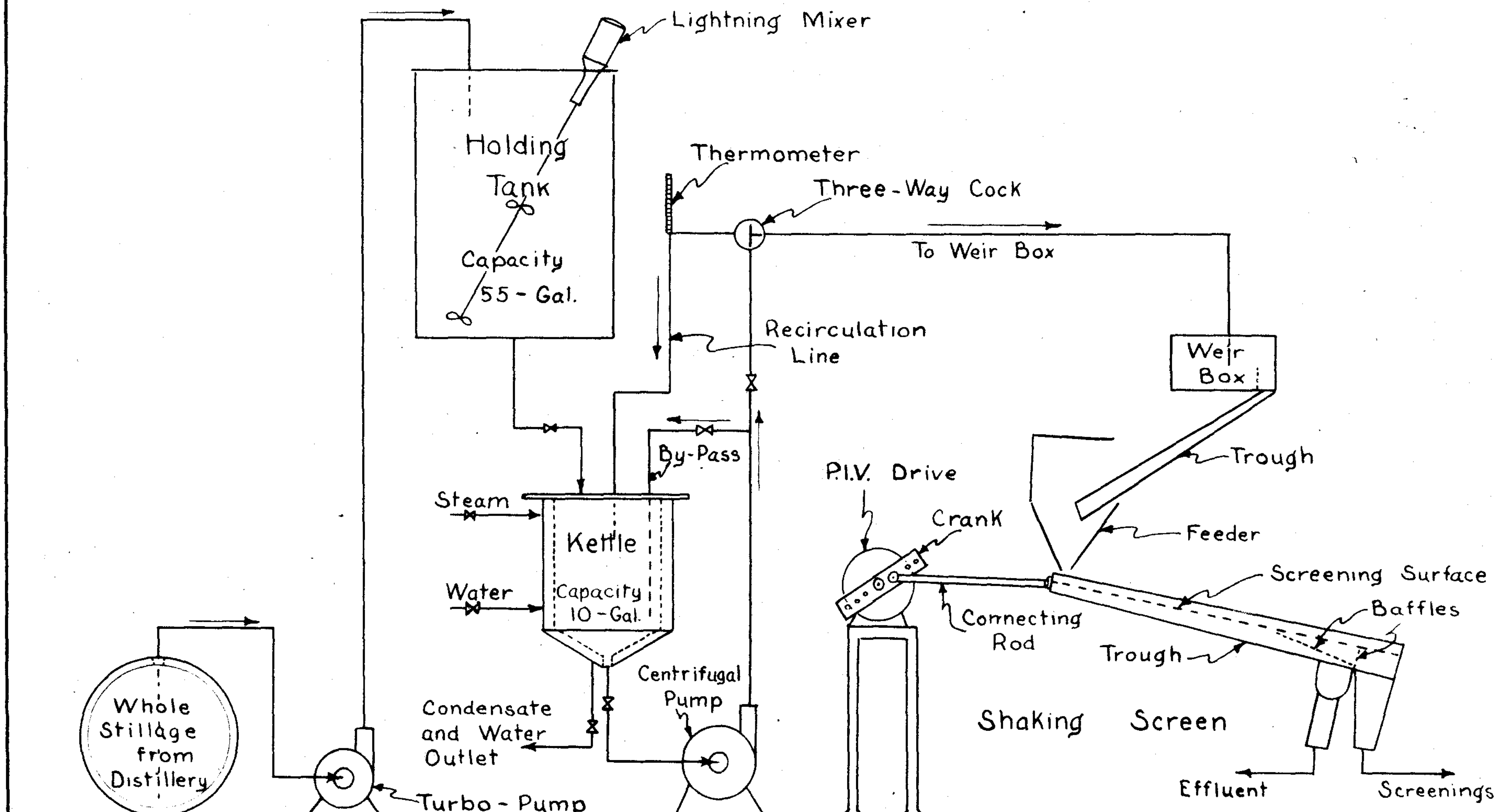


FIG. 18 - FLOW DIAGRAM OF EXPERIMENTAL SCREENING PROCESS

of Vibration, and Screen Type, according to which variable was to be studied.

Following sampling and adjustments, the shaking screen motor was started and the three-way cock turned so that the flow was diverted from the kettle to the shaking screen. As soon as some screenings were obtained, 350-375 cc samples of the effluent and screenings were secured. The three-way cock was then turned to its original position and the shaking screen motor turned off. The elapsed time between the two adjustments of the three-way cock was recorded, usually 26 to 40 seconds depending upon the variable-settings employed.

The total material pumped to the shaking screen was caught in a large container and weighed. From the total weight pumped and the time of pumping the average rate of flow was calculated.

The stock in the kettle was replenished with stillage from the Holding Tank and the procedure repeated using other desired variable-settings.

<u>Quality of Feed</u>
(Percentage of Suspended Solids in Feed) at different temperatures.

The percentage of suspended solids in the feed was varied by either adding water to, or driving water from, a standard stillage sample.

The suspended solids in Mash Type No. 1 were varied from 5.0 to 3.2 per cent at 75°C; and from 4.2 to 2.3 per cent at 29-32°C. The suspended solids in Mash Type No. 3 were varied from 2.6 to 1.4 per cent at 75°C; from 3.0 to 1.1 per cent at 50°C; and from 2.4 to 0.6 per cent at 28°C.

All these runs were made using a 4-inch horisontal displacement, a 4 degree screening slope, and 225 vibrations per minute.*

Feed Rate

With the shaking screen set at an angle of 8 degrees, and for 225 vibrations per minute with a horizontal displacement of 4 inches, the feed rate of the stillage (Mash Type No. 1) was varied from 68 to 237 pounds per minute.

Using Mash Type No. 3, the feed rate of the stillage was varied from 60 to 260 pounds per minute, with the screen set at a 4 degree angle, and for 146 vibrations per minute with a 4 inch horizontal displacement.

Feed Temperature with different mash types.

Using Mash Type No. 1, the screen was set at a 4 degree angle; the number of vibrations used with a 4 inch displacement were 225; and the feed temperature was varied from 29.5 to 92.0°C.

Using Mash Type No. 2, the screen was also set at a 4 degree angle; the number of vibrations used with a 4 inch displacement were 146; and the feed temperature was varied from 29.0 to 91.0°C.

Screening Angle at different frequencies.

Using Mash Type No. 1, the screen was set to give a 4 inch horizontal displacement. Screening angles of 0°, 4°, 8°, 12°, and 15°17' were used. Two sets of runs were made under these conditions, one at 225 vibrations per minute and the other at 146 vibrations per minute.

Type of Screen

Using the thirteen screens described under Apparatus (Item 5) and

*All runs, in this study, except where specifically mentioned, were made using Screen No. 00 (in present use at the Louisville Plant of Joseph E. Seagram & Sons, Incorporated), and a feed temperature of 75°C.

stillage of Type No. 2, the shaking screen was set as follows: Screening angle-4 degrees; horizontal displacement-4 inches, and number of vibrations per minute-146.

Frequency of Vibration

The shaking screen was set at a screening angle of 4 degrees, with a 3 inch horizontal displacement. Using Mash Type No. 2, the frequency was varied from 145 to 267 vibrations per minute.

Horizontal Displacement at different Screening Angles.

Using Mash Type No. 2, a frequency of 146 vibrations per minute, and horizontal displacement settings of 2, 3, 4, 5, 6 and 7 inches, the screening angle was changed from 0° to 4° and to 8°.

A duplicate run, using Mash Type No. 3, was made at the 0° screening angle.

Reproducibility of Results

Keeping all the variables constant, the shaking screen was set for a 4° slope, the number of vibrations per minute at 225 with a 4 inch displacement. These runs were made with Mash Type No. 1 at $75^{\circ}C$.

RESULTS AND DISCUSSION

The results of this screening study are represented in two ways: Per Cent Dewatered (Eq. 9) and Per Cent Retained (Eq. 15).

Since the dissolved solids in the mother liquor of the feed was not determined for Runs 1-44, inclusive, they were estimated by plotting M_e versus F for Runs 92-114. This procedure resulted in Curve No. 3, Fig. 19, representing Mash Type No. 2. Runs 115-120, representing Mash Type No. 1, were plotted, and an estimated curve was drawn (Curve No. 1, Fig. 19) so as to pass through the origin.

Curve 2, Fig. 19, was also used for estimating data (M_f) that seemed erroneous in isolated cases.

The values of M_e were used where M_f was not analytically determined, since theoretically,

$$M_f = M_e \tag{18}$$

Being physically impossible to keep the quality of the feed and the feed rate constant and uniform with the available equipment, corrections for deviations had to be made.

Arbitrarily, an average feed rate of 120 pounds stillage per minute was decided upon as a standard. Also chosen as standards were $(F - D_f)$ av. = 3.8, 3.5, and 3.5 for Mash Type Nos. 1, 2, and 3 respectively.

It should be noted that these corrections do not correlate data taken with different mash types. All they attempt to do is to put on the same basis all the data taken with one mash type. The curves do not represent actual experimentally determined percentages but corrected or pseudo Per Cent Retained or Dewatered figures.

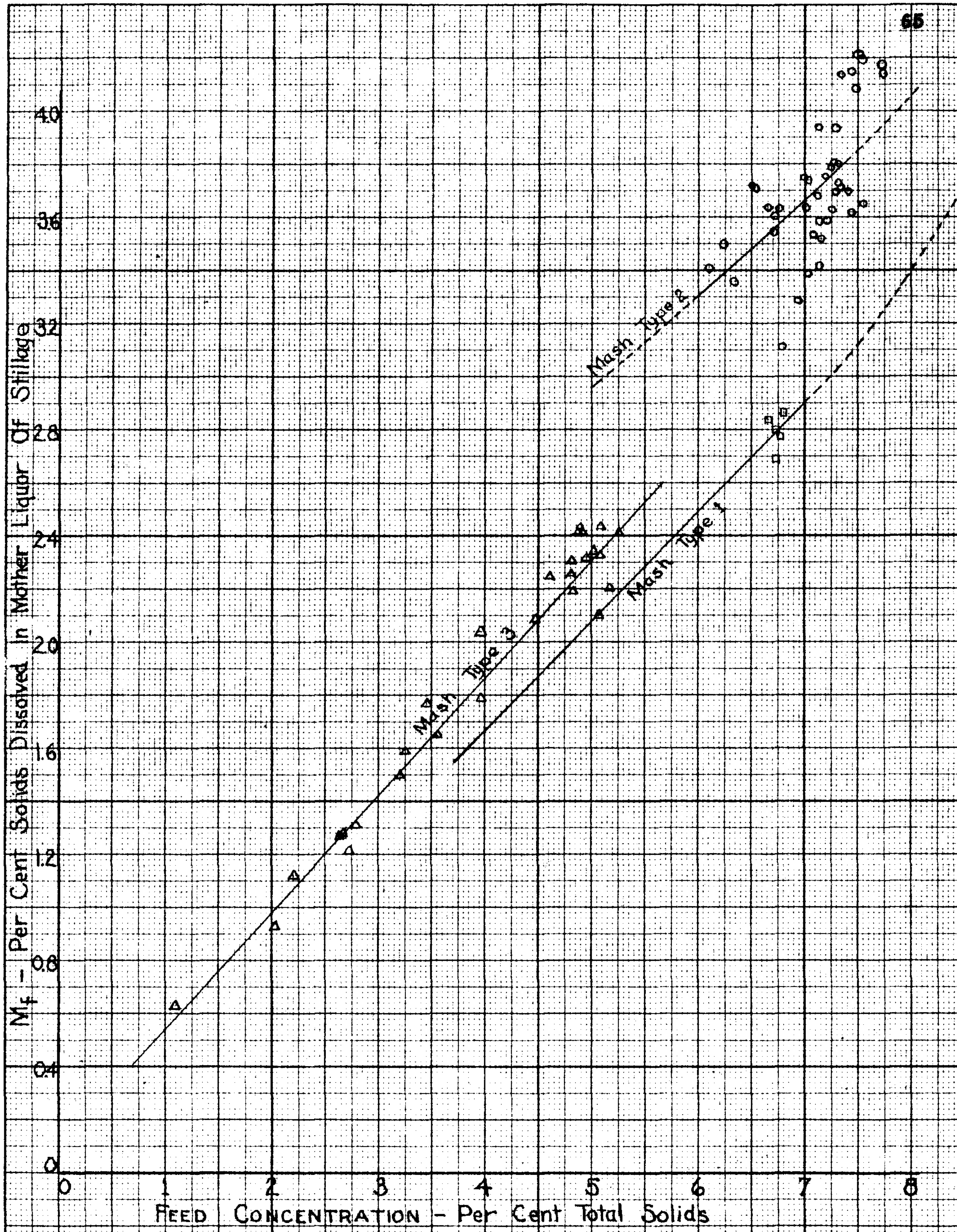


FIG. 19 - RELATION BETWEEN DISSOLVED AND TOTAL SOLIDS IN STILLAGE

For convenience in studying the results, both the Per Cent Retained and the Per Cent Dewatered are plotted on the same graph using the same ordinate, the abscissa being the variable in all cases.

Runs 34-40, in which all the variables were held constant, were made in an attempt to show the reproducibility of results and are presented in Table XVII.

Effect of Quality of Feed

Figure 20 shows the variation of Per Cent Dewatered (P.C.D.) and Per Cent Retained (P.C.R.) with the per cent suspended solids in the feed at several temperatures.

For mash types 1 and 3 a high concentration of suspended solids results in high retention and poor dewatering--the opposite being true for low solids concentrations. This result may be attributed to the fact that for a thin slurry (low concentration of solids) the effective viscosity is low and the grain particles as well as the dissolved solids, have ample opportunity to pass through the screen openings. The opposite is true in the case of stillage with a high concentration of suspended solids.

A comparison of curves representing one set of conditions, such as B, indicates that the P.C.D. curve is almost diametrically opposite in shape to the P.C.R. curve since the same factors that enable small particles to pass through the screen will allow the passage of the mother liquor. This relationship is found consistently in all such comparisons.

A change in temperature does not effect the slopes or shapes of the Curves. This absence of a trend is particularly evident in curves C, D, and E, representing Mash Type 3 at 28°, 50°, and 75°C., respectively.

