THE DRYING OF MATERIALS
USING
AN ATMOSPHERIC DRUM DRYER

by

Charles E. Thompson

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In Charge of Major Work

Head of Major Department

Dean of Engineering Division

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INTRODUCTION

In the preparation of practically all chemicals there is the necessity of drying, either of the final product or of one or more of the materials used in its preparation. If the material is in solution, or in a suspension, it can be easily handled by drying upon the surface of an internally heated drum. Continuous sheets such as paper and cloth are also dried this way. If the material is easily damaged by high temperatures it may be dried under a partial vacuum. Considering their adaptability, ease of operation, and relative efficiency of operation, it is not surprising that the drum driers are extensively used.

In spite of their wide acceptance and application, there is almost a complete absence of published data concerning the quantitative effect of variations in operation upon the character of the product produced, the capacity of the dryers, and heat consumption. This absence of data is more surprising in view of the fact that this method of drying has been used for more than one hundred years.

For anyone attempting to design a drum dryer, the above-mentioned data would be a necessity, and it is the object of this thesis to procure and correlate, by equations, some measured results of the change in operating procedure upon the product and capacity. The work has been done upon a single roll atmospheric dryer. The results will, therefore, apply mainly to this class of drums. Because of time and equipment limitations, it has been impossible to make a similar study on a vacuum dryer.

The object of this work has been to study the drying characteristics of the drum dryer and to determine the rate curves for several materials under varying conditions of operation. By a study of the effects of these various factors an attempt was made to formulate a method of predicting the results which may be expected by using a drum drier under a predetermined set of conditions. In addition to this, the steam consumption and the character of the final product were compared for each run.

LITERATURE REVIEW

1. Historical

The drum-type dryer dates from the Industrial Revolution in England when it first appeared in the paper and textile industries. The main problems of entering the steam and removing the condensate were solved as were the methods of driving the rolls and feeding the material to them[5]. The dryers were used upon continuous material; that is, material that was in sheet form, and it hasn't been until comparatively recently that the drum dryer has been successfully used upon solutions and pastes with their corresponding problems caused by surface tension, viscosity, corrosion, and fluidity. Harte[5] shows an advertisement for using a drum dryer upon liquids dated 1910 and states that as early as 1860 British patents were being granted upon this phase.

The following table is taken from an article by Sherwood[12] and gives the number of patents issued by years in the general field of drying. He gives this data graphically and the values here given have been read from his curve. These show the increasing interest in this chemical engineering unit operation.

Year	Number	Year	Number
1800	less 50	1890	1100
1820	50	1900	1800
1840	75	1910	2600
1860	90	1920	3500
1880	650	1930	about 4000

As in many other cases the more recent developments have been mechanical improvements over existing models. That is, alloy steels that are more resistant to corrosion, more efficient in their rate of transfer of heat, and that take a smoother polish on their surface as well as being able to stand higher pressures have been used; the knives for removing the material have been made to fit the drum more closely and, at the same time, last longer; more perfect machining of the faces which has permitted the double rolls with a clearance of only several thousandths of an inch to be used; and the improved methods of getting a smooth, continuous film of material upon the drum face have resulted in the more widespread use of drum dryers than in previous years and in their use upon a wider variety of materials.

2. Drying Apparatus

As the object of any drying operation is the removal of the solvent or supporting liquid from the material desired, any equipment that will accomplish this becomes a drying apparatus. However, certain machinery is manufactured for the chemical industry and accepted by it as being standard. It is only with this equipment that we are concerned.

Probably the first drying operation was the prehistoric drying of skins for clothing or of meat for its preservation and was accomplished by hanging the material either in a room or in the open air. Leather and tobacco are still dried by this method; commonly known as loft drying. The greatest disadvantage of this method is the absence of any exact control upon the drying and the constant care and manual inspection required. To overcome the disadvantage of absence of control in the loft method, chamber and cabinet dryers have been used. In general, these are smaller units than the loft and are built with a source of both heat and humidity control. This control allows more diversification in their use but, as they are intermittent in operation, their cost for manual labor is usually high; consequently, they are usually used for a material that must be seasoned as well as or during its drying.

In order to reduce the cost of labor, the attempt was made to make a more or less continuous dryer, and the tunnel dryer, as used in the lumber industry, was the result. These are usually long tunnels through which the material continually moves, always meeting different conditions of humidity and heat as it proceeds; finally emerging completely dried. The material is moved by being placed upon carts which are slowly pushed through the dryer.

If the material is placed in a sloping, revolving circular shell and allowed to work its own way through, the apparatus is called a rotary dryer. In these the material is usually dried by meeting either flue gas from a furnace or, if higher temperatures are desired, powdered coal or natural gas may be blown directly into the shell and allowed to burn there. These are only used upon materials that can take high temperatures and don't have to be kept too free from impurities, as in drying cement rock or other ores.

All of the types previously discussed have been for granular materials. If it should be a solution that is to be dried, either a spray or a drum dryer is used.

The spray drier is a large enclosed space through which heated air is blown and the liquid sprayed. The air and solution enter and flow parallel or countercurrent. The solvent is evaporated by the air and the solid, recoverable, material settles and is withdrawn. To recover all of the solid material usually requires recovery system as a great deal of the solids are very finely divided and are carried out by the exit air and lost unless some external recovery is used. This increases the cost of the apparatus and, as it is inconvenient and costly to recover the solvent if it should be valuable, has tended to limit the adoption of this method of drying. However, this method is used to dry milk and soap but has not been generally adopted for use upon many combustible organic materials because of the danger of dust explosions.

The other type of dryer for liquids is the drum dryer and, as this thesis deals with drum dryers, they will be discussed in the following sections.

For many materials the use of partial vacuums gives more satisfactory physical properties of the material and many of the above-mentioned types are enclosed in air-tight compartments and vacuums used. Although this increases the investment and the cost of drying, the procedure is required by some materials and for some others it increases their saleability by more than enough to pay for this extra cost.

Discussions of these types of dryers may be found in Badger and McCabe[2] or Walker, Lewis, McAdams, and Gilliland[10].

3. Types of Drum Dryers

a. Single roll atmospheric

The drum dryer of the simplest construction is the single roll atmospheric type. As the name implies there is but one roll upon which the material is dried. This roll is mounted upon a steel framework and rotated by an arrangement of gears. The steam is introduced through one end and the condensate removed through the opposite. The drum is usually fabricated by casting (some drums are made from a sheet by rolling and welding), followed by machining or grinding the surface until it is smooth and true[5]. The even distribution of steam, so that it will sweep out noncondensable gases and prevent stagnant regions, is important and is met by a suitable manifold arrangement which feeds steam to a number of points within the drum[5].

One of the simplest methods of feeding the material to the drum is to allow it to dip into a pan of the material to be dried. Frequently, a metal blade, "bubble breaker"[5], is placed just after the drum emerges from the solution. This affords a control upon the thickness of the material adhering to the drum and also tends to smooth the surface of the material and break the bubbles thus preventing "wet spots". Possible disadvantages of the dip method, as given by Harte[5], are:

(1) It does not lend itself to feeding a stiff paste or a liquid containing heavy crystals, although it may be used for a fairly thick slurry, and

(2) With some liquids the layer of liquid picked up by the drum tends to form drops rather than to remain in a smooth sheet.

An alternate method of feeding is by splashing, spraying, or pumping the liquid against the drum. This method permits a wide-range control of the thickness of the layer of material applied to the drum but requires rather skillful operation to take full advantage of this possible control. Very careful design of this sort of feed system is necessary, since the cold liquid gives "wet spots" on the drum unless the feed is uniform over the length of the drum. Some liquids which form drops with the dip feed will remain in a smooth layer when applied by a spray[5].

Still another method of feeding is to pour the liquid onto the drum from a reservoir at the top; an adjustable weir is sometimes used as a means of regulating the thickness of the layer thus applied to the drum. This method is useful where the material "bubbles" badly[5].

The removal of dried product from the drum is accomplished by means of a knife, sharpened and set at an angle that best serves the removal of the particular product being dried.

Harte[7] lists the important characteristics of the atmospheric, single-drum dryer as follows:

1. The product comes off the drum in thin flakes, a desirable form for materials which are to be redissolved where rapid dissolving is an advantage (soaps, detergents, water softeners, etc.); again, the flake form may appeal to the ultimate consumer (breakfast cereals); the drum-dried product frequently has a particular color or appearance which is of decided interest in marketing the product; the product delivered from the drying dry is usually quite uniform for an entire run of material and seldom requires subsequent grinding or blending.

2. The product is exposed to drying conditions (temperature) for a comparatively short time, a matter of seconds compared to hours (or even days) for some other methods of drying; this is important when materials are dried which have a tendency to deteriorate at drying temperatures.
3. The dryer is practically automatic, usually requiring only the part-time attention of one operator.
4. The steam economy is high compared to many types of dryers. To evaporate one pound of water requires from 1.25 to 2.00 pounds of steam. (Steam required varies with the temperature of the feed material, and with the size and radiation losses of the dryer.)
5. Capacities of 2.5 to 4.0 pounds of water evaporated per square foot of drum surface per hour are obtained for dryers operating on 50-pound (gage) steam; these capacities increase with increasing steam pressure, generally to a greater extent than corresponds to the increase in temperature difference between steam and material because film thickness is affected also. (In general, capacity depends primarily upon the characteristics of the material being dried, and the extent to which it adheres to the surface of the hot drum; and only secondarily on the steam pressure and the feed method.)