Curve	A	B	C	D	E
Temperature-°C	32	75	28	50	75
Displacement	4"	4"	4"	4"	4"
Screen Angle	4°	4°	4°	4°	4°
Vibrations/min.	225	225	225	225	225
Mash Type	1	1	3	3	3
Designation	△	□	×	○	▽

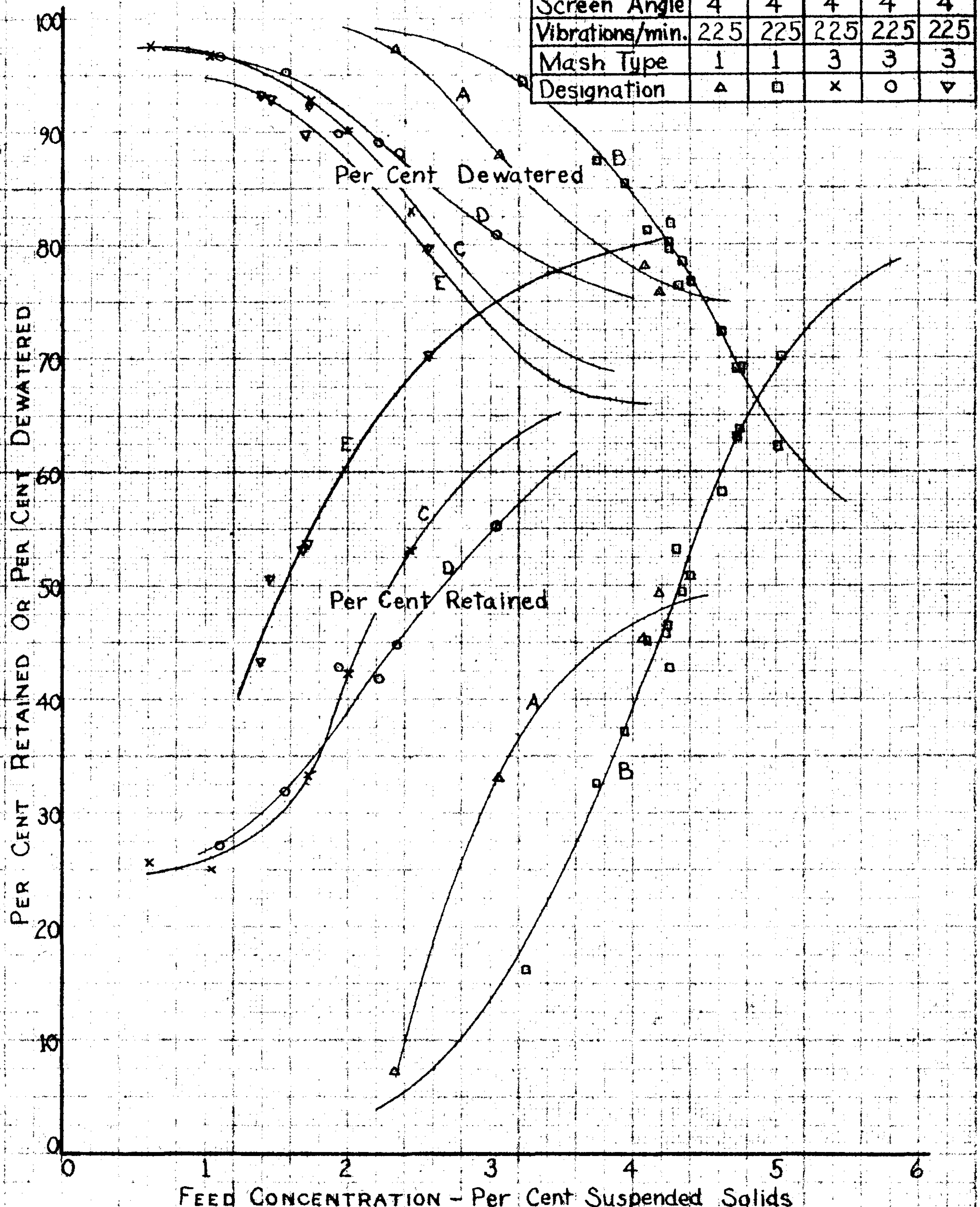


Fig. 20 - Variation Of Dewatering And Retention With Suspended Solids In The Feed At Different Temperatures

Curve	A	B	C	D	E
Temperature - °C	32	75	28	50	75
Displacement	4"	4"	4"	4"	4"
Screen Angle	4°	4°	4°	4°	4°
Vibrations/min.	225	225	225	225	225
Mash Type	1	1	3	3	3
Designation	△	□	×	○	▽

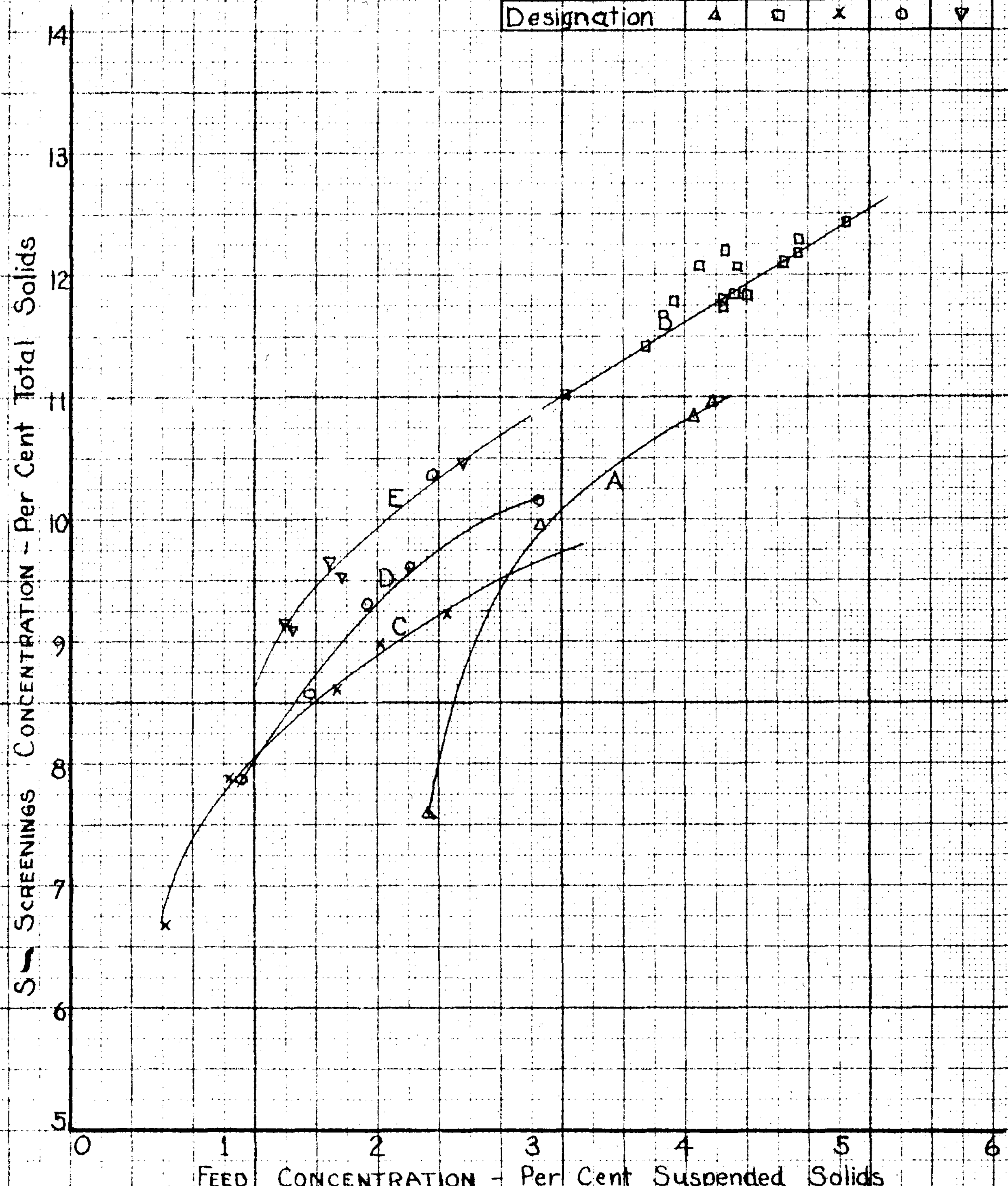


Fig. 21 - Variation Of Screenings With Suspended Solids In The Feed At Different Temperatures

The difference in mash types can be illustrated by noting that a concentration of 2.6% suspended solids of Mash Type 1 at 75°C results in a P.C.R. of 12.5, while Mash Type 3, at the same temperature and concentration, gives a P.C.R. of 70.6. The explanation is, that in their original form Mash Type 1 contained approximately 4% suspended solids while Mash Type 3 contained only 2.6%. Thus, Mash Type 1 would have to be diluted with water to attain a concentration of 2.6% suspended solids. This would end in a low viscosity slurry (since water rather than a mother liquor was used), which, as has been stated previously, results in low retention.

Another item concerning Fig. 20 is the slope of the curves, i.e., a small change in concentration results in a comparatively large change in P.C.R. and P.C.D. This effect is particularly important as far as this screening study is concerned because it was found impossible to keep the concentration of suspended solids uniform and constant. Hence, it was found impossible to decide in many cases, where small changes in P.C.D. or P.C.R. occurred, whether they were due to a change in the variable or a slight change in feed concentration. Consequently, the curves in Fig. 20 were used to make corrections for even minor deviations from the averages. Curve E was also used to make corrections for Mash Type 2, since it resembled Type 3 a little more closely than Type 1, as shown by Fig. 19.

Fig. 21 indicates that an increase in feed concentration is accompanied by an increase in concentration of solids in the screenings over the temperatures investigated. Looking at Curves C, D, E, one can see that they fall above one another, respectively, with Curve D being only slightly higher than Curve C.

Curve	A	B
Vibrations/min	146	225
Displacement	4"	4"
Screen Angle	4°	8°
Temperature °C	75	75
Mash Type	3	1
Designation	□	△

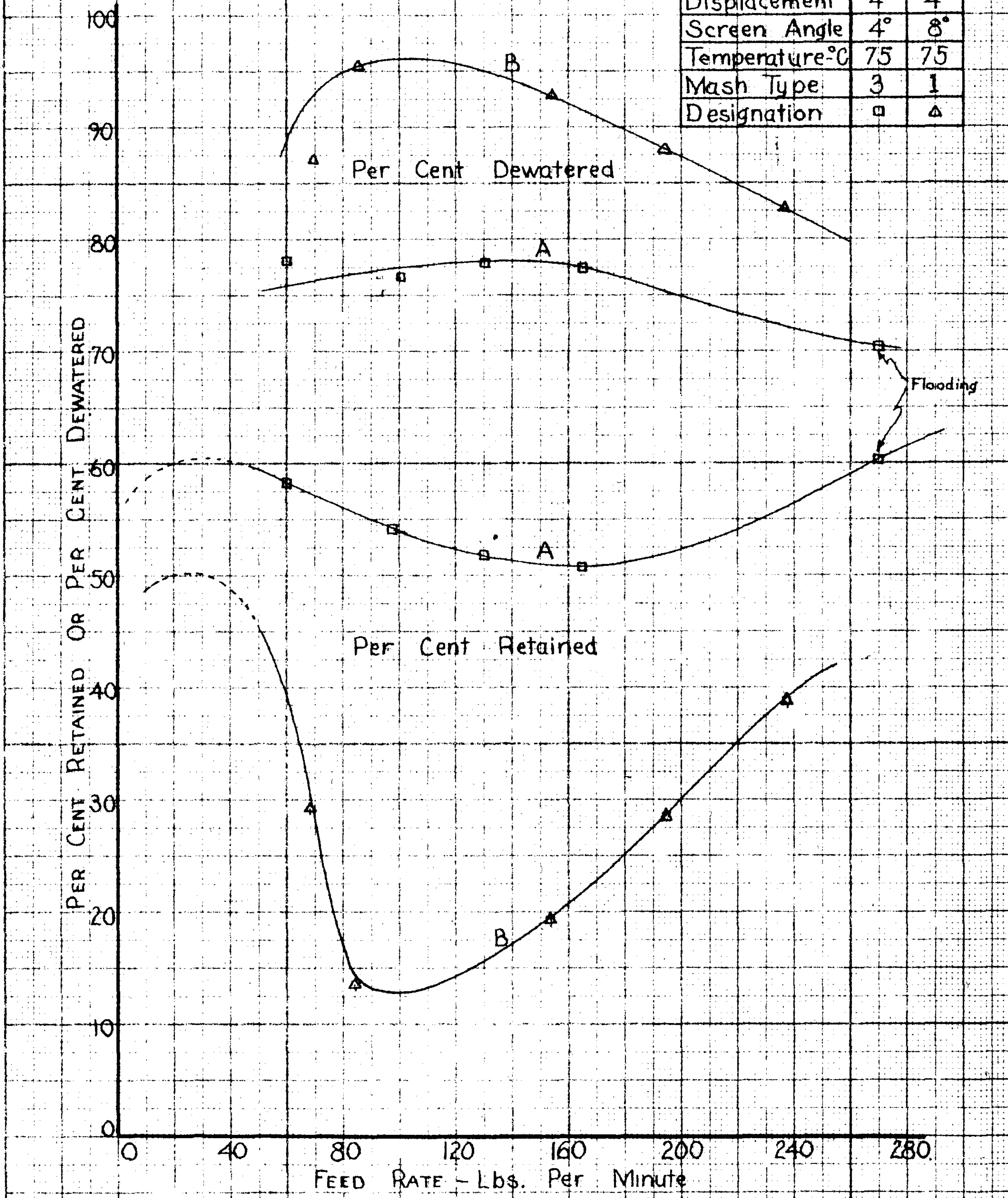


Fig. 22 – Variation Of Dewatering And Retention With Feed Rate

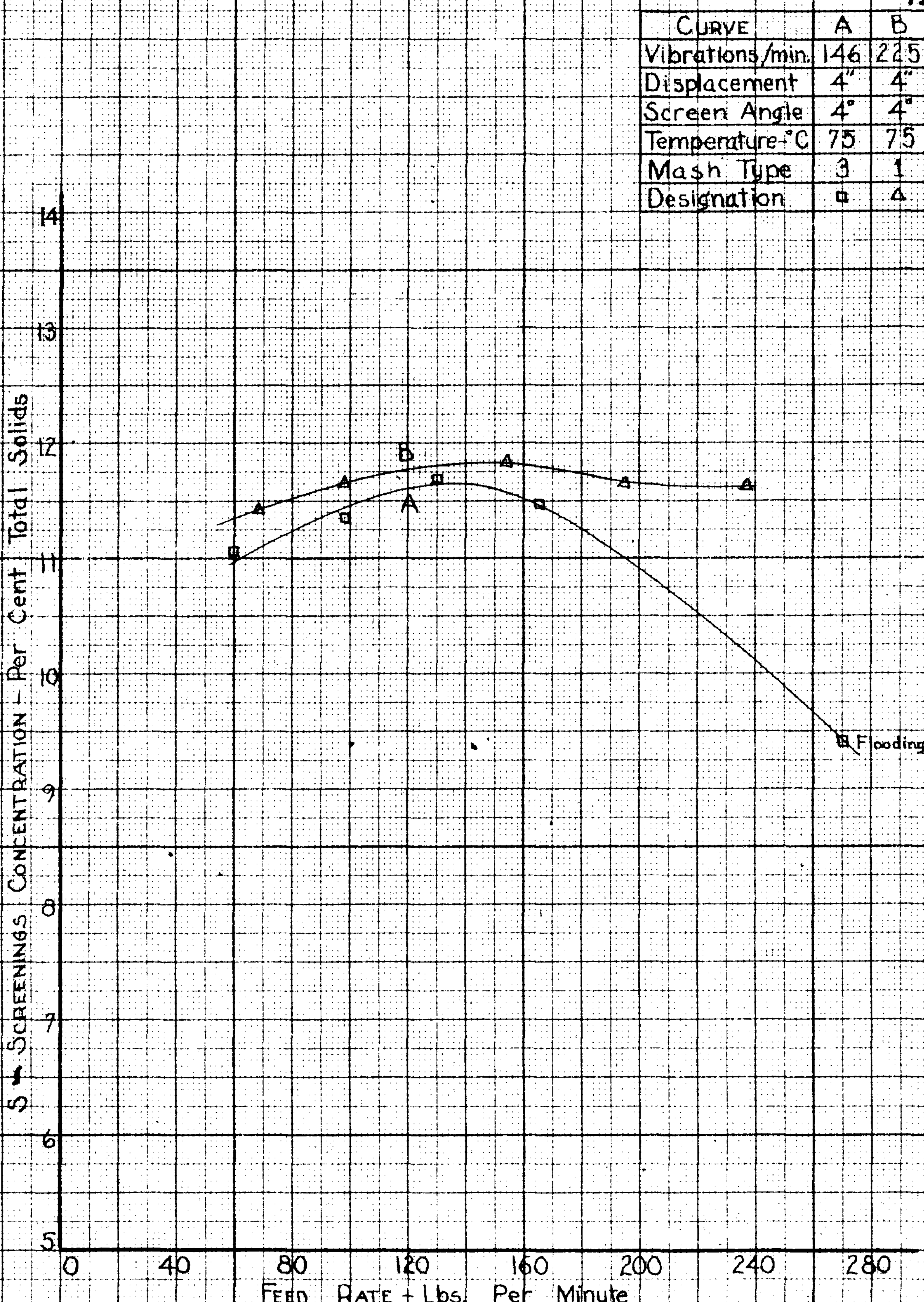


Fig. 23 – Variation Of Screenings With Feed Rate

Effect of Feed Rate

Two sets of curves are shown in Figure 22, depicting the case of Mash Type 1 with a certain set of conditions and the use of an entirely different set of conditions with Mash Type 3. Both sets of curves show maximum P.C.D. and minimum P.C.R. This action may be explained on the basis of the capacity of apparatus. Apparently when the screen is operated near flooding conditions, more retention is realized with an accompanying decrease in the dewatering.

The relatively low P.C.R. and high P.C.D. obtained under the condition of Curve B at 100 lbs of feed per minute is attributable to the rapid vibrations obtained using a frequency of 225 vibrations per minute with a 4 inch stroke. This particular combination with an 8° slope eliminates "blinding". As can be seen, Curve B for P.C.D. is much higher than Curve A, which was run at only a 4° slope, with 146 vibrations per min. with a 4 inch stroke. The effect of flooding is shown by Curve A of Fig. 23 where a sudden decrease in the screenings concentration occurs at a feed rate of 270 lbs. per minute.

Effect of Temperature

Figures 24 and 25 indicate that with increasing temperature, starting from room temperature, the P.C.R. increases, the P.C.D. remains fairly constant, and S increases, until a temperature between 65-68°C. is reached. At this point there occurs a sudden decrease in P.C.R., an accompanying increase in P.C.D., while S increases slightly. Then, starting at 80°C., the P.C.R. curves rise, the P.C.D. curves fall, while the S curves level off.

This phenomenon may be partially explained by the rapid increase

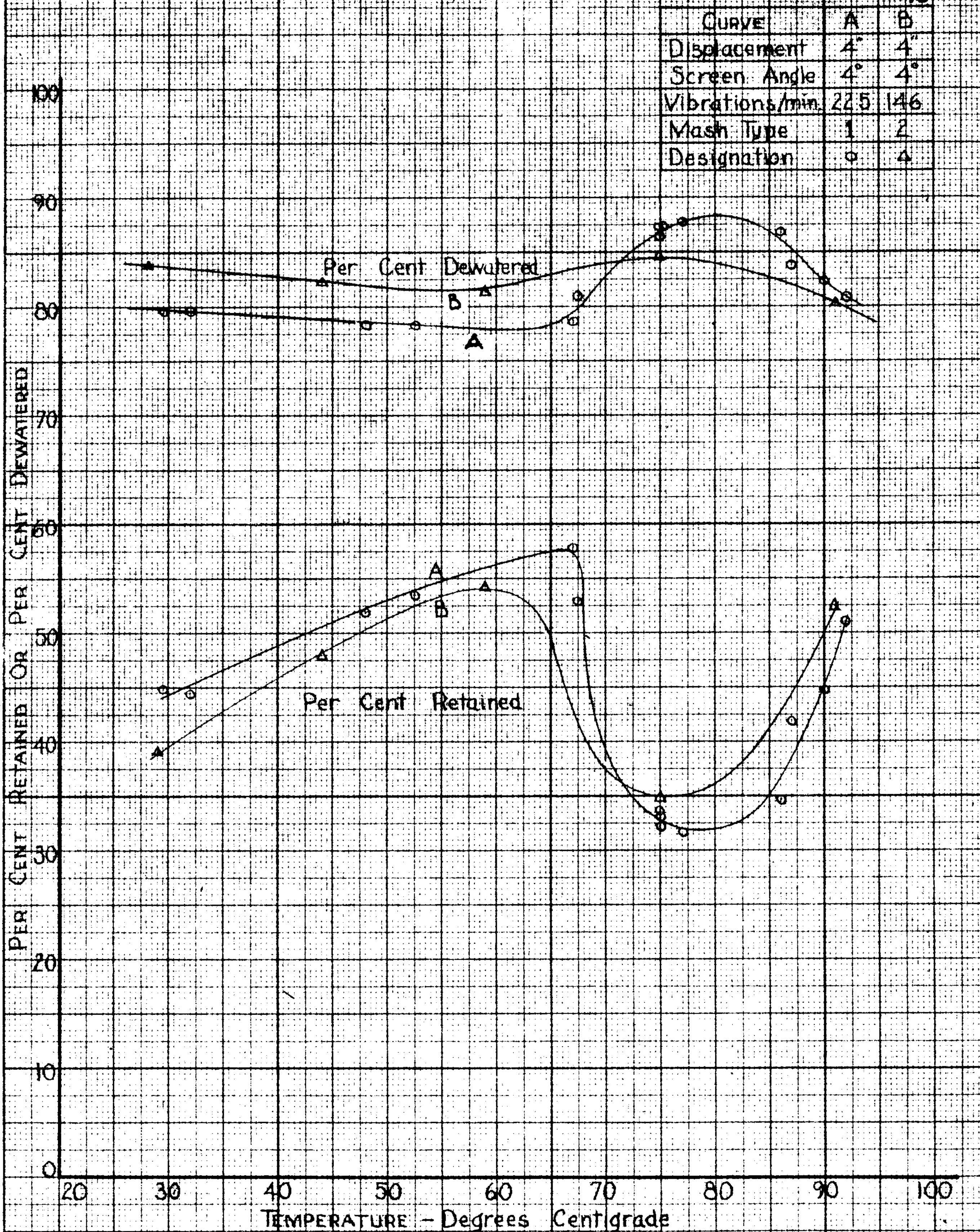


Fig. 24 – Variation of Dewatering and Retention With Temperature

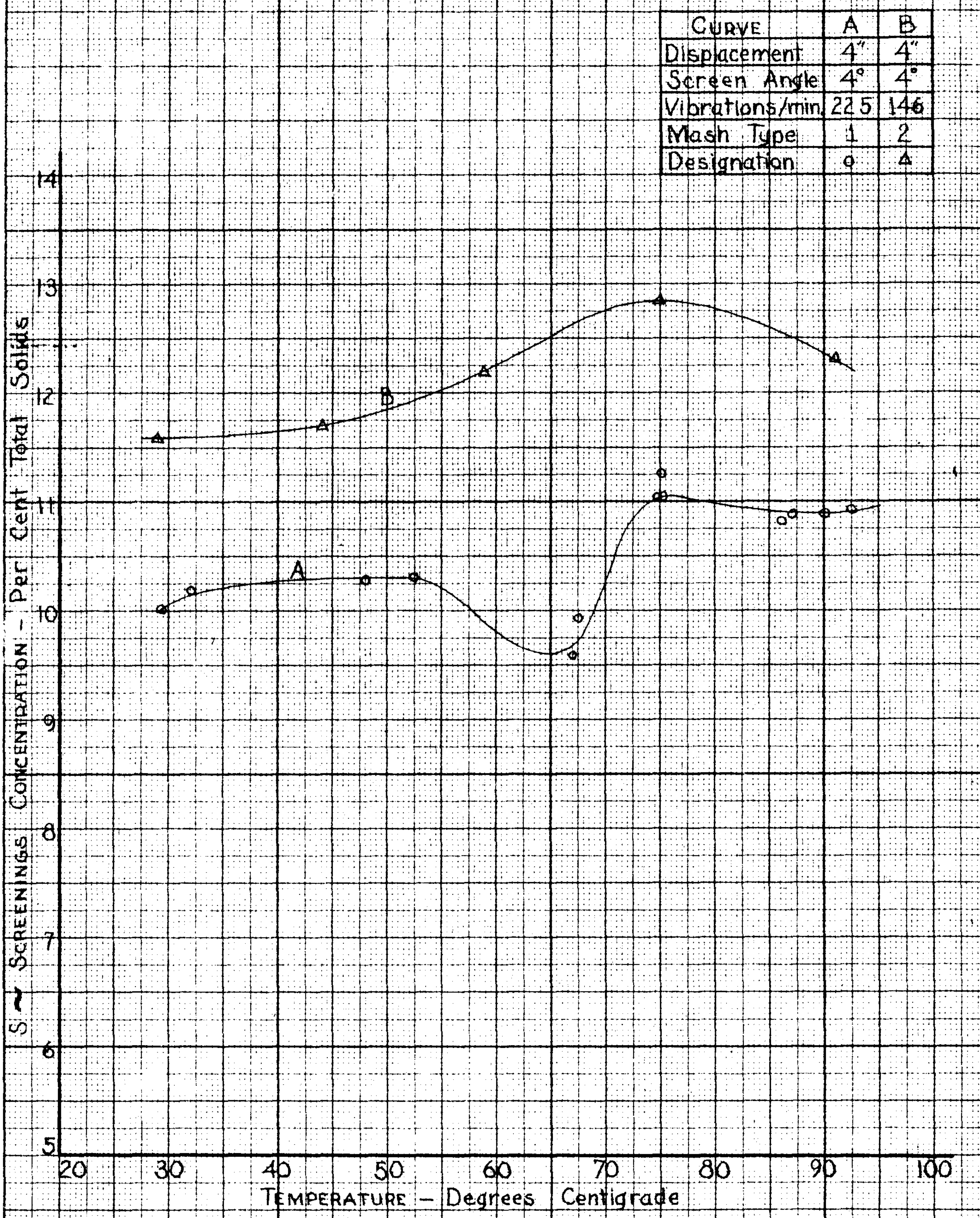


Fig. 25 - Variation Of Screenings With Temperature

in apparent viscosity that occurs between 60 and 100°C (See Fig. 13, Apparent Viscosity-Temperature).

Variation of Screening Angle

The angle at which screening occurs is important because it is one of the factors that controls the distance the particles move away from the screening surface. The curves of Fig. 26 indicate the effect of the screening angle. At 0°, the material does not move from the screen at all but is shuffled back and forth for a comparatively long period of time resulting in fair retention and dewatering and the highest concentration of screenings (Fig. 27). At 4°, the movement from the screen is not very pronounced, whereas the particle-time on the screen is appreciably lowered. This decrease in particle-time does not allow as many particles to pass through the screen as in the case of a level screen. At 8°,—an angle which seems to be optimum for dewatering with a frequency of 225 vibrations per minute and a stroke of 4 inches,—blinding is eliminated and the particles and mother liquor have ample opportunity to pass through the screen, resulting in a minimum P.C.R. and maximum P.C.D. Curve B, indicates that with a frequency of 146 vibrations per minute, this effect is minimized. At 12°, the particle-time is controlling and the P.C.D. and P.C.R. attain values approximating those at 4°.

Curve B indicates that a frequency of 146 vibrations per minute gives a much higher value of P.C.R., than at a frequency of 225. The P.C.D. does not change appreciably with change in slope and is just a little lower than Curve A, except at a slope of 8°. The screening concentration is higher at the lower screening angles as is shown by Fig. 27.

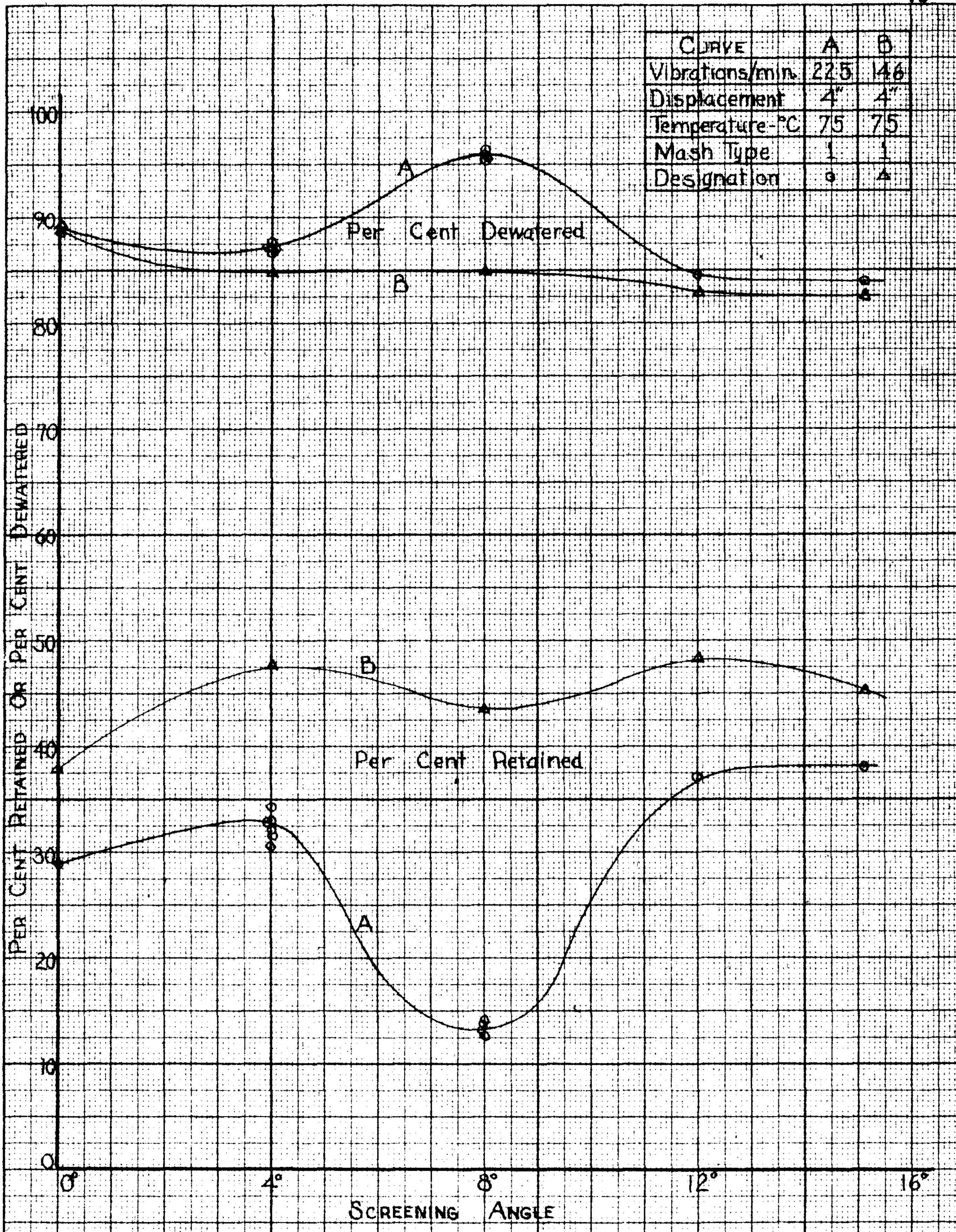


Fig. 26- Variation Of Dewatering And Retention With Screening Angle At Different Frequencies