Lower steam pressure is an inherent limitation in the single as compared with the double drum dryer. The reason for this is quite obvious from the following example. To obtain the same drum surface area as a 42-inch x

100-inch double drum dryer, requires a 60 x 144-inch single drum dryer. But using the same wall thickness and allowable stresses, the allowable steam pressure in the two dryers would be in the ratio of 60 to 42; so if the 42-inch roll had a maximum working pressure of 100 pounds per square inch, the 60-inch roll would be limited to a maximum of 70 pounds per square inch. However, when other features of design are also taken into account, the maximum working pressure on the 60-inch drum is further limited to about 50 pounds per square inch with the ultimate result that the capacity (in pounds per square foot) of the single drum dryer is reduced below that of the double drum type[4].

Harcourt[4] gives the following table of the results of operation for the several materials:

Material dried	Type of Feed	Feed Moisture	Steam Press	Drum Rpm.	Feed Temp.	Prod. lb/hr/ sq.ft.	Moist. in Produc.
Chrom. Sulphate	Spray	48.5%	50	5	--	3.69	5.47%
Chrom. Sulphate	Dip	48.0	50	4	--	1.30	8.06
Chrom. Sulphate	Pan	59.5	24	2½	158	1.53	5.26
Chrom. Sulphate	Splash	59.5	55	1.75	150	2.31	4.93
Chrom. Sulphate	Splash	59.5	53	4.75	154	3.76	5.35
Chrom. Sulphate	Dip	59.5	53	5.75	153	3.36	4.57
Vegetable Glue	Pan	60-70	20-30	6-7	--	1-1.6	10.12
Cal. Arsenate	Slurry	75-77	45-50	3-4	--	2 - 3	.5-1
Cal. Carbonate	Slurry	70.0	45	2-3	--	1.5-3	0.5

Frequently two drums are mounted in a single machine with the two drums spaced apart so that they function as two single drums. The two-drum construction permits certain economies because the two drums may be served by a single supporting framework, single driving motor, and single piping for part of the steam and condensate system, may save some floor space, and may be attended by a single operator.

b. Double Roll Atmospheric

The atmospheric double drum dryer consists of two perfectly smooth steam-heated drums rotated toward each other from the top, a trough-feed mechanism, and knife scrapers. The liquid or slurry to be dried is fed into the V-shaped trough formed by the two drums and two end boards. Material immediately adjacent to the drum adheres in a thin film and is carried around to the knives where it is scraped off and falls into a conveyor.

There are four variables[4] involved in the operation of this type of dryer on a given material. They are:

1. steam pressure, which governs the temperature of the drum surface,
2. speed of rotation, which determines the time of contact between the film and preheated surface,
3. thickness of film, which may be governed by the distance between the drums,
4. condition of the feed material; i.e., the concentration and temperature at which the solution to be dried reaches the drum.

A number of advantages of this type of dryer immediately suggest themselves. One of them is that all the material fed to the drums is dried, another is the ease of cleaning, a third is the ease with which the feed may be changed from one material to another, and still a fourth is the good correlation between results obtained on a small laboratory model and a plant-sized dryer[4].

A number of tests have been conducted on the atmospheric double drum dryer using milk as a drying material. The results of these tests are summarized as follows[4]:

	Variable Increased			
	Steam Pressure	Feed Temperature	Drum Rotation R.P.M.	Distance Between Drums
Film thickness	Increase	Increase	Decrease	Increase
Evaporation between drums	Increase	Decrease	Increase	Decrease
Evaporation on the drums	Increase	Increase	Decrease	Increase
Total heat transfer	Increase	Unchanged	Unchanged	Unchanged
Moisture content, powder	Decreased	Decreased	Increased	Increased
Concentration between drums	Decreased	Decreased	Increased	Decreased

Harte[5] lists the important characteristics of the vacuum drum as follows:

1. Like the atmospheric dryer, the vacuum dryer yields an uniform, flaky product, with a color or appearance which may be of special interest to the consumer.
2. As in the case of the atmospheric dryer, time of exposure to drying conditions is only a matter of seconds; also, the vacuum dryer (thanks to the boiling point lowering) permits drying to be accomplished at a temperature much lower than is feasible on the atmospheric machine, an important consideration when heat-sensitive materials are dried.
3. It is essentially automatic, but, with the added feature of vacuum facilities, it requires more attention than an atmospheric dryer of the same size.
4. Steam economy is essentially the same as for the atmospheric

dryer.

5. Capacity per square foot of drying surface per hour for a given steam pressure is greater for the vacuum dryer than for the atmospheric.
6. The capital cost of the vacuum machine, with its heavy vacuum casing and accessory vacuum facilities, is necessarily greater than that of the atmospheric machine of corresponding size (square feet of drying surface) and may run four or five times as much. Welded steel construction for the casing and receivers may reduce this ratio to as low as three times and also reduces the weight of the machine.

Harcourt[4] gives the following table of operating data for the atmospheric double drum dryer:

Material Dried	Type Feed	Feed Moisture	Steam Press	Drum R.P.M.	Product Rate	Product Moisture
Sod. Sulphonate	Std.	53.6%	63	8.5	7.75	6.40%
Sod. Sulphate	Std.	76	56	7	3.08	0.06
Sod. Phosphate	Std.	57	90	9	8.23	0.9
Sod. Acetate	Std.	39.5	70	3	1.51	0.44
Sod. Acetate	Std.	40.5	67	8	5.16	10.03
Sod. Acetate	Std.	63.5	67	8	3.26	9.53

The steam pressure is in pounds per square inch and the product rate is in pounds per hour per square foot of drying area.

c. Vacuum Drum Dryers

Some materials are adversely affected by heat during their drying such as food products containing enzymes, vitamins, and proteins. Others are oxidized by the ordinary concentrations of air and in other cases it may be desired to recover the solvent. In all these cases the use of vacuums affords a solution to the problem[4].

Originally, the vacuum drum dryer was made by merely enclosing an atmospheric dryer in a shell and applying a vacuum. Certain changes were required, however, notably in the removal of the dried product. Originally, the product was allowed to fall into a recepticle and intermittantly removed. As this necessitated the breaking of the vacuum each time, a continuous method of removal was installed. This consists of a screw conveyer which discharges through a suitable valve arrangement that does not require the breaking of the vacuum.

Harcourt[4] gives the following table of operating data for the vacuum drum dryer:

Material Dried	Feed Moisture Per Cent	Steam Press lb/sq.in	Drum R.P.M.	Vacuum in. Hg	Product Rate lb/hr/sq.ft	Product Moisture Per Cent
Extract	59	35	8	27.9	7.74	4.76
Extract	59	35	6	27.7	2.76	1.92
Extract	59	36	4	atm.	2.09	1.01
Extract	56.5	35	7.5	27.5	1.95	3.19
Extract	56.5	60	2.5	atm.	1.16	0.75
Skim milk	65	10-20	4-5	---	2-3	2.5-3.2
Malted milk	60	30-35	4-5	---	2	2.6
Coffee	65	5-10	1-1.5	---	2-3	1.6-2.1
Malt Extract	65	3-5	.5-1	---	3-4	1.3-1.6
Tannin extract	50-55	30-35	8-10	---	8-10	5.3-6.4
Vegetable glue	60-70	15-30	5-7	---	10-12	2-4

The last three materials listed were fed by a spray type feed and the others by the pan type feed.

4. Operating Data for Drum Dryers

From the discussions that can be found in the current literature, it would appear that any one installation that dries the material and gives a satisfactory product is considered a success. There is no data given that could be used in the design of a dryer; the closest to operating costs is given by Harte[5] when he says, "Capacities of 2.5 to 4.0 pounds of water evaporated per square foot of drum surface per hour are obtained for dryers operating on 50-pound (gage) steam," and again when he states, " — a rough estimate of installed cost is $75 to $100 per square foot of drying surface for small dryers (20 square feet or less), and $25 to $50 for the larger machines." Perry[6] gives capacities higher than this, stating, "their capacity varies greatly with the steam pressure and the nature of the material to be dried, but it is commonly from 2 to 8 pounds water evaporated per hour per square foot of roll surface." He also states, "The heat loss from drum dryers is not great, so the steam consumption is usually fairly low, being from 1.3 to 2.0 pounds of steam per pound of water evaporated." Harte[5] gives practically the same values for the steam consumption (1.25 to 2.00) but adds that the steam required varies with the temperature of the feed material, and with the size and radiation losses of the dryer.

Van Marle[9] gives the value for the overall coefficient of heat transfer as about 360 B.t.u./hour/square foot/°F. in the area between the drums and about 220 between the point of closest approach of the drums and the knives. Walker, Lewis, McAdams, and Gilliland[10] state that the overall coefficient was about 24 B.t.u./(hr.)(deg.F.)(sq. ft. of outer surface) when drying wood pulp. In this case the resistance to heat flow between the drum surface and pulp being dried amounts to about 76% of the total.