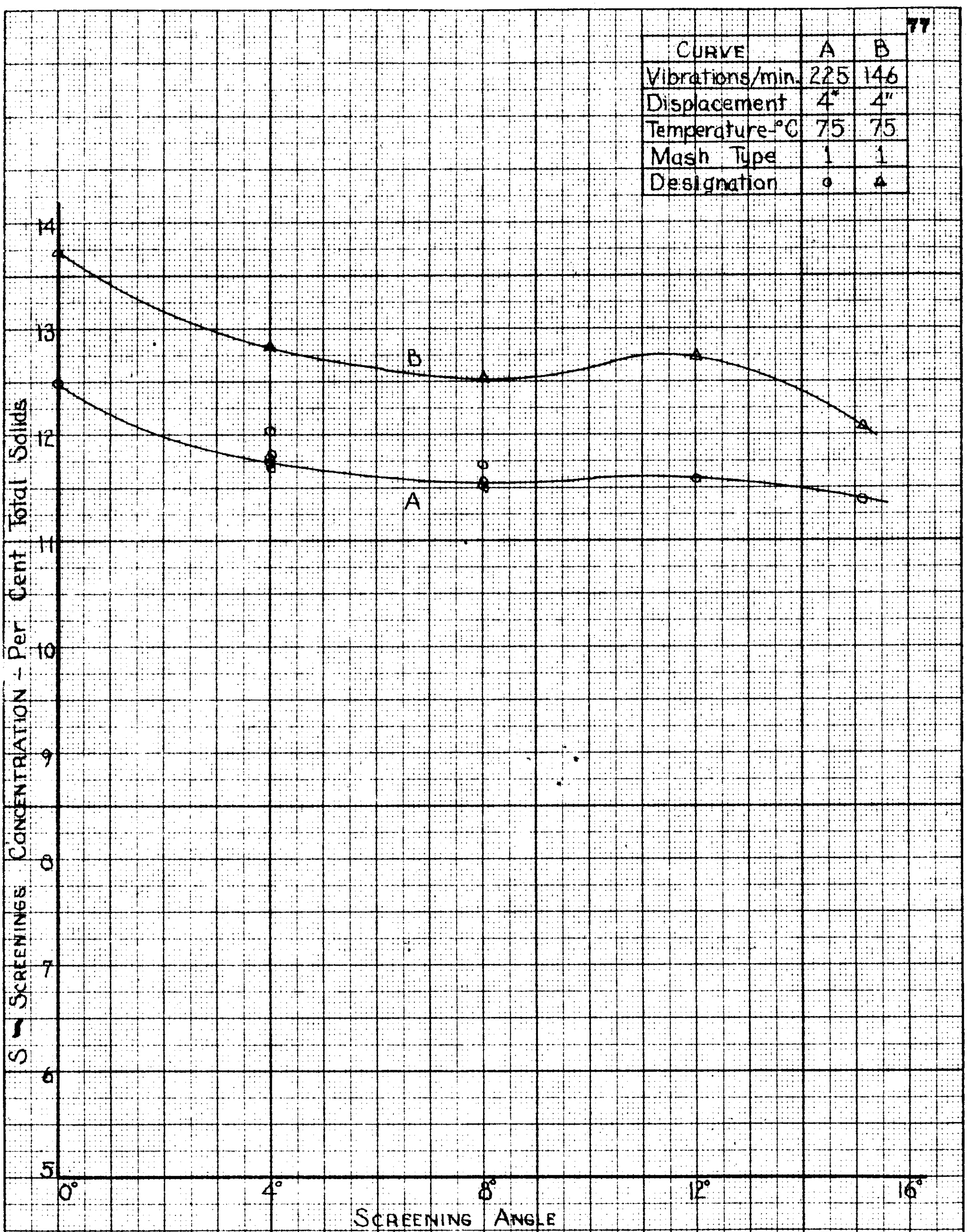


Fig. 27- Variation Of Screenings With Screening Angle At Different Frequencies

Variation of Screen Type and Openings

From a study of Figures 28 and 29 it seems that there is little difference between punched and woven wire screens from the viewpoint of dewatering and retention. However, operational characteristics of screens must also be considered. There seems to be a tendency for increased retention with a decrease in screen opening, which follows the theory. However, the curves of Figures 28 and 29 show little change with screen types. According to these curves it seems in general not to make very much difference what mesh screen is used. If it is found that particle size in the effluent is important to evaporator operation, the size of the screen opening becomes important.

Variation of Frequency of Vibration

Figs. 30 and 31 indicate that as the frequency is increased from 145 to 270 vibrations per min., the P.C.R. and S decreases, and the P.C.D. increases slightly. This same tendency is found in Figs. 22 and 26. Presumably this effect could be attributed to the violence of the action at the higher frequencies.

A. W. Fahrenwold and S. W. Stockdale (7) made a careful study of the effect of sieve motion on sieving efficiency. In their experiments with high-frequency vibrating sieves, the frequencies ranged from 500 to 2500 vibrations per minute, with amplitude of vibrations extending from 0.1 mm. to approximately 0.7 mm. Their results show "that amplitude of vibration has a greater effect on the rate of screening than frequency." Their results indicate a maximum point in the amplitude curve (which compares with Fig. 32), and the frequency curve has a shape similar to the

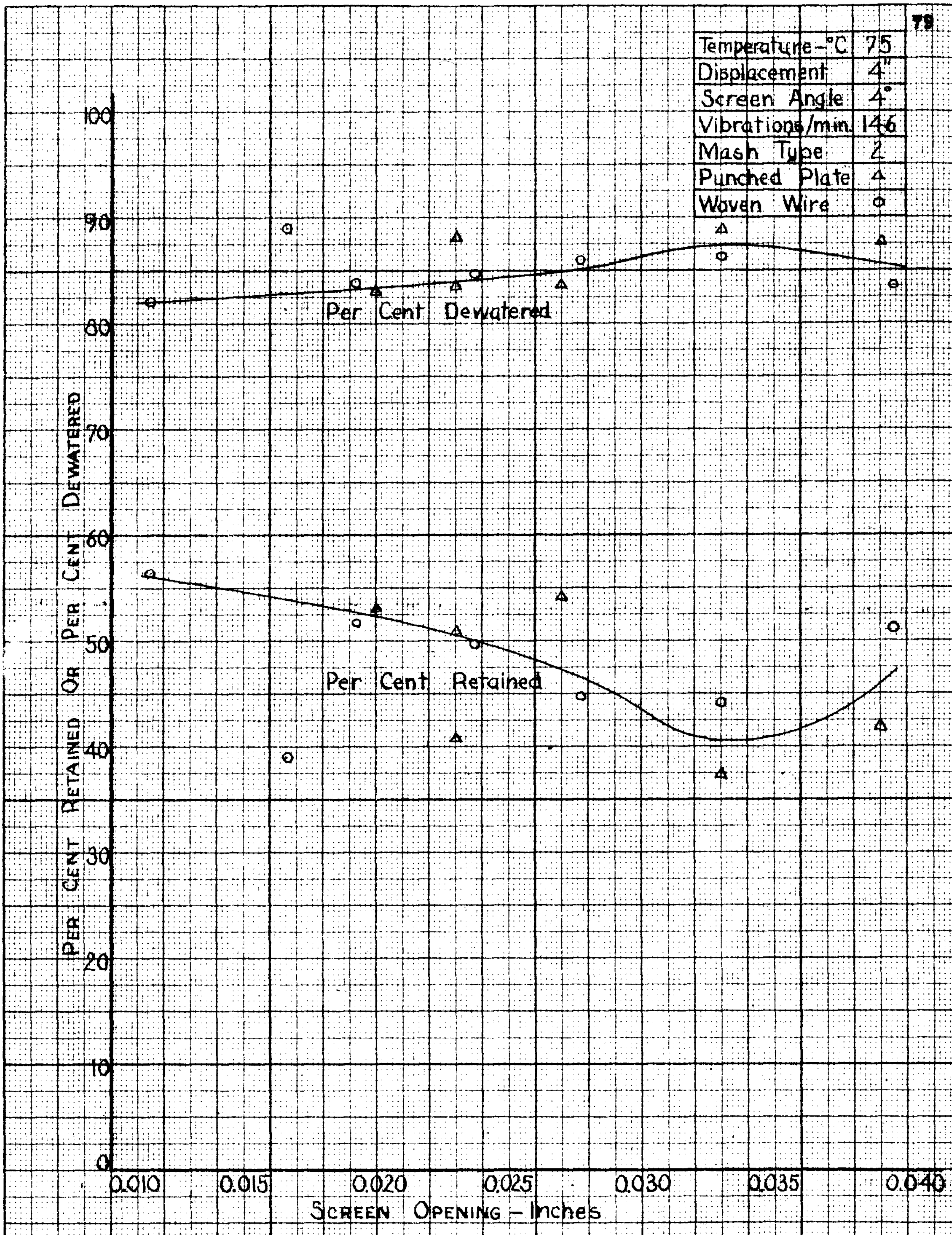


Fig. 28 – Variation Of Dewatering And Retention With Screen Openings

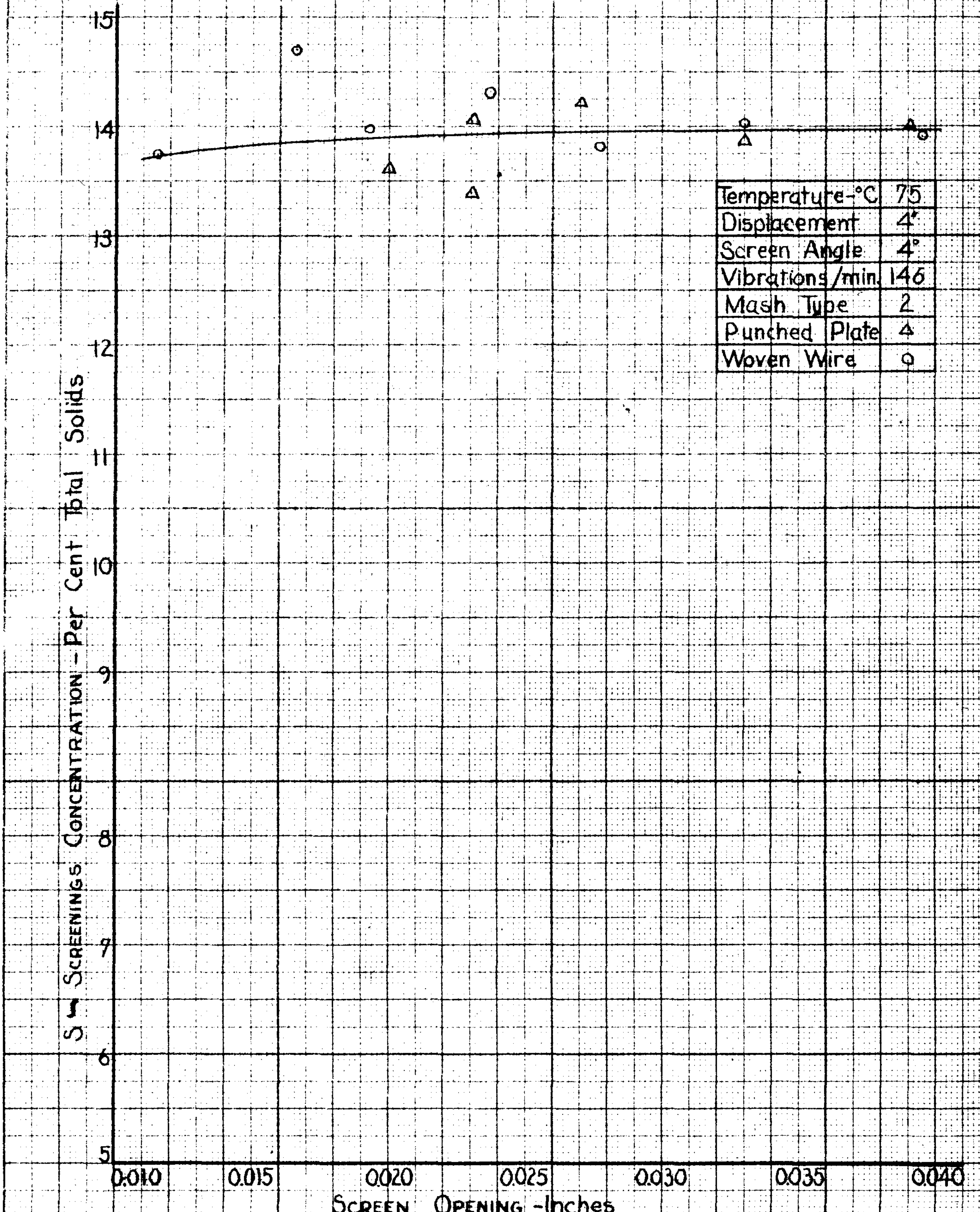


Fig. 29 - Variation Of Screenings With Screen Openings

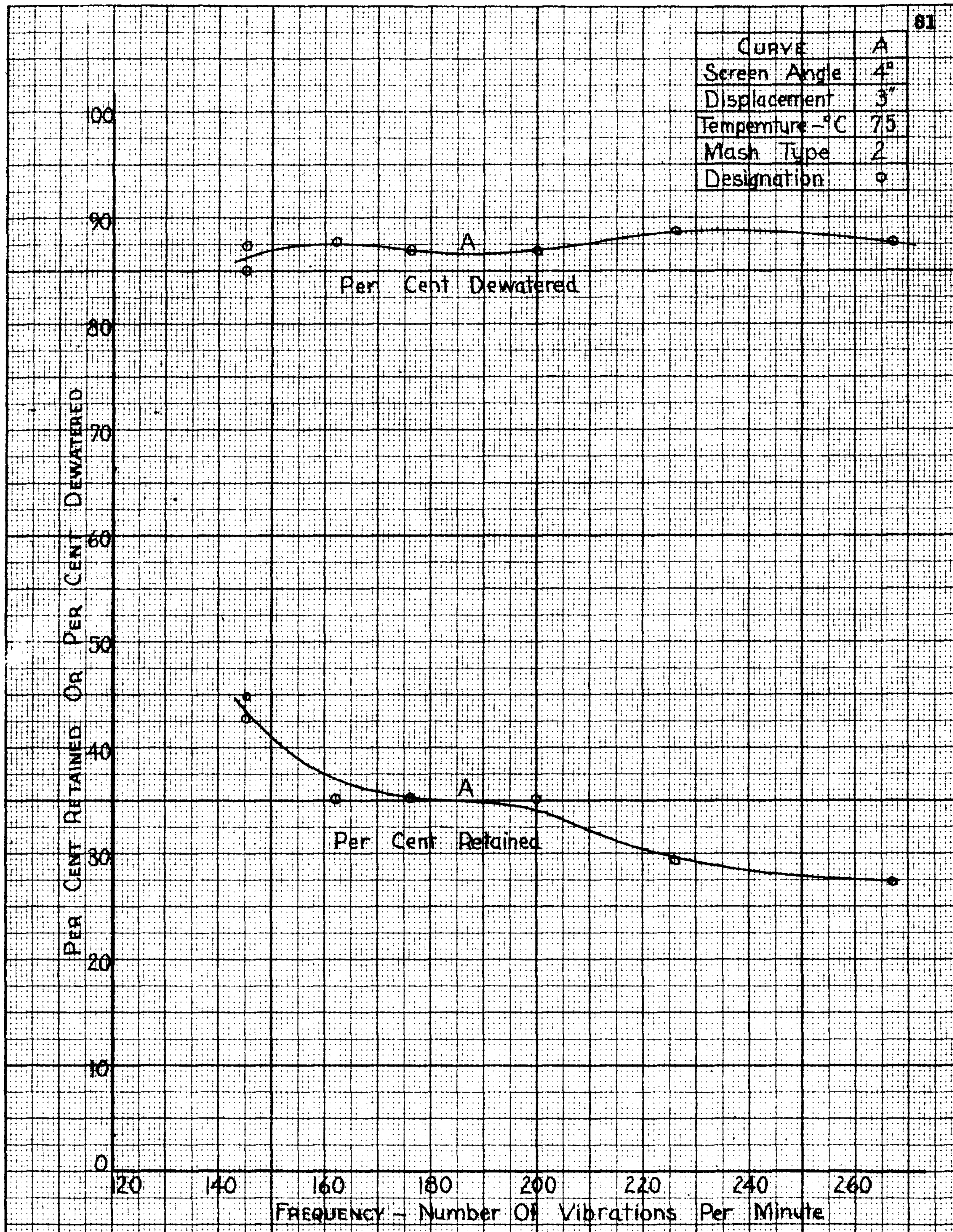


Fig. 30 – Variation Of Dewatering And Retention With Frequency Of Vibration

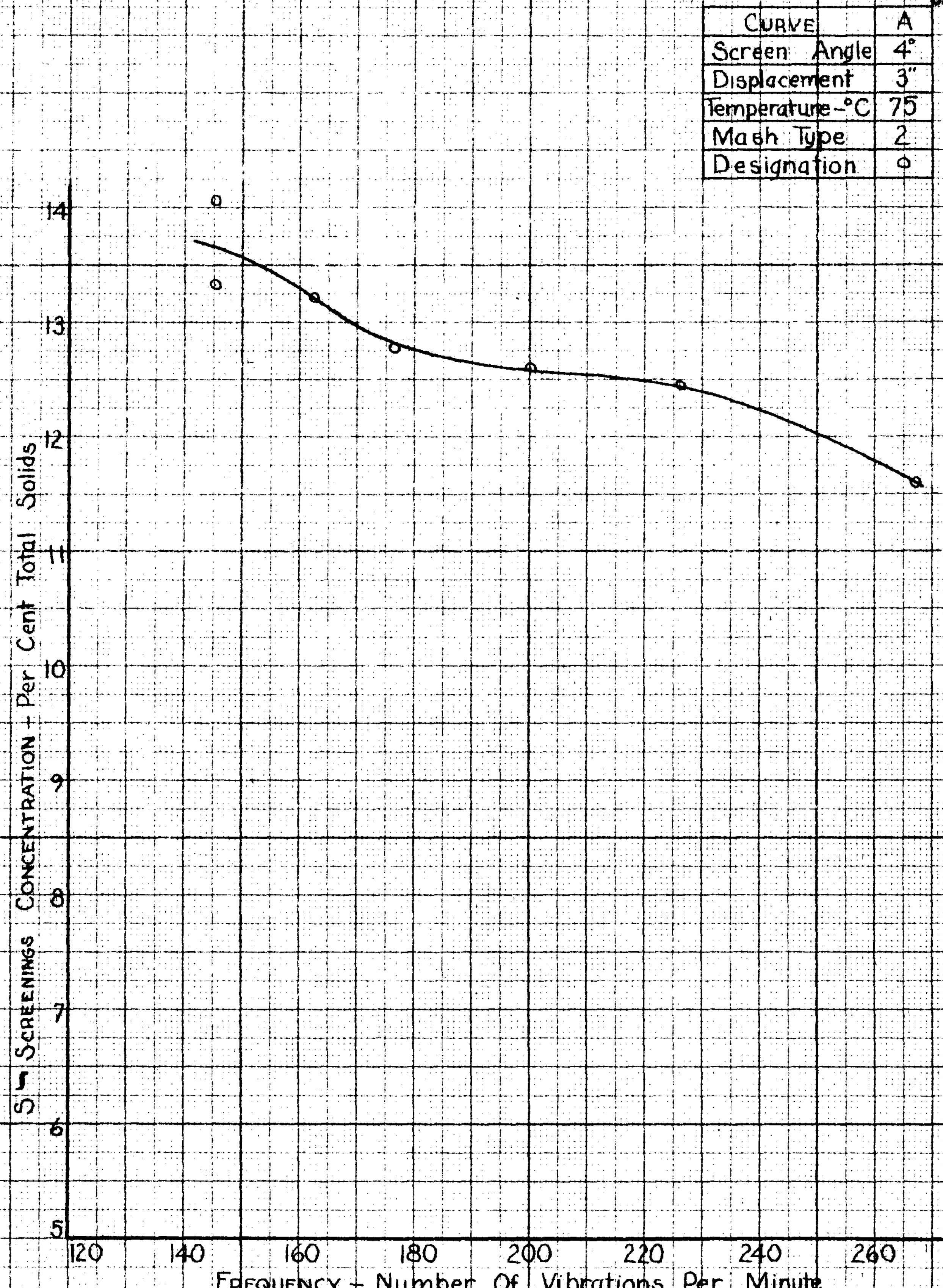


Fig. 31 - Variation Of Screenings With Frequency Of Vibration

P.C.R. curve of Fig. 30.

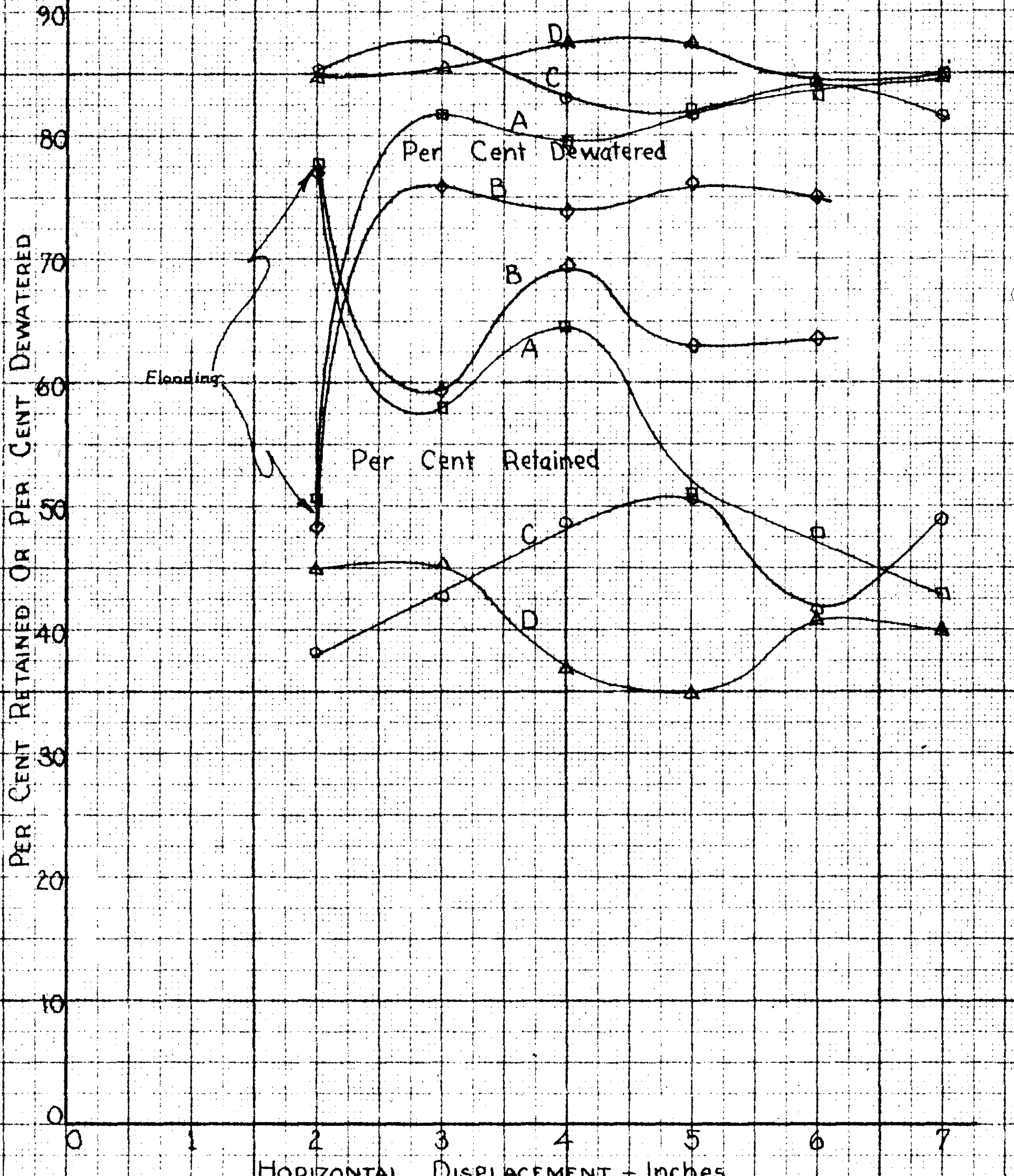
Variation of Amplitude of Vibration

Fig. 32 indicates that the amplitude of vibration gives larger fluctuations than any other variable and, hence, can be considered one of the more important factors in a screening operation.

All the runs shown were made using a frequency of 146 vibrations per min. If some other frequency were used, the curves would probably shift in their relative positions, but still fluctuate widely.

Looking at Fig. 33, Curves A, C, and D, as well as Fig. 32, one can see that with a 2 inch stroke, the best conditions are obtained with an 8° slope, which produces medium retentions, a high degree of dewatering, and a good screening concentration. The 0° slope points depict flooding conditions. With a 3 inch displacement, either a 0° or 4° screening angle is best. Operation at both angles produces about the same screenings concentration, but the 0° slope gives better retention than the 8° slope, while the 8° slope gives better dewatering results. Hence, if good retention is desirable, the 0° slope should be used; if efficient dewatering is desirable, the 8° slope should be used. If capacity is considered, the 8° slope should be used, since high rates of flow at 0° tend to cause flooding. It is possible to minimize the latter disadvantage by increasing the frequency of vibration.

The 0° slope gives the best results with the remaining strokes of 4, 5, 6, and 7 inches, with the P.C.R. and S decreasing, and the P.C.D. increasing, respectively. The same limitations on capacity also holds for these cases.



Curve	A	B	C	D
Screen Angle	0°	0°	4°	8°
Vibrations/min.	146	146	146	146
Temperature-°C	75	75	75	75
Mash Type	2	3	2	2
Designation	□	◇	○	△

Fig. 32 - Variation Of Dewatering And Retention With Horizontal Displacement Or Amplitude Of Vibration At Different Screening Angles

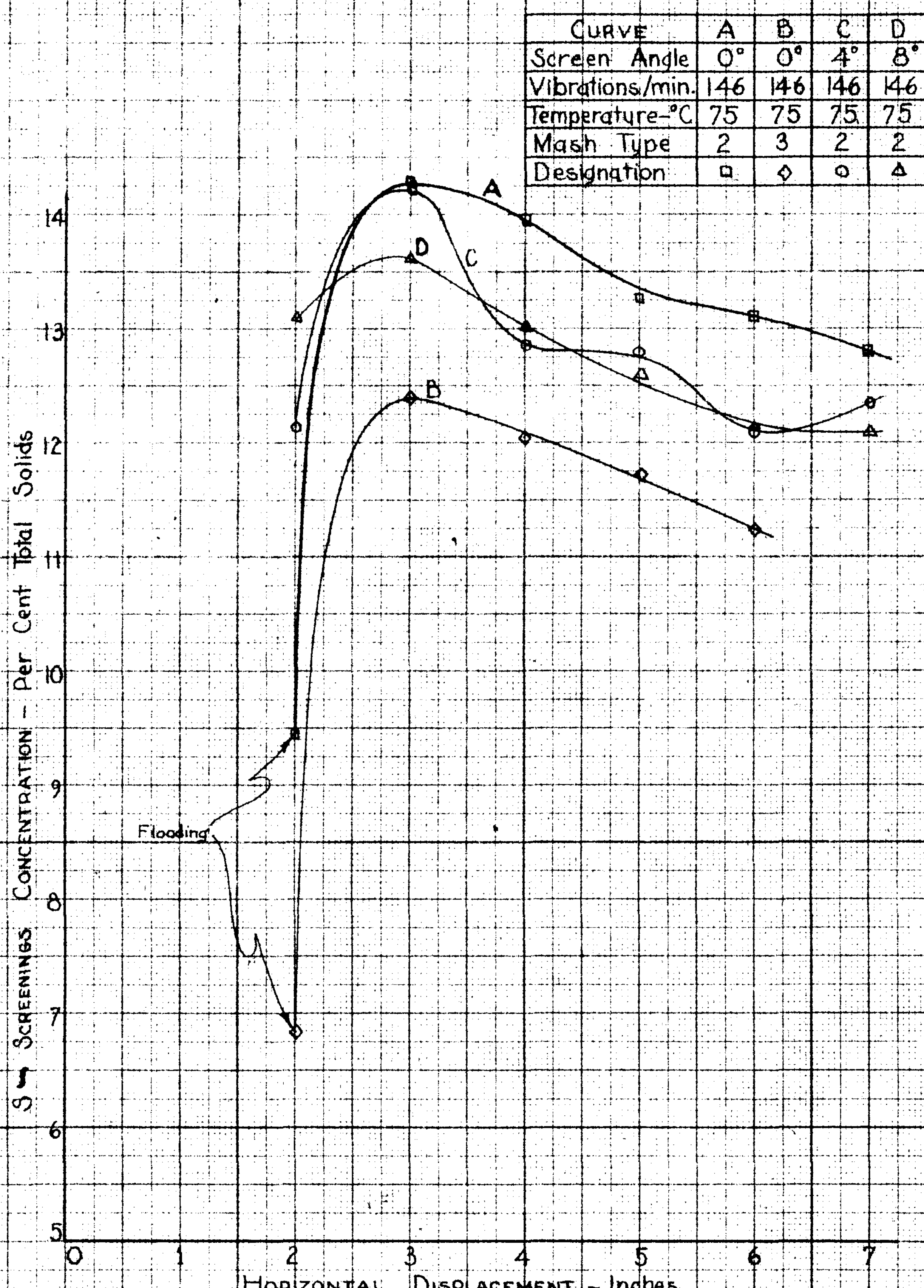


Fig. 33 - Variation Of Screenings With Horizontal Displacement Or Amplitude Of Vibration At Different Screening Angles

Reproducibility of Results

As shown by Table XVII, representing a set of runs in which all the variables were held constant (corrections were made for slight deviations of feed concentration and feed rate), the average error was only ±0.4 P.C.D. and ±0.8 P.C.R.

SUMMARY AND CONCLUSIONS

Physical Characteristics of Whole Stillage

Stillage is similar to water as far as boiling point (from 82.5-94.9 per cent water), specific heat, and density (slightly higher at 20°C. and slightly lower at 90°C.) is concerned. The apparent viscosity of stillage is much higher than water although at 100°C. the stillage values approach those of water. At 20°C the viscosity of water is 1.005 centipoises, whereas the apparent viscosity of stillage is about 36 centipoises.

Screening Study

For any mash type a high concentration of suspended solids in the feed results in comparatively high retention, poor dewatering, and a high concentration of solids in the screenings--the opposite being true for low suspended solids concentrations. Also, a small change in feed concentration results in a comparatively large change in P.C.R., P.C.D., and S.