Roeser and Mueller[7] gives the temperature deistribution around a double roll atmospheric drum dryer. They used a compensating themocouple. Their results show a drop in temperature as the drum face passes through the liquid and a constant rise in surface temperature throughout the remainder of the revolution.

Harcourt[4], in a general discussion of drum dryers, gives several tables of operating data when the dryers are used on chemicals but makes no comment upon these except to say that they yield a somewhat quantitative conception of the effects of steam pressure, drum speed, and feed temperature. These tables have been reproduced in the preceding sections. Van Marle[9] states: "The influence of steam pressure on capacity is very complicated and is by no means in proportion to over-all temperature difference." He explains this increase in capacity on account of the increase in steam pressure being more than expected, because with most products the layer adhering to a revolving heated surface increases in thickness, the higher the temperature of the surface. Increase in drum speed reduces the time of contact between the drum and the liquid and tends to reduce the thickness of the layer of adhering liquor with a decrease in capacity per revolution.

5. Theory of Drum Drying

The only discussion of the theory of drum drying that was found is that given by Walker, Lewis, McAdams, and Gilliland[10] on page 660. The following is taken verbatim from this source:

a. Drum Driers for Solids. The first resistance (from steam to metal) depends on the percentage of noncondensable gas in the steam (this should be small in good practice), the velocity of the steam, the fraction of the total internal heat-transfer surface that is submerged in condensate, etc.

The second resistance (that of the wall itself) depends on the thickness and thermal conductivity of the metal used. Where very thick cast-iron rolls are employed, this resistance may be an appreciable percentage of the total resistance.

The third resistance (from drum to the stock, through the stock, and into the air) is usually the greatest of the three resistances. Hence it is clear that design should be based on results of experiments for the type of drier and material in question, conditions in the experiments being as similar as possible to those to be used in production.

As the thickness of the stock is doubled, the water to be evaporated is doubled and the heat has to travel twice as far. It would, therefore, be anticipated that the drying time would vary with the square of the thickness of the stock. The drying time would also increase with increase in the fraction of water removed.

b. Drum Driers for Liquids. When solutions or suspensions are concentrated or reduced to a solid on a steam-heated drum, the film of material in immediate contact with the drum becomes dry in a very short time, and this dry inner layer serves as an insulation to separate the more moist layers from the heating surface. The process then reduces to a conduction of heat through the dry layer into that portion which still remains wet. When the rate of heat flow is great, the temperature of the sheet will approach the boiling temperature of the liquid at the pressure used. Hence it follows that the use of vacuum in the chamber housing the drum will lower the surface temperature and thus increase the rate of heat flow and consequently the evaporative rate.

EXPERIMENTAL

1. Purpose of the Investigation

The purpose of this work was to study the operation of the drum dryer and to determine the drying characteristics and rate curves for several materials under different conditions of operation. By a study of the effects of these various factors, the attempt was made to formulate a method of predicting the results which may be expected by using a drum dryer under a predetermined set of conditions. In addition to this, the thermal efficiency of the dryer, its capacity, and the character of the final product were compared for each set of operating conditions.

2. Plan of the Investigation

As the main variables in the operation of the dryer that was tested were

a. Steam pressure
b. Rate of revolution of the drum
c. Concentration of the slurry

each of these were varied individually and the resulting capacity, steam consumption, and moisture content of the product were determined.

In general, each run, during which samples were taken, lasted fifteen minutes. The results of each of these runs were then compared with all of the others and the general trends were correlated both by plotting and by equations.

In order to check the equations several "spot" runs; i.e., runs at intermediate values from those previously done, were made and the results from these compared with the calculated values.

3. Materials Used

Filter Cell. The filter cell used was a diatomacious silica sold by the Johns-Manville Company under the trade name of Standard Super-Cel.

Soap. The soap used was a flake washing soap sold by the Proctor and Gamble Company under the trade name of Clean Quick.

Sodium Sulphate. A standard commercial grade of bulk sodium sulphate was used.

Sodium Carbonate. A grade of 58 per cent light soda ash was obtained from the Mathesion Alkali Company.

Sodium Chloride. A commercial grade of sodium chloride was used. It was the rock crystal form before dissolving.

Water. The water used was tap water directly as delivered to the department from the college mains.

Steam. The steam was drawn directly from the supply line for the department. It was furnished from the central heating plant for the entire college. As the laboratory was towards the end of the line the steam was at all times wet, and it was necessary to blead the supply line rather heavily.

4. Apparatus

Drum Dryer. The pictures of the apparatus are shown in Figures 3, 4, 5, and 6. The numbers refer to different parts of the dryer and are discussed below. The dimensions of the equipment are given on the drawing.

Number 1. The main supporting framework was made from standard cast-iron pipe and fittings.

Number 2. The supporting framework for the drum and its accessories was made of inch and one-half by inch and one-half angle iron. This was bolted together with one-fourth inch machine bolts.

Number 3. The support for the motor and pulleys was made of one-half inch ply-wood. It was bolted to the angle iron frame (2) and to two supports which were welded to the pipe framework (1).

Number 4. The motive power for the drum was furnished by a Craftsman (Sears Roebuck and Company) one-third horse power electric motor. This motor had a rated r. p. m. of 1750.

Number 5. The r. p. m. of the motor was first reduced by a worm gear with a reduction ratio of twenty-four to one. The shaft from this reduction was connected to the four stage cone pulley which drove another of the same dimensions. The largest diameter of the pulleys was five inches and the smaller two inches. The rate of revolution of the drum was controlled by these two pulleys. It was possible to vary the rate of the drum to the following values:

10.00 revolutions per minute

6.04 revolutions per minute

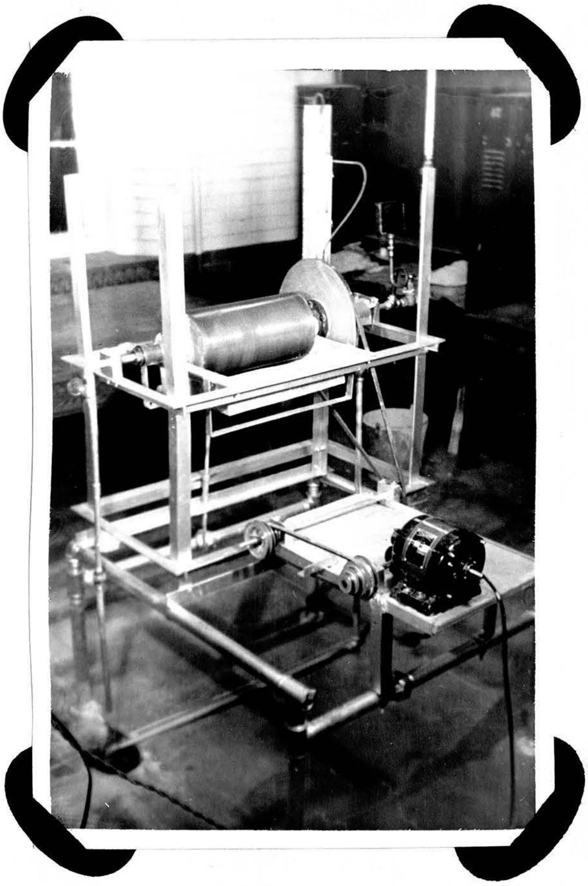


Figure 3

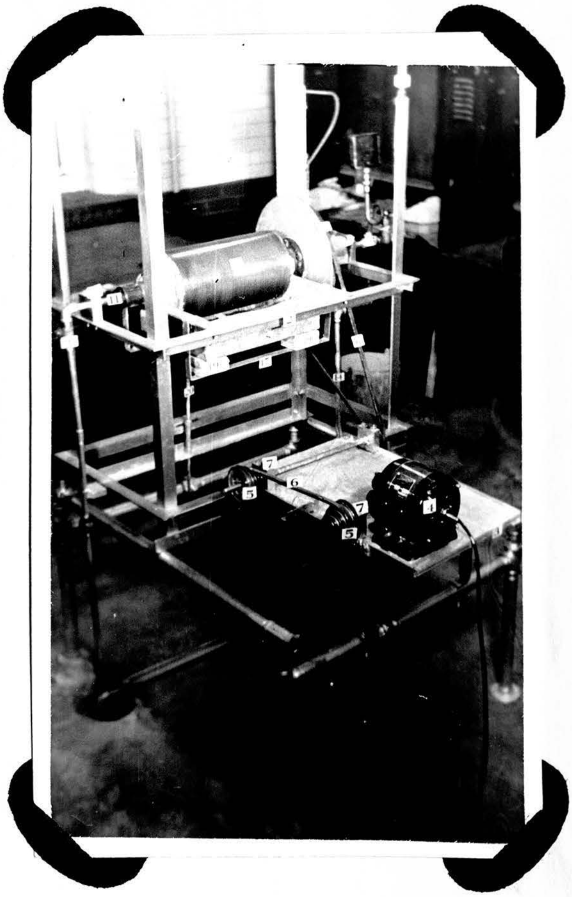


Figure 4

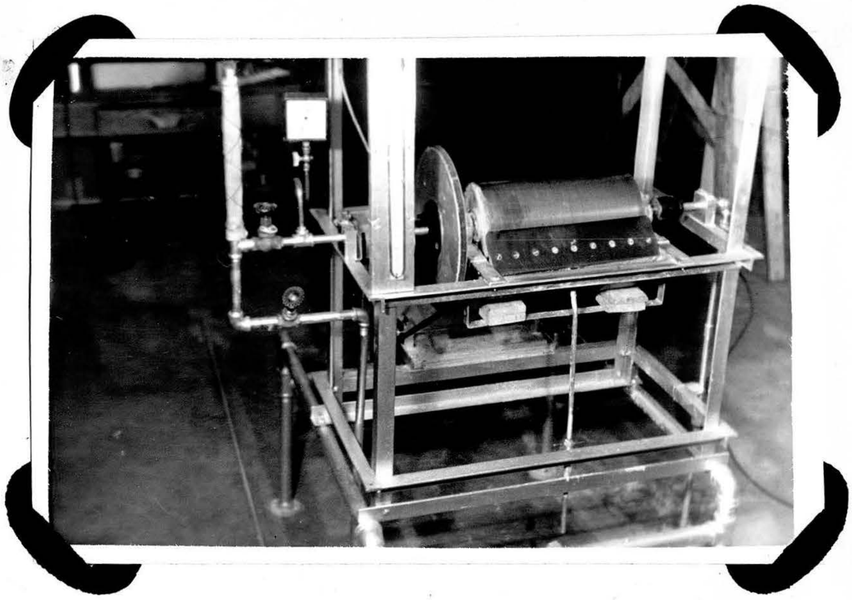


Figure 5

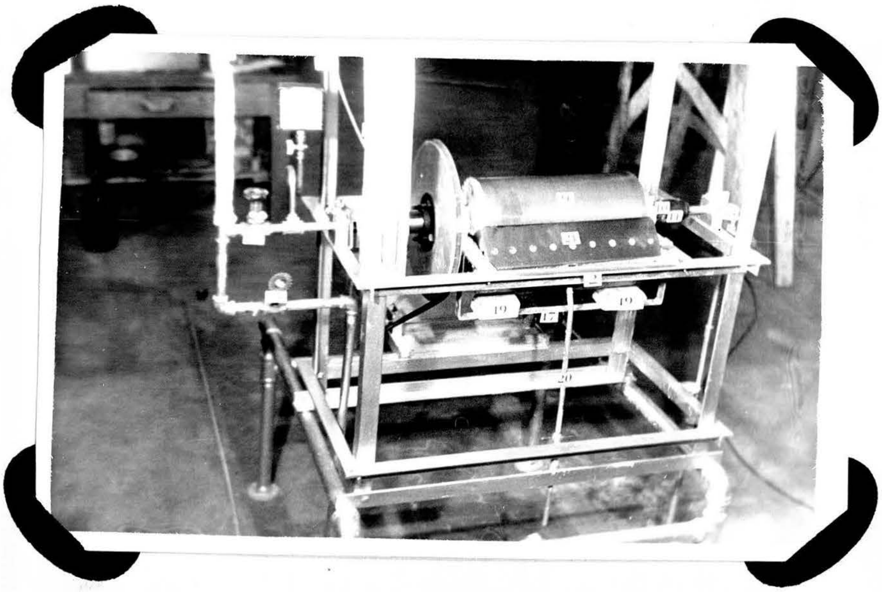
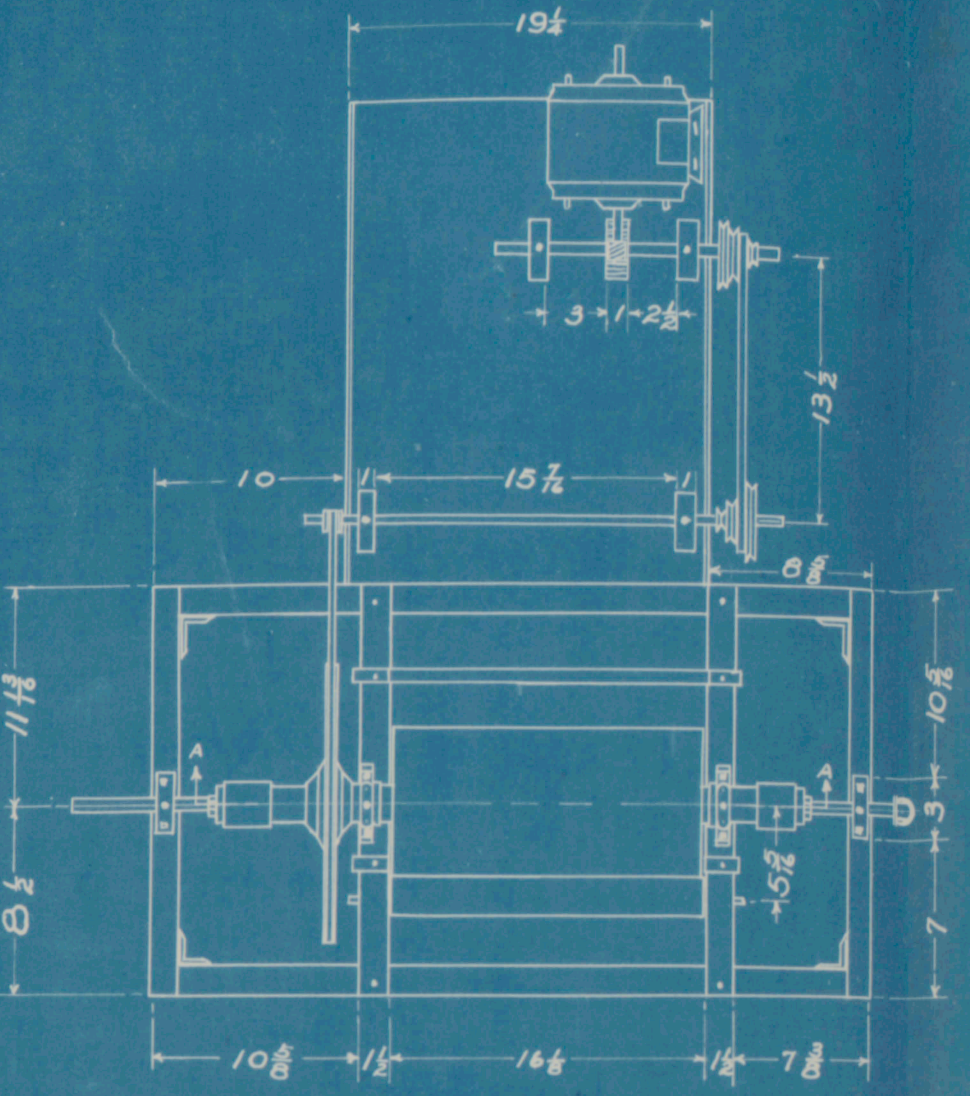
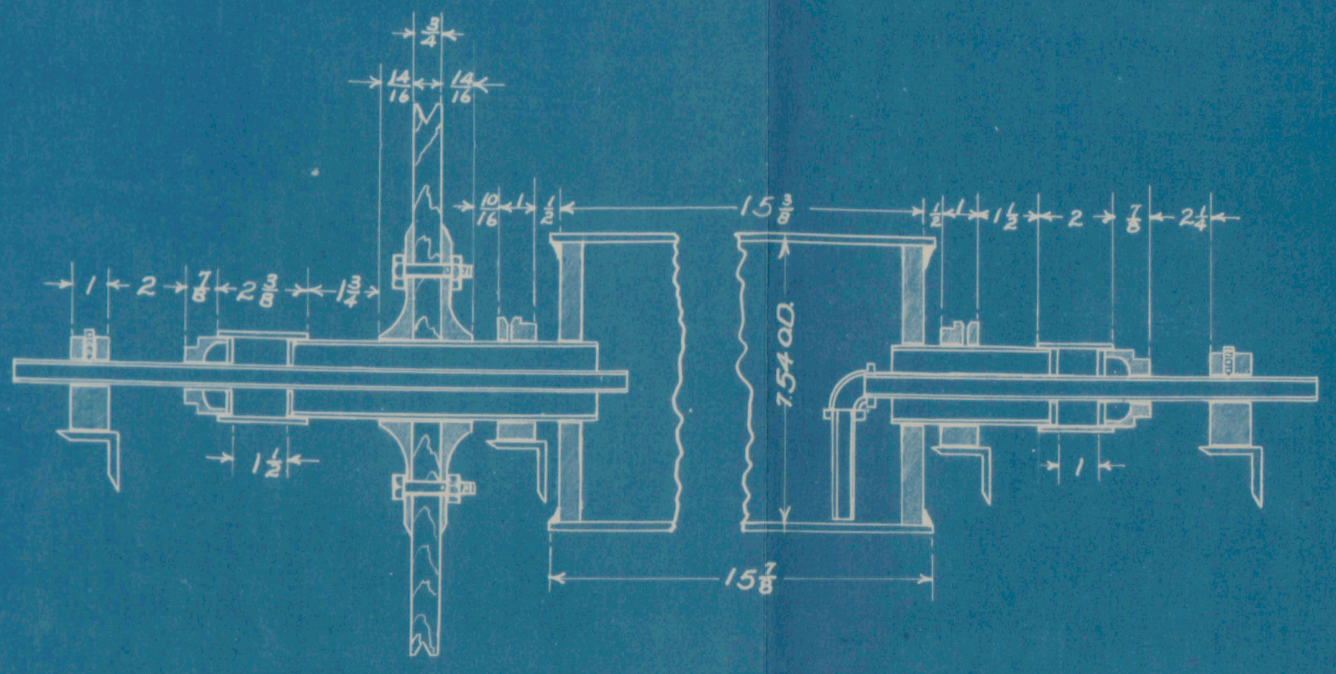
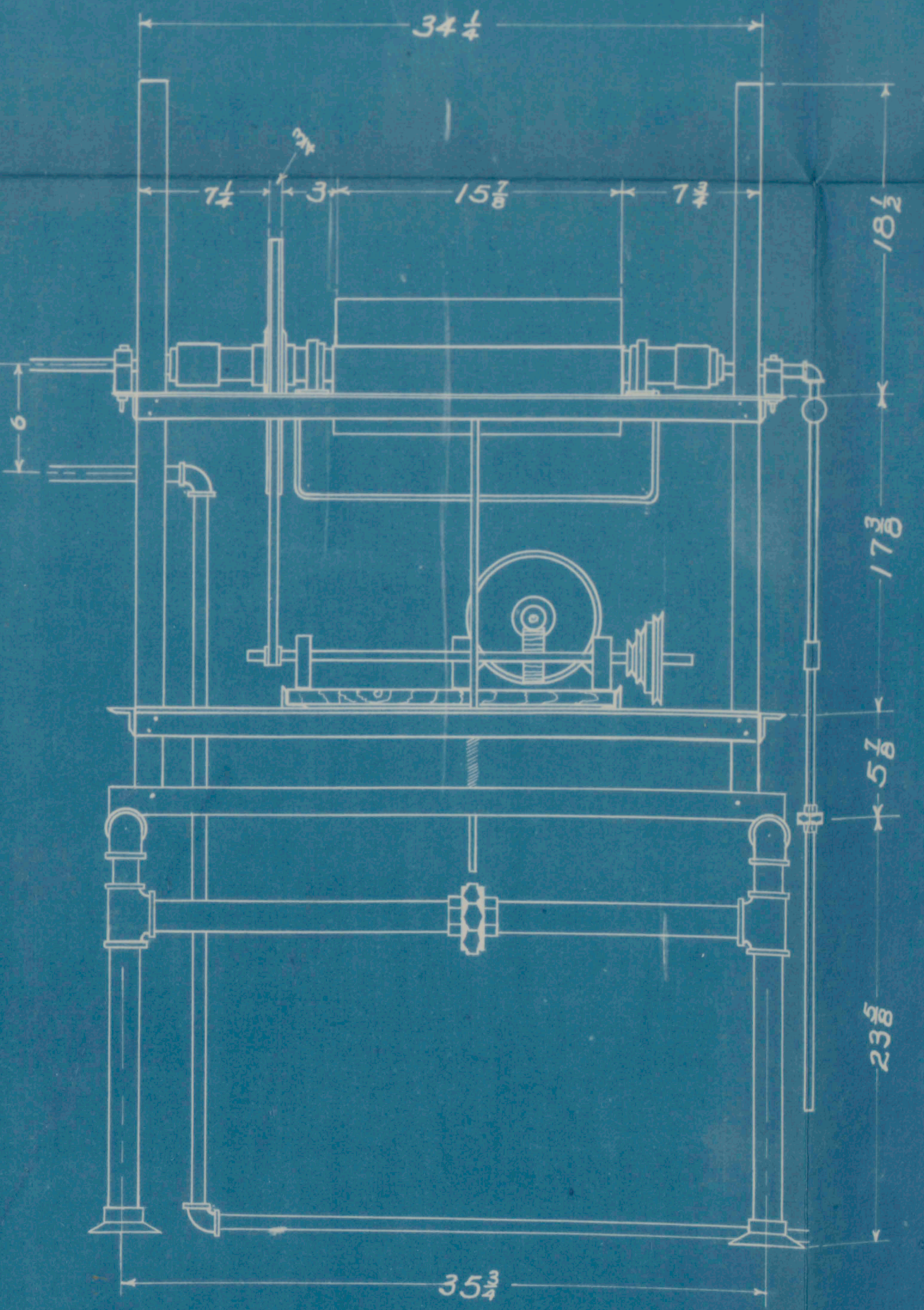


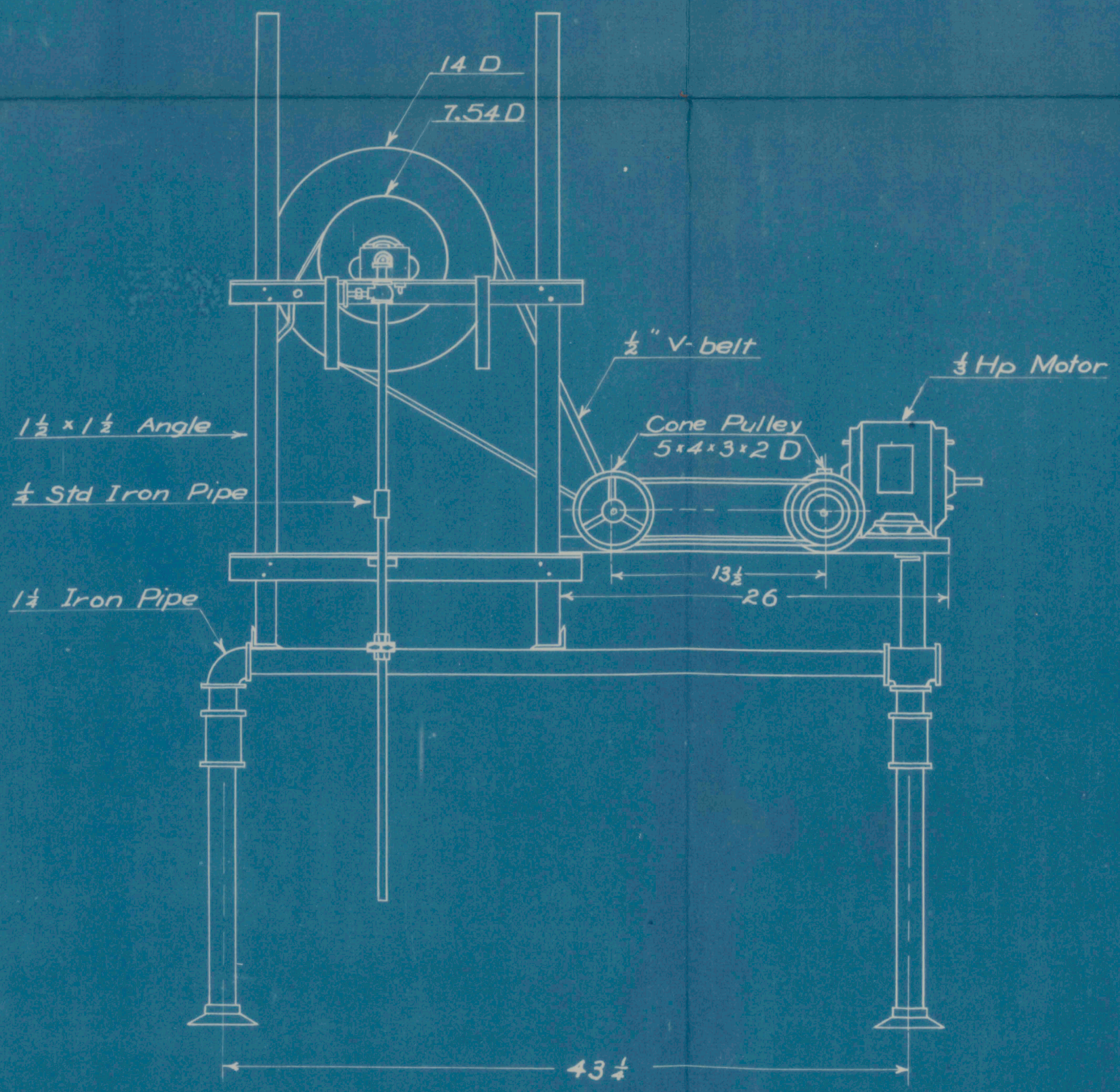
Figure 6





SECTION A-A





DEPARTMENT OF CHEMICAL ENGINEERING
VIRGINIA POLYTECHNIC INSTITUTE
BLACKSBURG, VIRGINIA

SINGLE ROLL ATMOSPHERIC
DRUM DRYER

SCALE	1 inch = 5 inch		
DATE	4-28-40		
DR. BY	Cel	TR. BY	cel
CH. BY	N.B.R.	APP. BY	a.M.C.

3.39 revolutions per minute

2.06 revolutions per minute

The last pulley in this set was a one-inch V-belt aluminum pulley which was connected to the one driving the drum.

Number 6. The V-belt driving the two cone pulleys is numbered six.

Number 7. The bearings were blocks of cast iron through which holes for the shaft to pass were bored. There was also a one-eighth-inch hole bored vertically in order to lubricate the bearing.

Number 8. The V-belt for driving the pulley connected to the drum is standard 0.5 inch fiber belt, 30 inches long. The pulley connected to the drum was machined from three-fourths-inch ply-wood and was 14.00 inches in diameter.