Efficient dewatering is usually accompanied by poor retention.

The use of high temperature feeds (80°-90°C.) gives better all-around results.

The screening angle is the controlling factor in "blinding". Low or almost horizontal screening is always accompanied by blinding. Hence, the screening angle employed will control whether good dewatering or retention prevails. Blinding aids in retention and if accompanied by high particle-time on the screen, results in good dewatering. The disadvantage to this set of conditions is low capacity.

Lowering particle-time on the screen will decrease the dewatering effect and increase the degree of retention.

The frequency of vibration, the amplitude of vibration, and the screening angle are intrinsically tied together and cannot be considered apart from one another, although amplitude of vibration can be considered a major factor.

The use of a screen with small openings assures the passage of small particles only and "blinding" is not necessary to obtain high retention. With such conditions, a combination of screening angle, frequency of vibration, and amplitude of vibration can be chosen to attain optimum and efficient dewatering, without detracting from the capacity of the screen.

It should also be noted that, with high values of P.C.R., evaporator fouling will be lessened and the stillage can be concentrated to a higher value of per cent solids than at present, which is 30 per cent. This will aid in drum dryer operations.

The methods of obtaining the results, as stated herein, can be adapted to any mechanical dewatering process, including the dewatering of slurry which does not contain dissolved solids. Hence, a substantial comparison can be made of industrial dewatering equipment, whether it be screening, pressing, centrifuging or filtering apparatus.

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APPENDIX

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GLOSSARY

Amplitude of Stroke:

See Vibration, Amplitude of

Angle of Screening:

The angle the screening surface forms with a horizontal plane.

Blending:

Screening condition, such that the grain particles form a matting on the screening surface reducing the open area available for the passage of effluent.

Dewatering, Per Cent:

The percentage of original water in whole stillage removed by the screening operation.

Displacement, Horizontal:

See Vibration, Amplitude of

Distillers' Dark Grain:

Final product processed from a mixture of the press cake and the syrup.

Distillers' Dried Grains:

See distillers' light grain, dark grain, and dried solubles.

Distillers' Dried Solubles:

Final product processed from the syrup.

Distillers' Light Grain:

Final product processed from the press cake.

Effluent:

The material, dissolved and fine suspended solids, passing through the screening or pressing surfaces.

Feed, Rate of:

The amount of whole stillage passing to the screens per unit time.

Glossary Cont.

Flooding:

Screening condition, such that thin liquor passes over the exit end of the screen, as part of the screening.

Mash:

Mixture of gelatinized grain and malt.

Mashing Ratio:

The number of gallons of water used per bushel of ground grain.

Meal:

Ground grain.

Mother Liquor:

Any stillage liquor containing only dissolved solids.

Particle-time:

The average length of time any single stillage particle remains on the screen.

Press Cake:

Wet grain from the pressing process; pressed screenings.

Retention, Per Cent:

The percentage of original suspended solids in whole stillage retained by the screens.

Screenings:

Wet grain from the screening process; material retained by screen.

Slope of Screen:

See Angle of Screening.

Stillage:

Residue left after distillation of fermented mash--commonly referred to as "distillery slop".

Glossary Cont.

Syrup:

Concentrated thin stillage; sometimes called thick stillage.

Thin Stillage:

The effluent or filtrate from the screening and pressing operations, processed stillage, from which the large grain particles have been removed.

Vibration, Amplitude of:

The horizontal distance the screen travels per stroke or vibration.

Vibration, Frequency of:

The number of vibrations or strokes the screen makes per minute.

Whole Stillage:

See Stillage.

LIST OF SYMBOLS

A	Lbs of water in the feed per lb of B.D. solids in the feed.
B	Lbs of water in the screenings per lb of B.D. solids in the feed.
D	Per cent dissolved solids.
E	Effluent concentration, per cent total solids in the effluent.
F	Feed concentration, per cent total solids in the feed.
M	Per cent dissolved solids in supernatant mother liquor of the effluent as obtained by centrifuging.
PCD	Per Cent Dewatered.
PCR	Per Cent Suspended Solids Retained.
R	Rate of flow, lbs per minute.
S	Screenings concentration, per cent total solids in the screenings.
T	Rate of flow of suspended solids, lbs per minute.

Subscripts

e, f, s Referring to effluent, feed, and screenings, respectively.

SAMPLE CALCULATIONS

Run No. 34 -- Reproducibility of Results

Original Data:

$F = 6.76\%$ total solids $R_f = 112$ lbs./min.

$E = 5.51\%$ total solids Mash Type No. 1

$S = 12.07\%$ total solids

Calculation of Per cent Retained

M_f and M_e are estimated by use of Fig. 19.

$M_e = M_f = 2.79$

Using Eq. 17,

$$D_f = \frac{(M_f)(100-F)}{100-M_f}$$

$$D_f = \frac{(2.79)(100-6.76)}{100-2.79} = 2.67$$

Using Eq. 19,

$$D_e = \frac{M_e(100-E)}{100-M_e}$$

$$D_e = \frac{(2.79)(100-6.76)}{100-2.79} = 2.71$$

Using Eq. 15,

$$P.C.R. = \left[1 - \frac{(S-F)(E-D_e)}{(S-E)(F-D_f)}\right] 100$$

$$P.C.R. = \left[1 - \frac{(12.07-6.76)(5.51-2.71)}{(12.01-5.51)(6.76-2.67)}\right] 100 = 44.6\%$$

Calculation of Per Cent Dewatered

Using Eq. 9,

$$P.C.D. = \left[1 - \frac{(100-S)(F-E)}{(100-F)(S-E)}\right] 100$$

$$P.C.D. = \left[1 - \frac{(100-12.07)(6.76-5.51)}{(100-6.76)(12.07-5.51)}\right] 100 = 82.0\%$$

Sample Calculations (Continued)

Corrections

A. - For Quality of Feed to a base of $(F-D_f)_{av.} = 3.8$

From Fig. 20, Curve B,

at $(F-D_f)_{av.} = 3.8$; PCR = 33.0 and P.C.D. = 87.5

at $(F-D_f) = 4.09$; PCR = 41.6 and P.C.D. = 83.0

Thus the correction for P.C.R. is minus 8.6% and for P.C.D. is plus 4.5%.

B. - For Feed Rates to a base of $R_f = 120$.

From Fig. 22,

at $R_{f av.} = 120$; P.C.R. = 14.3 and P.C.D. = 95.6

at $R_f = 112$; P.C.R. = 13.6 and P.C.D. = 95.9

Thus the correction for P.C.R. is plus 0.7% and for P.C.D. is minus 0.3%.

Hence;

Corrected P.C.R. 44.6 - 8.6 + 0.7 = 36.7

Corrected P.C.D. 82.0 - 0.3 + 4.5 = 86.2

Calculation of Corrected Screenings Concentration

S = 12.07 (Original Data)

A. Correction for Quality of Feed to the average $(F-D_f) = 4.27$

From Fig. 21, Curve B

at $(F-D_f) = 4.27$; S = 11.82

at $(F-D_f) = 4.09$; S = 11.62

Thus the correction is plus 0.20%

Hence, corrected S = 12.07 + .20

TABLE X-A

Refers to Figure 20 - Curve A

VARIATION OF SUSPENDED SOLIDS IN THE FEED

Screening Data:- Temperature - 32°C
Screen Angle - 4°
Displacement - 4"
Vibr./min. - 225
Mesh Type 1

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR FEED RATE	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE %SUSPENDED SOLIDS IN THE FEED
	R_f	F	E	S			P.C.D.	P.C.R.	F-D$_f$
1	97	3.91	3.82	7.58	-0.4	1.0	97.3	7.3	*2.34
9	117	5.09	4.40	9.96	-0.2	0.2	88.0	33.1	*3.06
43	80	6.73	5.45	10.82	0.9	-3.4	78.1	45.4	*4.07
42	80	6.93	5.48	10.96	0.9	-3.4	75.7	49.3	*4.18

* Estimated D_f

TABLE X-B

Refers to Figures 20 & 21-Curve B

VARIATION OF SUSPENDED SOLIDS IN THE FEED

Screening Data:- Temperature - 75°C
Screen Angle - 4°
Displacement - 4"
Vibr./min. - 225
Mash Type 1

RUN NO.	FEED RATE #/min. R_f	%TOTAL SOLIDS IN THE FEED F	%TOTAL SOLIDS IN THE EFFLUENT E	%TOTAL SOLIDS IN THE SCREENINGS S	%DEWATERED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR FEED RATE	CORRECTED OR PSUEDO %DEWATERED P.C.D.	CORRECTED OR PSUEDO %RETAINED P.C.R.	VARIABLE %SUSPENDED SOLIDS IN THE FEED F-D_f
12	116	5.38	5.04	11.01	-0.2	0.4	94.5	16.5	*3.22
17	112	6.51	5.56	11.79	-0.3	0.7	85.3	37.1	*3.93
26	108	7.71	5.92	12.12	-0.4	0.9	72.1	58.2	*4.63
27	108	7.90	5.87	12.19	-0.4	0.9	69.0	63.4	*4.72
28	107	7.93	5.90	12.28	-0.4	1.0	69.3	63.2	*4.73
29	106	8.66	6.27	12.43	-0.4	1.0	62.4	70.1	*5.04
31	116	6.20	5.41	11.42	-0.2	0.4	87.4	32.5	*3.74
34	112	6.76	5.51	12.07	-0.3	0.7	81.7	45.3	*4.09
35	118	7.11	5.55	11.84	-0.1	0.2	76.3	53.3	*4.31
36	114	7.26	5.79	11.84	-0.3	0.5	76.6	50.9	*4.40
37	111	7.05	5.85	12.21	-0.3	0.8	81.9	43.3	*4.26
38	113	6.99	5.73	11.80	-0.3	0.6	80.0	45.7	*4.24
39	112	7.03	5.75	11.75	-0.3	0.7	79.5	46.5	*4.24
40	94	7.16	5.74	12.07	-0.3	0.7	78.5	49.5	*4.34

* Estimated D_f

TABLE X-C

Refers to Figures 20 and 21-Curve C

VARIATION OF SUSPENDED SOLIDS IN THE FEED

Screening Data:- Temperature - 28°C
Screen Angle - 4°
Displacement - 4"
Vibr./min. - 225
Mash Type 3

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR FEED RATE	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE %SUSPENDED SOLIDS IN THE FEED
	R_f	F	E	S			P.C.D.	P.C.R.	$F-D_f$
110	136	4.61	3.64	9.23	-0.2	1.0	83.3	53.1	2.45
111	140	3.98	3.39	8.98	-0.1	1.1	89.9	42.3	2.02
112	139	3.46	3.03	8.61	-0.1	1.1	92.6	33.9	1.73
113	139	2.20	2.00	7.89	-0.1	1.1	96.7	25.0	*1.04
114	139	1.23	1.09	6.67	-0.1	1.1	97.5	25.7	*0.62

*Estimated D_f

TABLE X-D

Refers to Figures 20 and 21-Curve D

VARIATION OF SUSPENDED SOLIDS IN THE FEED

Screening Data:- Temperature - 50°C
Screen Angle - 4°
Displacement - 4"
Vibr./min. - 225
Mash Type 3

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR FEED RATE	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE %SUSPENDED SOLIDS IN THE FEED
	R_f	F	E	S			P.C.D.	P.C.R.	$F-D_f$
103	124	5.16	3.91	10.16	-0.1	0.3	81.0	55.3	3.04
104	133	4.49	3.66	10.36	-0.2	0.8	88.2	44.8	*2.35
105	126	3.96	3.23	9.61	-0.1	0.4	89.1	41.9	2.21
106	132	3.56	2.88	9.31	-0.2	0.8	89.8	42.8	1.93
107	145	2.74	2.44	8.58	-0.1	1.3	95.3	31.8	1.56
108	122	2.02	1.80	7.88	0	0.2	96.6	27.2	1.11

*Estimated D_f

TABLE X-E

Refers to Figures 20 and 21-Curve E

VARIATION OF SUSPENDED SOLIDS IN THE FEED

Screening Data:- Temperature - 75°C
Screen Angle - 4°
Displacement - 4"
Vibr./min. - 225
Mash Type 3

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR FEED RATE	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE %SUSPENDED SOLIDS IN THE FEED
	R_e	F	E	S			P.C.D.	P.C.R.	$F-D_e$
87	113	4.90	3.36	10.45	0.1	-0.4	79.7	70.2	2.56
88	126	3.19	2.61	9.54	-0.1	0.5	92.1	53.5	1.72
89	125	3.25	2.46	9.66	-0.1	0.4	89.7	53.0	1.69
90	128	2.63	2.11	9.11	-0.2	0.5	92.9	50.6	1.45
91	138	2.66	2.14	9.15	-0.1	1.0	93.0	43.2	1.39

TABLE XI-A

Refers to Figures 22 and 23-Curve A

VARIATION OF FEED RATE

Screening Data:- Temperature - 75°C
Screen Angle - 4°
Displacement - 4"
Vibr./min. - 146
Mash Type 3

RUN NO.	%SUSPENDED SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR F-D_f	%RETAINED CORRECTION FOR F-D_f	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE FEED RATE #/min.	CORRECTED OR PSUEDO SCREENINGS CONTENT
	F-D_f	F	E	S			P.C.D.	P.C.R.	R_f	S
97	3.00	5.06	3.70	11.29	-5.1	3.3	78.1	57.9	60	11.06
98	*2.65	4.82	3.81	11.29	-10.9	7.0	76.5	54.1	98	11.36
99	2.61	4.80	3.90	11.58	-11.4	7.4	77.7	52.0	130	11.69
100	2.66	4.94	3.98	11.42	-10.7	6.9	77.3	50.5	165	11.48
101	2.72	5.02	3.86	9.40	-9.6	6.0	70.4	60.5	270	9.41**

* Estimated D_f

**Flooding

TABLE XI-B

Refers to Figures 22 and 23-Curve A

VARIATION OF FEED RATE

Screening Data:- Temperature - 75°C
Screen Angle - 8°
Displacement - 4"
Vibr./min. - 225
Mash Type 1

RUN NO.	%SUSPENDED SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR $F-D_f$	%RETAINED CORRECTION FOR $F-D_f$	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE FEED RATE #/min.	CORRECTED OR PSUEDO SCREENINGS CONTENT
	$F-D_f$	F	E	S			P.C.D.	P.C.R.	R_f	S
22	*4.40	7.28	5.95	11.42	10.3	-19.2	87.1	29.2	68.9	11.43
21	*4.59	7.61	6.54	11.80	14.7	-26.0	95.2	13.8	84.6	11.66
23	*4.38	7.24	6.23	11.81	10.0	-18.2	92.8	19.4	154	11.83
25	*4.23	6.99	5.89	11.50	6.9	-12.7	88.2	28.5	195	11.65
24	*4.44	7.35	5.53	11.66	11.1	-20.7	82.8	38.9	237	11.64

*Estimated D_f

TABLE XII-A

Refers to Figures 24 and 25-Curve A

VARIATION OF FEED TEMPERATURE

Screening Data:- Screen Angle - 4°
Displacement - 4"
Vibr./min. - 225
Mash Type 1