Number 9. The drum was a machined steel pipe, the ends of which were sealed by welding a cast iron flange into them. The diameter of the drum was 7.54 inches and the length 14.24 inches. Standard one and one-quarter-inch steel pipe was screwed into the flanges and used both for support for the drum and as a shaft for turning it as well as the means of entering the steam and removing the condensate. The details of the construction are shown on drawing 4.

Number 10. The bearings that the drum supports turned on were made of cast iron and fitted with a zerk cap for lubricating.

Number 11. The end of the steel pipe was fitted with a coupling. Against the shoulder that the end of the pipe made inside the coupling was a washer that fitted both the inside of the coupling and the outside of the steam or condensate pipe very closely. Into the other end of the coupling was screwed a plug that was drilled to permit the smaller pipe to pass. This plug forced another washer similar to the first tightly against the steam packing. The packing used was standard high pressure Garlock steam packing. The details of the construction are shown on the drawing of the equipment.

Number 12. The cast-iron block that kept the condensate and steam lines centered was similar to the blocks used for number seven except a set screw was threaded into the oil hole. This set screw kept the pipe from revolving with the drum.

Number 13. The steam line was of standard one-half-inch cast-iron pipe.

Number 14. The steam line was bled through the valve marked 14 and allowed to discharge into the drain.

Number 15. The steam was allowed to enter the drum through the valve marked 15. Here the pressure was reduced from the line pressure to the pressure desired inside the drum by throttling the steam through the valve.

Number 16. The condensate was removed from the drum through the valve numbered 16. The end of the line inside the drum had an elbow and a short piece of pipe which just cleared the inside of the drum. This kept a minimum of liquid water inside the drum. The value was partially opened and only the liquid condensate allowed to drain through.

Number 17. The bracket for supporting the feed pan was made of strap iron, one-eighth by one inch. This was bolted to the frame using one-quarter-inch machine bolts.

Number 18. The feed pan was made of medium weight galvanized iron. The seams were soldered and were reinforced by riveting. The dimensions of the pan were:

16 inches wide
4 inches deep
12 inches long

Number 19. In order to put the feed pan under the drum, it was necessary to have sufficient clearance between the supports and the drum. In order to lessen the amount of slurry required to fill the pan to the depth on the drum that was required for the run, the feed pan was supported upon the wooden blocks marked 19.

Number 20. The rod which kept the knife firmly against the drum face was a three-eighths-inch wrought iron. A compression spring was used to furnish the force. The rod was threaded and by turning the nut either way the compressional force of the spring was increased or decreased and this either increased or decreased the pressure with which the knife bore upon the drum face.

Number 21. The knife for removing the dried material from the face of the drum was made of steel and was sharpened on the edge that bore upon the drum face. It was kept in place by screws which held it to a bar. The ends of this bar were held in place by being passed through two holes drilled in the angle iron which supported the drum.

Number 22. The gage for measuring the steam pressure in the drum was located in the line through which the steam passed after being throttled.

This was a standard Bourdon tube gage and was calibrated before any runs were started. The calibration showed the gage to be accurate to within one pound over the range used in the experiment.

Number 23. Several of the runs were run at pressures less than two pounds. When these runs were made the differential mercury manometer, 23, was used.

Number 24. A rubber tube connection was used when the manometer was used to measure the pressure. The steam gage was disconnected and the manometer connection substituted for it.

Drying Oven. The drying oven was manufactured by E. H. Sargent and Company of Chicago. It had a rating of 660 watts using 110 volts. The oven was equipped with a rheostat which easily kept the temperature within one degree of 105° C., which was the temperature used for drying the samples.

Balance. The balance used was manufactured by Seederer-Kohlbusch, Incorporated, of Jersey City, New Jersey. It was a chainomatic and had an accuracy of 0.0002 grams. The weights were weighed against each other and found to be of the same accuracy.

Scales. The scales used were made by the Fisher Scientific Company and sold under the trade name of "Ohaus". It had a maximum capacity of 10 kilograms. The rider was calibrated and accurate to one gram.

5. Experimental Procedure

Preliminary Operations. A 3.5-gallon bucket full of slurry was mixed very thoroughly and about three-fourths of it poured into the feed pan. It was found that the slurry had to be well mixed or lumps would become attached to the drying surface and result in "wet spots". The steam was introduced to the drum up to the pressure for the run and then the drum started revolving. After about thirty minutes, when it was assumed that the feed had reached a constant temperature and the material coming off the drum appeared constant, the run was started.

After each run was finished the steam pressure was immediately changed and about five minutes after it had become constant, the next run was started.

Steam. The steam that came to the dryer was not dry and in order to remove the condensed water that it contained and to prevent this from causing a higher indicated steam consumption than actually required, the steam line was heavily bled. The weight of the steam used was taken as the weight of condensate which was blown out of the drum. This was collected in a bucket, and, as the weight of the bucket was counter-balanced, only the actual weight of the steam collected was recorded.

Rate of Revolution of the Drum. The rate of revolution of the drum was controlled by the cone pulleys. The rate was held constant for an entire series of steam pressures, then changed, and the series of steam pressures repeated. This prevented any variations in the results that may have arisen by alternately changing both steam pressure and rate of revolution and the corresponding longer time required for a state of constant operation.

Concentration of the Slurry. The concentration of the slurry was changed only after the complete data for both drum revolutions and steam pressures had been obtained. This was necessary because the concentration of the slurry was determined by the operating conditions of the drum, and it was hard to duplicate any definite concentration after the slurrys had once been destroyed. The slurrys used were:

1. The minimum concentrates that the drum would dry in a sufficient quantity to accurately weigh for a fifteen-minute run.

2. The maximum concentration that the drum would dry under the steam pressures and rates of revolution that it was possible to use, and

3. Intermediate concentration.

In order to check the concentration and make sure that it was remaining substantially constant for each family of runs, samples of the slurry were taken during each run.

Sampling of the Slurry. When each concentration of slurry was made up an amount greater than required to fill the feed pan was prepared and used to keep the level in the pan constant, compensating for that removed in the drying. One sample of slurry was taken from the feed pan about half way through each run. This sample was taken neither just before nor just after the addition of the new solution.

Sampling of the Dry Product. The samples of the dry product were taken immediately as the material was removed from the drum by the knife. A thin blade spatula was used to pick these off. The spatula was run along the line of contact of the knife and the drum and was held approximately perpendicular to the face of the drum. This removed the material just as it came from the drum face and before it had laid upon the heated knife and dried any there. Only the central two-thirds of the drum face was sampled in order to diminish the end effects of the drum and not obtain samples from the poorer dried material in these regions.

The sample on the spatula was immediately transferred into the sample bottle by pouring it into a funnel and jarring it into the bottle. As soon as sufficient sample had been taken the cover was securely screwed on the bottle.

Analysis of Samples for Moisture. The bottles containing the sample were weighed without removing their covers. They were then dried in a drying oven kept at 105° C. and left for at least seventy-two hours. The time required for constant weight was found to be at least forty-eight hours, the long time being caused by the nature of the sample bottle. After removing from the oven the covers were replaced, the sample reweighed, the bottle cleaned out, and then the empty weight of the bottle taken.

IV. DATA AND RESULTS

1. Data

Drying Rate. The drying rate data and curves are presented consecutively. All moisture contents are given as the ratio of the grams of water in the moist sample to the weight of the sample after drying. Each set of data taken at a constant rate of revolution of the drum and for a definite concentration of the slurry are given on one sheet. The graph following each data sheet is a plot of the data on that sheet.

Capacity and Steam Consumption. The data on the capacity and steam consumption for each run have the run number to correspond to the drying rate data under the same conditions. The bottle numbers here given are the same as given on the data sheet entitled Drying Rate except when the table for the moisture content of the material is given upon the same sheet. The column entitled, grams per hour per square foot, is the value of the total capacity of the dryer divided by the surface drying area between the knife and the solution. The plots of this data are given under the calculations for the capacity. Steam pressures are given in pounds per square inch as read by the gage.

Effect of Liquid Level. The effect of a variation in the depth to which the drum dipped in the slurry is given both upon the moisture content of the material coming from the knife and upon the capacity of the drum and its steam consumption. The plots refer to the data sheet immediately preceding them.

2. Results

Drying Rate

1. Super-Cel. It was impossible to correlate the moisture content of the material coming from the knife with any of the variables of operation. It is undoubtedly a complex function of all of them plus the way the drum is working; i.e., the presence of "wet spots". In general, the moisture content decreased with an increase in steam pressure, increased with a decrease in water content of the slurry, and judging from runs 5-a through 8-a, a decrease in rate of revolution of the drum increases the moisture content of the product. The rate of change of the moisture content with a change in steam pressure was found to be a linear function of the rate of revolution of the drum and to decrease with increasing speed of the drum.

2. Soap. Like the Super-Cel, the moisture content of the soap decreased with increasing steam pressure. The capacities varied oppositely from one another. The moisture content of the material coming from the knife varied with the concentration of the slurry, decreasing rather rapidly with increasing water content until at 6.05 grams H_2O per gram dry soap there is a definite break in the curve. For more dilute solutions than this the product moisture content is but little effected by the concentration of the slurry. The rate of revolution of the drum had a very decided affect upon the moisture content of the product, increasing the speed of the drum greatly increased it. Increasing the rate from 2.06 to 3.33 r. p. m. gave a thick, liquid, product for all of the steam pressures it was possible to obtain.

Steam Consumption

1. Super-Cel. Figure 17 shows that for each run the steam consumption increased with the steam pressure. This curve is misleading because the capacity also increases with increasing steam pressure. A plot of the ratio of grams of steam condensed to the grams of water evaporated against the steam pressure is given on Figure 18. Here it is seen that, in general, increasing the steam pressure decreases the ratio and it would appear that the concentration of the slurry has no effect upon the ratio. On Figure 19 the ratio is plotted against the rate of revolution of the drum, and it is apparent that increasing the rate of revolution greatly decreases the ratio. Figure 20 shows the ratio of the grams of steam condensed to the grams of dry Super-Cel as product plotted against the concentration of the slurry for different steam pressures. This graph shows that the ratio increases linearly with increasing concentration of the slurry and is practically independent of the pressure of the steam used.

2. Soap. When the same ratios as (1) are plotted against the concentration of the feed solution, Figures 21 and 22, it is clear that the ratio increases in direct proportion to the increase in the concentration in both cases. From the data given in Table II for run 10-b, the ratio increases with increasing steam pressure but slightly.

Effect of Liquid Level

1. Super Cel. Although there is a wide variation in the moisture content of the product between different samples it appears, from Figure 23, that the moisture content of the product is independent of the depth to which the drum dips into the solution. On the other hand, the capacity of the drum decreases linearly with increasing depth for all depths greater than about 0.60 inches. For depths less than this, the capacity increases with the increasing depth.

2. Soap. Unlike the Super-Cel the moisture content of the dried soap increased rather rapidly with increasing drum submergence. The maximum in the capacity with change in drum submergence is again obtained and the maximum occurs at the same depth of drum submergence as it did in the case of the Super-Cel. The slope of the two parts of the curve are different from the previous case.

TABLE I

Moisture Content of Material Being Removed
and of
The Slurry Being Dried

Run Number: 1-a

Material: Super-cel

Date: March 19, 1940

Rate of Drum: 10 R.p.m.

Sample Number	Steam Press gage	Sample Source	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
1	5 lb.	Prod.	0.2466	0.0339	0.1374
2	5	Prod.	0.3175	0.0388	0.1222
3	5	Soln.	0.1417	1.2788	9.0250
4	5	Soln.	0.5563	4.7774	8.5800
5	3	Prod.	0.4326	0.0270	0.0625
6	3	Prod.	0.4719	0.0118	0.0262
7	3	Soln.	0.8304	5.5316	6.6600
8	3	Prod.	0.2492	0.0130	0.0522
9	3	Prod.	0.3917	0.0095	0.0243
10	3	Soln.	0.4694	3.9721	8.4800
11	1	Prod.	0.3685	0.0208	0.0565
12	1	Prod.	0.4985	0.0502	0.1008
13	1	Soln.	0.6664	5.2826	7.9300
14	0.5	Soln.	0.4554	0.1559	0.3410
15	0.5	Prod.	0.5706	0.1443	0.2520
16	0.5	Soln.	0.9944	6.8894	6.9300

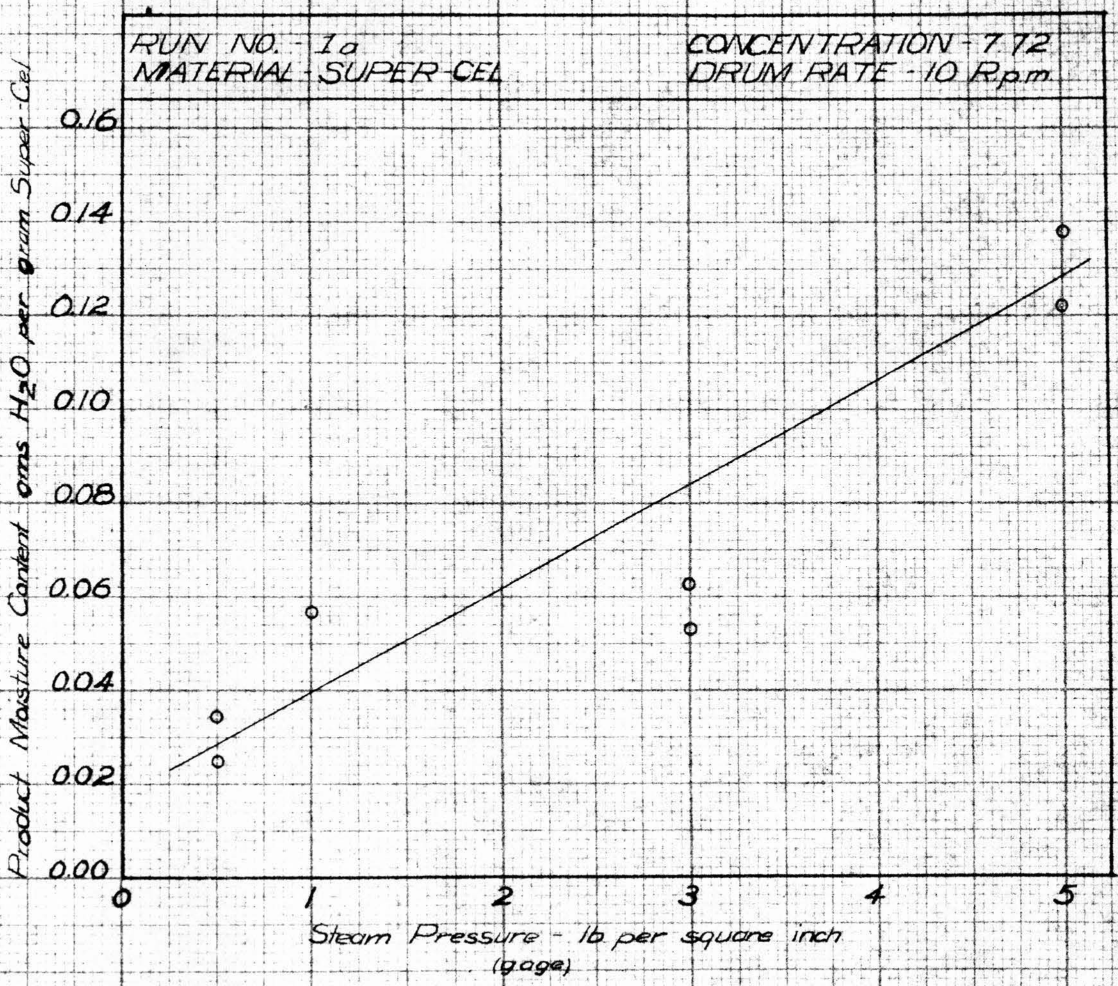


Figure 7 - Effect of Steam Pressure upon Moisture Content of the Product

TABLE II

MOISTURE CONTENT OF MATERIAL BEING REMOVED
and of
THE SLURRY BEING DRIED

Run Number: 2-a
Material: Super-Cel

Date: March 25, 1940
Rate of Drum: 6.04 R.p.m.

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
17	Prod.	1 lb.	0.3517	0.0059	0.01680
18	Prod.	1	0.3287	0.0068	0.02065
19	Soln.	1	9.4023	7.9853	6.69000
20	Prod.	0	0.3921	0.0068	0.01731
21	Prod.	2	0.3644	0.0058	0.15910
22	Soln.	2	1.4168	7.4508	5.26500
23	Prod.	3	0.2992	0.0056	0.01833
24	Prod.	3	0.4323	0.0083	0.01920
25	Soln.	3	1.4122	7.7477	5.45000
26	Prod.	4	0.3118	0.0041	0.01315
27	Prod.	4	0.4008	0.0063	0.01573
28	Soln.	4	1.1116	7.6042	5.39000
29	Prod.	5	0.4831	0.0067	0.01387
30	Prod.	5	0.5527	0.0059	0.01068
31	Soln.	5	7.6742	7.6742	5.39000
32	Prod.	3	0.5918	0.0082	0.01385
33	Prod.	3	0.6136	0.0063	0.01029
34	Soln.	3	1.4534	7.8094	5.36000