RUN NO.	FEED RATE #/min. R_f	%TOTAL SOLIDS IN THE FEED F	%SUSPENDED SOLIDS IN THE FEED $F-D_f$	%TOTAL SOLIDS IN THE EFFLUENT E	%TOTAL SOLIDS IN THE SCREENINGS S	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR $F-D_f$	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR $F-D_f$	CORRECTED OR PSUEDO %DEWATERED P.C.D.	CORRECTED OR PSUEDO %RETAINED P.C.R.	VARIABLE FEED TEMPERATURE °C	CORRECTED OR PSUEDO SCREENINGS CONTENT S
1	97	3.91	*2.34	3.82	7.58	-0.4	-17.8	1.0	37.7	79.5	44.9	29.5	10.01
9	117	5.09	*3.06	4.40	9.96	-0.2	-8.5	0.2	11.6	79.5	44.5	32.0	10.19
13	110	6.09	*3.67	4.84	10.70	-0.4	-1.1	0.8	1.4	78.2	51.8	48.0	10.28
10	117	5.66	*3.40	4.65	10.44	-0.2	-5.0	0.2	10.9	78.2	53.5	52.5	10.32
4	94	4.36	*2.61	3.77	9.05	-0.3	-10.5	0.8	25.5	78.6	57.8	67.0	9.58
3	102	4.20	*2.51	3.75	9.26	-0.4	-10.9	1.1	26.8	81.0	52.9	67.5	9.94
17	112	6.51	*3.93	5.56	11.79	-0.3	2.0	0.7	-4.0	87.3	33.1	75.0	11.26
31	116	6.20	*3.74	5.41	11.42	-0.2	-0.9	0.4	1.8	86.5	34.3	75.0	11.03
38	113	6.99	*4.24	5.73	11.80	-0.3	7.3	0.6	-13.5	87.3	32.2	75.0	11.03
12	116	5.38	*3.22	5.04	11.01	-0.2	-6.8	0.4	15.2	87.7	31.7	77.0	11.03
6	101	4.76	*2.86	4.54	10.49	-0.4	-9.4	1.1	22.2	86.7	34.7	86.0	10.82
5	97	4.53	*2.71	4.14	10.41	-0.4	-10.1	1.0	24.2	83.7	41.8	87.0	10.89
14	96	6.16	*3.72	5.10	11.26	-0.4	-1.0	0.9	2.2	82.3	44.7	90.0	10.89
11	96	5.41	*3.25	4.59	10.93	-0.4	-6.5	0.9	14.8	80.9	51.1	92.0	10.92

*Estimated D_f

TABLE XII-B

Refers to Figures 24 and 25-Curve B

VARIATION OF FEED TEMPERATURE

Screening Data:- Screen Angle - 4°
Displacement - 4"
Vibr./min. - 146
Mash Type 2

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%SUSPENDED SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR F-D_f	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR F-D_f	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE FEED TEMPERATURE °C	CORRECTED OR PSUEDO SCREENINGS CONTENT
	R_f	F	F-D_f	E	S					P.C.D.	P.C.R.		S
82	129	6.34	3.07	5.55	11.64	-0.1	-4.0	0.6	3.1	83.7	39.1	29	11.58
83	122	6.10	2.78	5.29	11.61	0	-5.6	0.2	8.9	82.3	48.0	44	11.70
84	130	6.25	*2.85	5.26	12.14	-0.1	-5.0	0.8	8.0	81.4	54.2	59	12.18
86	105	6.51	*2.90	5.84	12.82	0.3	-6.7	-1.0	4.3	84.6	34.7	75	12.85
85	103	6.65	*3.13	5.42	12.47	0.3	-3.7	-1.1	2.4	80.2	52.5	91	12.31

*Estimated D_f

TABLE XIII-A

Refers to Figures 26 and 27-Curve A

VARIATION OF SCREENING ANGLE

Screening Data:- Temperature - 75°C
Displacement - 4"
Vibr./min. - 225
Mash Type 1

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%SUSPENDED SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR $F-D_f$	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR $F-D_f$	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE SCREENING ANGLE	CORRECTED OR PSUEDO SCREENINGS CONTENT
	R_f	F	$F-D_f$	E	S					P.C.D.	P.C.R.		S
16	101	6.86	*4.14	5.79	12.42	-0.4	5.5	1.1	-10.5	89.1	28.9	0°	12.50
17	112	6.51	*3.93	5.56	11.79	-0.3	1.9	0.7	-4.0	87.2	33.1	4°	12.04
26	108	7.71	*4.63	5.92	12.12	-0.4	15.5	0.9	-27.6	87.6	30.6	4°	11.81
31	116	6.20	*3.74	5.41	11.42	-0.2	-0.7	0.4	1.8	86.7	34.3	4°	11.81
36	114	7.26	*4.40	5.79	11.84	-0.3	10.3	0.5	-19.2	86.9	31.7	4°	11.73
38	113	6.99	*4.24	5.73	11.80	-0.3	7.3	0.6	-13.5	87.3	32.2	4°	11.81
39	112	7.03	*4.24	5.75	11.75	-0.3	7.3	0.7	-13.5	86.8	33.0	4°	11.76
21	84.6	7.61	*4.59	6.54	11.80	0.4	14.7	-0.9	-26.0	95.6	12.9	8°	11.55
23	154	7.24	*4.38	6.23	11.81	2.9	10.0	-5.6	-18.2	95.7	13.8	8°	11.72
24	237	7.35	*4.44	5.53	11.66	13.0	11.2	-25.0	-20.7	95.9	13.9	8°	11.52
25	195	6.99	*4.23	5.89	11.50	7.9	6.9	-15.0	-12.7	96.1	13.5	8°	11.52
19	116	6.80	*4.11	5.53	11.47	-0.2	5.0	0.4	-9.5	84.5	37.3	12°	11.58
20	109	6.84	*4.14	5.53	11.32	-0.4	5.9	0.9	-10.5	83.9	38.1	15°7'	11.39

*Estimated D_f

TABLE XIII-B

Refers to Figures 26 and 27-Curve B

VARIATION OF SCREENING ANGLE

Screening Data:- Temperature - 75°C
Displacement - 4"
Vibr./min. - 146
Mash Type 1

RUN NO.	FEED RATE #/min. R_f	%TOTAL SOLIDS IN THE FEED F	%SUSPENDED SOLIDS IN THE FEED $F-D_f$	%TOTAL SOLIDS IN THE EFFLUENT E	%TOTAL SOLIDS IN THE SCREENINGS S	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR $F-D_f$	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR $F-D_f$	CORRECTED OR PSUEDO %DEWATERED P.C.D.	CORRECTED OR PSUEDO %RETAINED P.C.R.	VARIABLE SCREENING ANGLE	CORRECTED OR PSUEDO SCREENINGS CONTENT S
117	136	6.75	4.07	5.24	13.73	1.1	4.5	-2.4	-8.5	89.2	37.8	0°	13.73
115	134	6.74	4.18	4.78	12.94	0.9	6.3	-2.0	-11.5	84.8	47.6	4°	12.85
116	146	6.73	4.05	5.07	12.52	2.0	3.9	-4.1	-7.7	85.0	43.6	8°	12.53
118	136	6.66	3.94	5.03	12.66	1.1	2.0	-2.4	-4.2	83.1	48.3	12°	12.75
119	120	6.80	4.04	5.26	12.08	0	3.8	0	-7.3	82.6	45.3	15°7'	12.09

TABLE XIV

Refers to Figures 28 and 29

VARIATION OF TYPE OF SCREEN

Screening Data:- Temperature - 75°C
Screen Angle - 4°
Displacement - 4"
Vibr./min. - 146
Mash Type 2

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%SUSPENDED SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR F-D_f	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR F-D_f	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE SCREEN NO.	VARIABLE SCREEN OPENING	CORRECTED OR PSUEDO SCREENINGS CONTENT
	R_f	F	F-D_f	E	S					P.C.D.	P.C.R.		Inches	S
44	114	7.14	*3.69	5.60	13.62	0.1	0.9	-0.3	-0.8	83.1	53.1	00	0.020	13.62
45	113	7.03	*3.67	5.58	13.37	0.1	0.8	-0.4	-0.7	83.6	50.8	0	0.023	13.39
46	112	7.08	3.68	5.94	14.04	0.2	0.9	-0.5	-0.8	88.1	40.7	0A	0.023	14.05
47	113	7.32	3.72	5.71	14.24	0.1	1.0	-0.4	-1.0	83.6	54.0	1	0.027	14.22
48	116	7.00	*3.66	5.98	13.84	0	0.8	-0.2	-0.7	88.8	37.4	2	0.033	13.87
49	120	7.00	*3.66	5.84	13.97	0	0.8	0	-0.7	87.6	41.9	3	0.039	14.00
50	114	7.31	*3.64	5.68	13.73	0.1	0.7	-0.3	-0.6	82.0	56.4	50	0.0115	13.74
51	118	7.29	*3.64	6.21	14.67	0	0.7	-0.1	-0.6	89.0	39.0	35	0.0166	14.71
52	112	7.34	*3.65	5.86	13.96	0.2	0.7	-0.5	-0.6	83.9	51.6	32	0.01925	13.99
53	109	7.54	*3.71	6.08	14.34	0.2	1.0	-0.7	-1.0	84.8	49.7	28	0.0237	14.32
54	113	7.28	*3.68	6.02	13.81	0.1	0.9	-0.4	-0.8	86.0	44.7	24	0.0277	13.82
55	112	7.44	*3.68	6.19	14.01	0.2	0.9	-0.5	-0.8	86.3	44.1	20	0.033	14.02
56	98	7.41	*3.67	5.90	13.89	0.4	0.8	-1.6	-0.7	83.6	51.3	16	0.0395	13.91

*Estimated D_f

TABLE XV

Refers to Figures 30 and 31

VARIATION OF FREQUENCY OF VIBRATION

Screening Data:- Temperature - 75°C
Screen Angle - 4°
Displacement - 3"
Mash Type 2

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%SUSPENDED SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR F-D_f	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR F-D_f	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE FREQUENCY NO. OF VIBRATIONS PER MIN.	CORRECTED OR PSUEDO SCREENINGS CONTENT
	R_f	F	F-D_f	E	S					P.C.D	P.C.R.		S
76	127	6.94	*3.39	5.81	13.40	-0.1	-0.9	0.5	0.5	85.1	44.9	145	13.33
59	114	7.25	3.59	6.08	14.29	0.1	0.5	-0.4	-0.3	87.4	42.8	145	14.07
77	113	6.78	*3.30	5.96	13.22	0.1	-1.7	-0.4	1.3	87.9	35.2	162	13.23
81	118	6.72	*3.25	5.93	12.75	0	-2.1	-0.1	1.5	87.1	35.3	176	12.79
78	133	6.71	*3.25	5.95	12.57	-0.2	-2.1	0.8	1.5	87.0	35.3	200	12.61
79	117	6.75	*3.27	6.12	12.43	0.1	-1.9	-0.1	1.5	86.8	29.4	226	12.45
80	106	6.55	*3.15	6.00	11.61	0.2	-3.1	-1.0	2.3	87.8	27.4	267	11.71

*Estimated D_f

TABLE XVI-A

Refers to Figures 32 and 33-Curve A

VARIATION OF HORIZONTAL DISPLACEMENT

Screening Data:- Temperature - 75°C
Screen Angle - 0°
Vibr./min. - 146
Mesh Type 2

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%SUSPENDED SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR $F-D_f$	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR $F-D_f$	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE HORIZONTAL DISPLACEMENT	CORRECTED OR PSUEDO SCREENINGS CONTENT
	R_f	F	$F-D_f$	E	S					P.C.D.	P.C.R.	Inches	S
63	102	7.49	3.55	5.56	9.35	0.3	0.3	-1.2	-0.1	80.7	77.5	2	9.43**
64	115	7.74	3.76	6.00	14.34	0.1	1.0	-0.2	-1.0	81.7	58.0	3	14.26
65	110	7.44	*3.53	5.58	13.67	0.2	0.1	-0.6	-0.1	79.4	64.4	4	13.96
66	112	7.72	3.70	6.30	13.31	0.2	0.9	-0.5	-0.7	82.1	51.0	5	13.26
67	104	7.51	*3.57	6.24	13.06	0.3	0.4	-1.1	-0.2	83.2	47.7	6	13.12
68	131	7.53	*3.58	6.48	12.78	0	0.4	0.8	-0.2	84.7	42.7	7	12.83

*Estimated D_f

**Flooding

TABLE XVI-B

Refers to Figures 32 and 33-Curve B

VARIATION OF HORIZONTAL DISPLACEMENT

Screening Data:- Temperature - 75°C
Screen Angle - 0°
Vibr./min. - 146
Mash Type 3

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%SUSPENDED SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR F-D_f	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR F-D_f	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE HORIZONTAL DISPLACEMENT	CORRECTED OR PSUEDO SCREENINGS CONTENT
	R_f	F	F-D_f	E	S					P.C.D.	P.C.R.	Inches	S
92	139	4.80	2.50	3.57	6.70	-0.1	-13.0	1.1	8.8	48.4	77.3	2	6.84**
93	137	4.90	2.56	3.86	12.32	-0.1	-12.5	1.0	7.8	76.1	59.2	3	12.39
94	133	4.90	2.58	3.60	11.99	-0.1	-11.7	0.9	7.6	73.9	69.5	4	12.05
95	128	5.23	2.86	3.82	11.89	-0.1	-7.5	0.5	4.6	76.2	63.0	5	11.72
96	130	5.08	2.74	3.84	11.31	-0.1	-9.2	0.7	5.8	75.2	63.7	6	11.24

**Flooding

TABLE XVI-C

Refers to Figures 32 and 33-Curve C

VARIATION OF HORIZONTAL DISPLACEMENT

Screening Data:- Temperature - 75°C
Screen Angle - 4°
Vibr./min. - 146
Mesh Type 2

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%SUSPENDED SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR F-D_f	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR F-D_f	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE HORIZONTAL DISPLACEMENT	CORRECTED OR PSUEDO SCREENINGS CONTENT
	R_f	F	F-D_f	E	S					P.C.D.	P.C.R.	Inches	S
58	107	7.26	3.77	6.25	12.24	0.2	1.0	-0.9	-1.0	85.3	38.0	2	12.14
59	114	7.26	3.59	6.08	14.29	0.1	0.5	-0.4	-0.3	87.4	42.8	3	14.21
57	103	7.14	3.86	5.70	13.01	0.3	1.2	-1.1	-1.3	83.0	48.6	4	12.84
60	130	7.34	3.76	5.94	12.86	-0.1	1.0	0.7	-1.0	81.9	50.9	5	12.78
61	130	7.22	3.76	6.16	12.17	-0.1	1.0	0.7	-1.0	84.2	41.5	6	12.09
62	110	7.28	3.72	5.94	12.42	0.2	0.9	-0.6	-0.9	81.6	49.1	7	12.36

TABLE XVI-D

Refers to Figures 32 and 33-Curve D

VARIATION OF HORIZONTAL DISPLACEMENT

Screening Data:- Temperature - 75°C
Screen Angle - 8°
Vibr./min. - 146
Mash Type 2

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%SUSPENDED SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR F-D_f	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR F-D_f	CORRECTED OR PSUEDO %DEWATERED	CORRECTED OR PSUEDO %RETAINED	VARIABLE HORIZONTAL DISPLACEMENT	CORRECTED OR PSUEDO SCREENINGS CONTENT
	R_f	F	F-D_f	E	S					P.C.D.	P.C.R.	Inches	S
69	117	7.03	3.42	5.92	12.93	0	-0.6	-0.1	0.5	84.6	44.9	2	13.11
70	122	7.26	3.61	6.05	13.59	-0.1	0.6	0.2	-0.4	85.6	45.2	3	13.62
71	111	7.12	3.57	6.18	12.95	0.2	0.4	-0.6	-0.2	87.6	36.6	4	13.00
72	111	7.13	*3.55	6.27	12.54	0.2	0.2	-0.6	-0.1	87.5	34.7	5	12.61
73	116	7.18	3.56	6.18	12.08	0	0.3	-0.1	-0.1	84.3	41.0	6	12.14
74	112	7.15	*3.56	6.17	12.03	0.2	0.2	-0.5	-0.1	84.5	39.8	7	12.09

*Estimated D_f

TABLE XVII

REPRODUCIBILITY OF RESULTS

Screening Data:- Temperature - 75°C
Screen Angle - 4°
Displacement - 4"
Vibr./min. - 222

RUN NO.	FEED RATE #/min. R_f	%TOTAL SOLIDS IN THE FEED F	%SUSPENDED SOLIDS IN THE FEED $F-D_f$	%TOTAL SOLIDS IN THE EFFLUENT E	%TOTAL SOLIDS IN THE SCREENINGS S	%DEWATERED CORRECTION FOR FEED RATE	%DEWATERED CORRECTION FOR $F-D_f$	%RETAINED CORRECTION FOR FEED RATE	%RETAINED CORRECTION FOR $F-D_f$	CORRECTED OR PSUEDO %DEWATERED P.C.D.	CORRECTED OR PSUEDO %RETAINED P.C.R.	CORRECTED OR PSUEDO SCREENINGS CONTENT S
34	112	6.76	*4.09	5.51	12.07	-0.3	4.5	0.7	-8.6	86.2	36.7	12.22
35	118	7.11	*4.31	5.55	11.84	-0.1	8.4	0.2	-16.5	84.7	36.8	11.81
36	114	7.26	*4.40	5.79	11.84	-0.3	10.3	0.5	-19.2	86.9	31.7	11.94
37	111	7.05	*4.26	5.85	12.21	-0.3	7.5	0.8	-14.7	89.4	28.6	12.22
38	113	6.99	*4.24	5.73	11.80	-0.3	7.3	0.6	-13.5	87.3	32.2	11.82
39	112	7.03	*4.24	5.75	11.75	-0.3	7.3	0.7	-13.5	86.8	33.0	11.77
40	94	7.16	*4.34	5.74	12.07	-0.3	9.0	0.7	-17.6	87.5	31.9	12.02
										av. 86.9	av. 33.0	av. 11.97

*Estimated D_f

$$\text{Average Error} = \frac{\pm\Sigma(d)}{n\sqrt{n}}$$

where: d = sum of deviations (absolute value) from arithmatical mean

n = number of observations

$$\text{Av. Error of P.C.D.} = \pm\frac{6.5}{7\sqrt{7}} = \pm 0.35$$

$$\text{Av. Error of P.C.R.} = \pm\frac{15.1}{7\sqrt{7}} = \pm 0.81$$

$$\text{Av. Error of S} = \pm\frac{1.09}{7\sqrt{7}} = \pm 0.06$$

TABLE XVIII

ORIGINAL SCREENING DATA

RUN NO.	FEED RATE #/min. R_f	%TOTAL SOLIDS IN THE FEED F	%TOTAL SOLIDS IN THE EFFLUENT E	%TOTAL SOLIDS IN THE SCREENINGS S	HORIZONTAL DISPLACEMENT Inches	FREQUENCY OF VIBRATION No./min.	SCREEN ANGLE Degrees	TEMP. OF FEED °C	BARREL NO.	SCREEN TYPE
1	97	3.91	3.82	7.58	4	224	4	29.5*	1	00
3	102	4.20	3.75	9.26	4	224	4	67.5*	1	00
4	94	4.36	3.77	9.05	4	224	4	67.0*	1	00
5	97	4.53	4.14	10.41	4	224	4	87.0*	1	00
6	101	4.76	4.54	10.49	4	224	4	86.0*	1	00
7	62	5.35	5.14	10.97	4	224	4	96.5*	1	00
8	54	5.96	5.35	11.06	4	224	4	97.0*	1	00
9	117	5.09	4.40	9.96	4	224	4	32.0*	1	00
10	117	5.66	4.65	10.44	4	224	4	52.5*	1	00
11	96	5.41	4.59	10.93	4	224	4	92.0*	1	00
12	116	5.38	5.04	11.01	4	224	4	77.0*	1	00
13	110	6.09	4.84	10.70	4	224	4	48.0*	1	00
14	96	6.16	5.10	11.26	4	224	4	90.0*	1	00
15	117	6.68	5.45	11.63	4	224	4*	75	1	00
16	101	6.86	5.79	12.42	4	224	0*	75	1	00
17	112	6.51	5.56	11.79	4	224	4*	75	1	00
19	116	6.80	5.53	11.47	4	224	12*	75	1	00
20	109	6.84	5.53	11.32	4	224	15.1*	75	1	00
21	85*	7.61	6.54	11.80	4	224	8	75	2	00
22	69*	7.28	5.95	11.42	4	224	8	75	2	00

*Variable

TABLE XVIII (Continued)

ORIGINAL SCREENING DATA

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	HORIZONTAL DISPLACEMENT	FREQUENCY OF VIBRATION	SCREEN ANGLE	TEMP. OF FEED	BARREL NO.	SCREEN TYPE
	R_f	F	E	S	Inches	No./min.	Degrees	°C		
23	154*	7.24	6.23	11.61	4	224	8	75	2	00
24	237*	7.35	5.53	11.66	4	224	8	75	2	00
25	195*	6.99	5.89	11.50	4	224	8	75	2	00
26	108	7.71*	5.92	12.12	4	224	4	75	2	00
27	108	7.90*	5.87	12.19	4	224	4	75	2	00
28	107	7.93*	5.90	12.28	4	224	4	75	2	00
29	106	8.66*	6.27	12.43	4	224	4	75	2	00
31	116	6.20*	5.41	11.42	4	224	4	75	2	00
33	117	5.76*	4.57	10.80	4	224	4	75	2	00
34	112	6.76	5.51	12.07	4	222	4	75	2	00
35	118	7.11	5.55	11.84	4	222	4	75	2	00
36	114	7.26	5.79	11.84	4	222	4	75	2	00
37	111	7.05	5.85	12.21	4	222	4	75	2	00
38	113	6.99	5.73	11.80	4	222	4	75	2	00
39	112	7.03	5.75	11.75	4	222	4	75	2	00
40	94	7.16	5.74	12.07	4	222	4	75	2	00
42	80	6.93	5.46	10.96	4	222	4	32	3	00
43	80	6.73	5.45	10.82	4	222	4	32	3	00

*Variable

TABLE XVIII (Continued)

ORIGINAL SCREENING DATA

RUN NO.	FEED RATE #/min. R_f	%TOTAL SOLIDS IN THE FEED F	%TOTAL SOLIDS IN THE EFFLUENT E	%TOTAL SOLIDS IN THE SCREENINGS S	%DISSOLVED SOLIDS IN MOTHER LIQUOR OF EFFLUENT M_e	FREQUENCY OF VIBRATION No./min.	SCREEN ANGLE Degrees	HORIZONTAL DISPLACEMENT Inches	TEMP. OF FEED °C	BARREL NO.	SCREEN TYPE
44	114	7.14	5.60	13.62	3.58	146	4	4	75	3	00*
45	113	7.03	5.58	13.37	3.39	146	4	4	75	3	0*
46	112	7.08	5.94	14.04	3.54	146	4	4	75	3	0A*
47	113	7.32	5.71	14.24	3.73	146	4	4	75	3	1*
48	116	7.00	5.98	13.84	3.64	146	4	4	75	3	2*
49	120	7.00	5.84	13.97	3.75	146	4	4	75	3	3*
50	114	7.31	5.68	13.73	3.80	146	4	4	75	3	50*
51	118	7.29	6.21	14.67	3.94	146	4	4	75	3	35*
52	112	7.34	5.86	13.96	4.14	146	4	4	75	3	32*
53	109	7.54	6.08	14.34	3.65	146	4	4	75	3	28*
54	113	7.28	6.02	13.81	3.80	146	4	4	75	3	24*
55	112	7.44	6.19	14.01	3.62	146	4	4	75	3	20*
56	98	7.41	5.90	13.89	3.70	146	4	4	75	3	16*
57	103	7.14	5.70	13.01	3.42	146	4	4*	75	3	00
58	107	7.26	6.25	12.24	3.63	146	4	2*	75	3	00
59	114	7.25	6.08	14.29	3.78	146	4	3*	75	3	00
60	130	7.34	5.94	12.86	3.72	146	4	5*	75	3	00
61	130	7.22	6.16	12.17	3.59	146	4	6*	75	3	00
62	110	7.28	5.94	12.42	3.70	146	4	7*	75	3	00
63	102	7.49	5.56	9.35**	4.08	146	0	2*	75	3	00

*Variable

TABLE XVIII (Continued)

ORIGINAL SCREENING DATA

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DISSOLVED SOLIDS IN MOTHER LIQUOR OF EFFLUENT	FREQUENCY OF VIBRATION	SCREEN ANGLE	HORIZONTAL DISPLACEMENT	TEMP. OF FEED	BARREL NO.	SCREEN TYPE
	R_f	F	E	S	M_e	No./min.	Degrees	Inches	°C		
64	115	7.74	6.00	14.34	4.14	146	0	3*	75	3	00
65	110	7.44	5.58	13.87	4.15	146	0	4*	75	3	00
66	112	7.72	6.30	13.31	4.18	146	0	5*	75	3	00
67	104	7.51	6.24	13.06	4.21	146	0	6*	75	3	00
68	131	7.53	6.48	12.78	4.20	146	0	7*	75	3	00
69	117	7.03	5.92	12.93	3.74	146	8	2*	75	3	00
70	122	7.26	6.05	13.59	3.79	146	8	3*	75	3	00
71	111	7.12	6.18	12.95	3.68	146	8	4*	75	3	00
72	111	7.13	6.27	12.54	3.94	146	8	5*	75	3	00
73	116	7.18	6.18	12.08	3.75	146	8	6*	75	3	00
74	112	7.15	6.17	12.03	3.52	146	8	7*	75	3	00
76	127	6.94	5.81	13.40	3.29	145*	4	3	75	3	00
77	113	6.78	5.96	13.22	3.11	162*	4	3	75	3	00
78	133	6.71	5.95	12.57	3.55	200*	4	3	75	3	00
79	117	6.75	6.12	12.43	3.63	226*	4	3	75	3	00
80	106	6.55	6.00	11.61	3.71	267*	4	3	75	3	00
81	118	6.72	5.93	12.75	3.60	176*	4	3	75	3	00

*Variable

TABLE XVIII (Continued)

ORIGINAL SCREENING DATA

RUN NO.	FEED RATE #/Min.	%TOTAL SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DISSOLVED SOLIDS IN MOTHER LIQUOR OF FEED	%DISSOLVED SOLIDS IN MOTHER LIQUOR OF EFFLUENT	SCREEN ANGLE	FREQUENCY OF VIBRATION	HORIZONTAL DISPLACEMENT	TEMP. OF FEED	BARREL NO.	SCREEN TYPE
	R_f	F	E	S	M_f	M_e	Degrees	No./min.	Inches	°C		
82	129	6.34	5.55	11.64	3.37	3.35	4	146	4	29*	3	00
83	122	6.10	5.29	11.61	3.45	3.41	4	146	4	44*	3	00
84	130	6.25	5.26	12.14	3.37	3.50	4	146	4	59*	3	00
85	103	6.65	5.42	12.47	3.52	3.64	4	146	4	91*	3	00
86	105	6.51	5.84	12.82	3.81	3.72	4	146	4	75*	3	00
87	113	4.90*	3.36	10.45	2.40	2.42	4	225	4	75	4	00
88	126	3.19*	2.61	9.54	1.50	1.75	4	225	4	75	4	00
89	125	3.25*	2.46	9.66	1.59	1.58	4	225	4	75	4	00
90	128	2.63*	2.11	9.11	1.20	1.34	4	225	4	75	4	00
91	138	2.66*	2.14	9.15	1.29	1.28	4	225	4	75	4	00
92	139	4.80	3.57	6.70**	2.36	2.26	0	146	2*	75	5	00
93	137	4.90	3.86	12.32	2.41	2.45	0	146	3*	75	5	00
94	133	4.90	3.60	11.99	2.38	2.44	0	146	4*	75	5	00
95	128	5.23	3.82	11.89	2.44	2.39	0	146	5*	75	5	00
96	130	5.08	3.84	11.31	2.41	2.46	0	146	6*	75	5	00
97	60*	5.06	3.70	11.29	2.13	2.07	4	146	4	75	5	00
98	98*	4.82	3.81	11.29	2.15	2.23	4	146	4	75	5	00
99	130*	4.80	3.90	11.58	2.25	2.26	4	146	4	75	5	00
100	165*	4.94	3.98	11.42	2.34	2.30	4	146	4	75	5	00
101	270*	5.02	3.86	9.40**	2.36	2.34	4	146	4	75	5	00

TABLE XVIII (Continued)

ORIGINAL SCREENING DATA

RUN NO.	FEED RATE #/min.	%TOTAL SOLIDS IN THE FEED	%TOTAL SOLIDS IN THE EFFLUENT	%TOTAL SOLIDS IN THE SCREENINGS	%DISSOLVED SOLIDS IN MOTHER LIQUOR OF FEED	%DISSOLVED SOLIDS IN MOTHER LIQUOR OF EFFLUENT	SCREEN ANGLE	FREQUENCY OF VIBRATION	HORIZONTAL DISPLACEMENT	TEMP. OF FEED	BARREL NO.	SCREEN TYPE
	R_f	F	E	S	M_f	M_e	Degrees	No./min.	Inches	°C		
103	124	5.16*	3.91	10.16	2.18	2.23	4	225	4	50	5	00
104	133	4.49*	3.66	10.36	1.98	2.19	4	225	4	50	5	00
105	126	3.96*	3.23	9.61	1.77	1.80	4	225	4	50	5	00
106	132	3.56*	2.88	9.31	1.66	1.65	4	225	4	50	5	00
107	145	2.74*	2.44	8.58	1.19	1.31	4	225	4	50	5	00
108	122	2.02*	1.80	7.88	0.92	0.97	4	225	4	50	5	00
110	136	4.61*	3.64	9.23	2.22	2.25	4	225	4	28	5	00
111	140	3.98*	3.39	8.98	2.00	2.09	4	225	4	28	5	00
112	139	3.46*	3.03	8.61	1.76	1.79	4	225	4	28	5	00
113	139	2.20*	2.00	7.89	1.05	1.19	4	225	4	28	5	00
114	139	1.23*	1.09	6.67	0.55	0.71	4	225	4	28	5	00
115	134	6.74	4.78	12.94	2.67	2.70	4*	146	4	75	6	00
116	146	6.73	5.07	12.52	2.80	2.81	8*	146	4	75	6	00
117	136	6.75	5.24	13.73	2.79	2.77	0*	146	4	75	6	00
118	136	6.66	5.03	12.66	2.84	2.84	12*	146	4	75	6	00
119	120	6.80	5.26	12.08	2.87	2.86	15.1*	146	4	75	6	00

*Variable
**Flooding

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