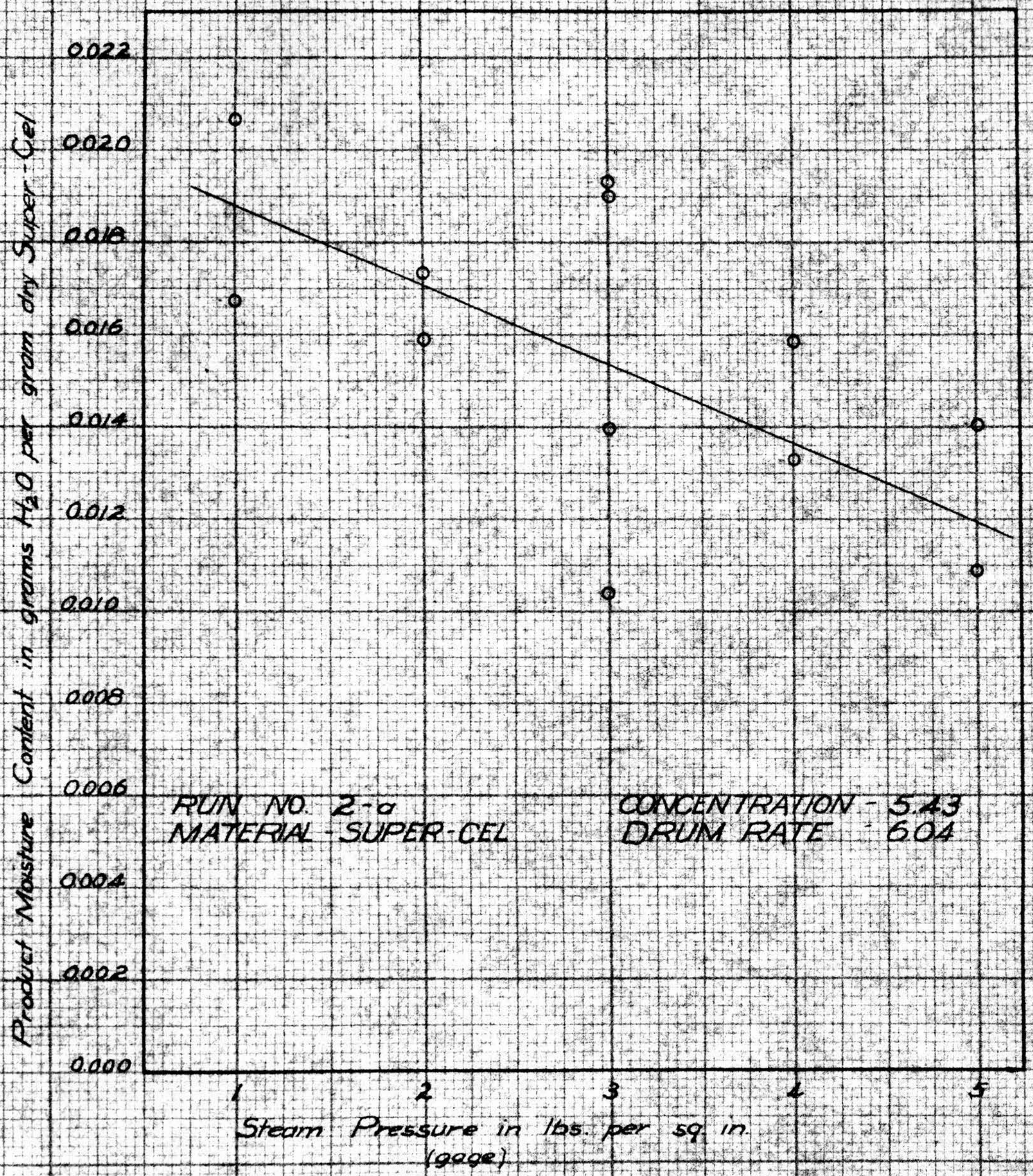


Figure 8 - EFFECT OF STEAM PRESSURE ON MOISTURE CONTENT OF THE PRODUCT

TABLE III

MOISTURE CONTENT OF MATERIAL BEING REMOVED

and of

THE SLURRY BEING DRIED

Run Number: 3-a

Material: Super-Cel

Date: March 30, 1940

Rate of Drum: 10 R.p.m.

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
35	Prod.	2 lb.	0.2598	0.0146	0.0562
36	Prod.	2	0.2890	0.0236	0.0816
37	Soln.	2	1.6672	7.7991	4.6800
38	Prod.	2	0.6153	0.3275	0.5300
39	Prod.	3	0.2814	0.0261	0.0929
40	Prod.	3	0.2580	0.0100	0.0380
41	Soln.	3	1.6195	7.6458	4.7200
42	Prod.	3	0.2360	0.0625	0.2645
43	Prod.	4	0.4276	0.0069	0.0611
44	Prod.	4	0.4502	0.0060	0.0133
45	Soln.	4	1.5778	7.9367	5.0300
46	Prod.	5	0.4480	0.0034	0.0076
47	Prod.	5	0.4925	0.0051	0.0104
48	Soln.	5	1.6574	7.7930	4.7000
49	Prod.	6	0.3917	0.0032	0.0082
50	Prod.	6	0.4683	0.0070	0.0149

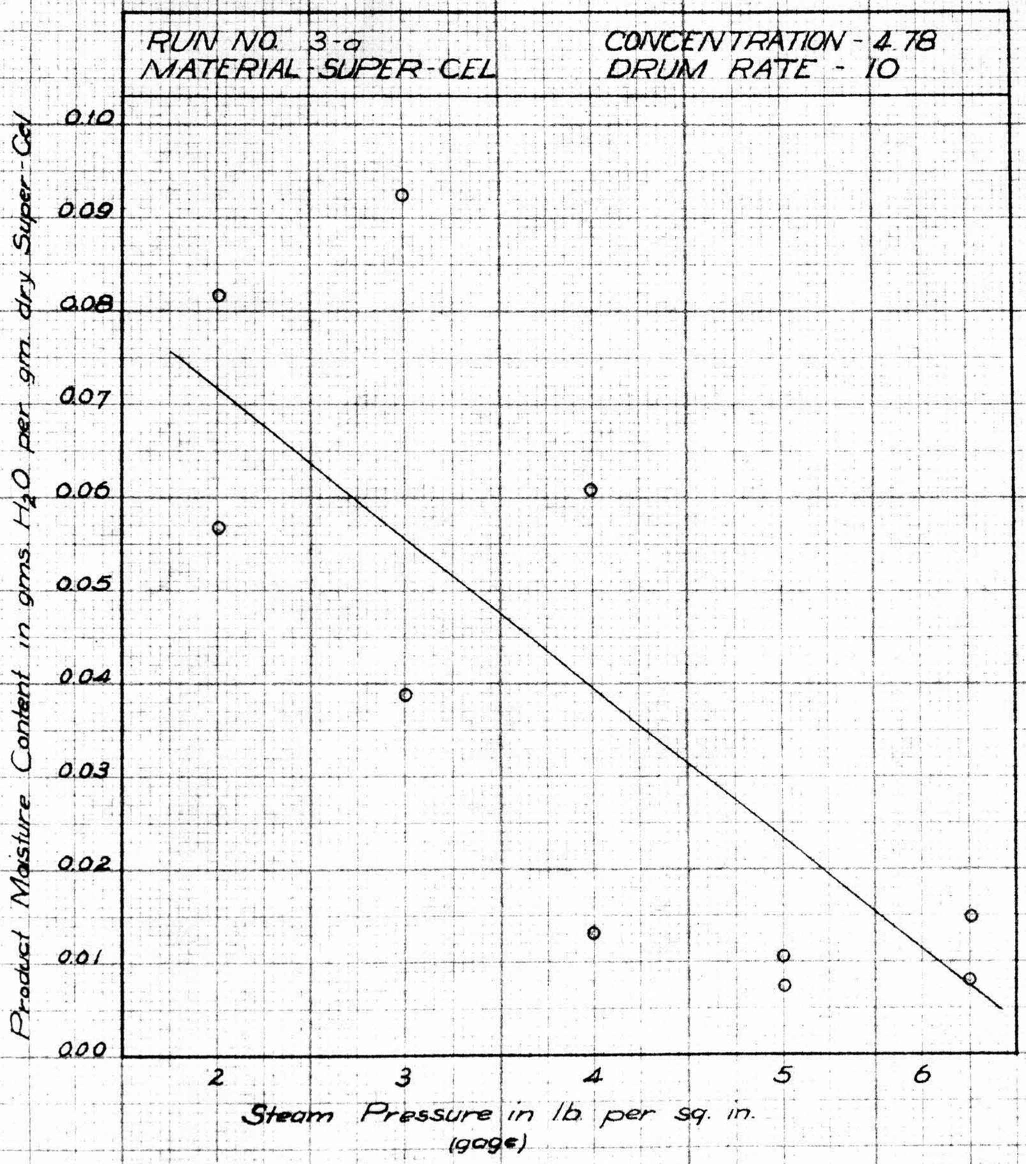


Figure 9 - Effect of Steam Pressure on Moisture Content of the Product

TABLE IV

MOISTURE CONTENT OF MATERIAL BEING REMOVED

and of

THE SLURRY BEING DRIED

Run Number: 4-a	Material: Super-Cel
Date: March 30, 1940	Rate of Drum: 6.04 R.p.m.

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
51	Prod.	2 lb.	0.4861	0.0063	0.0129
52	Prod.	2	0.4680	0.0062	0.0132
53	Soln.	2	1.7967	7.7454	4.3000
54	Prod.	3	0.4964	0.0058	0.0168
55	Prod.	3	0.4318	0.0075	0.0174
56	Soln.	3	1.7687	7.5167	4.2600
57	Prod.	4	0.5741	0.0078	0.0136
58	Prod.	4	0.4197	0.0061	0.0145
59	Soln.	4	1.7271	7.3395	4.2500
60	Prod.	5	0.8038	0.0058	0.0115
61	Prod.	5	0.5355	0.0061	0.0114
62	Soln.	5	1.7522	7.5040	4.2900

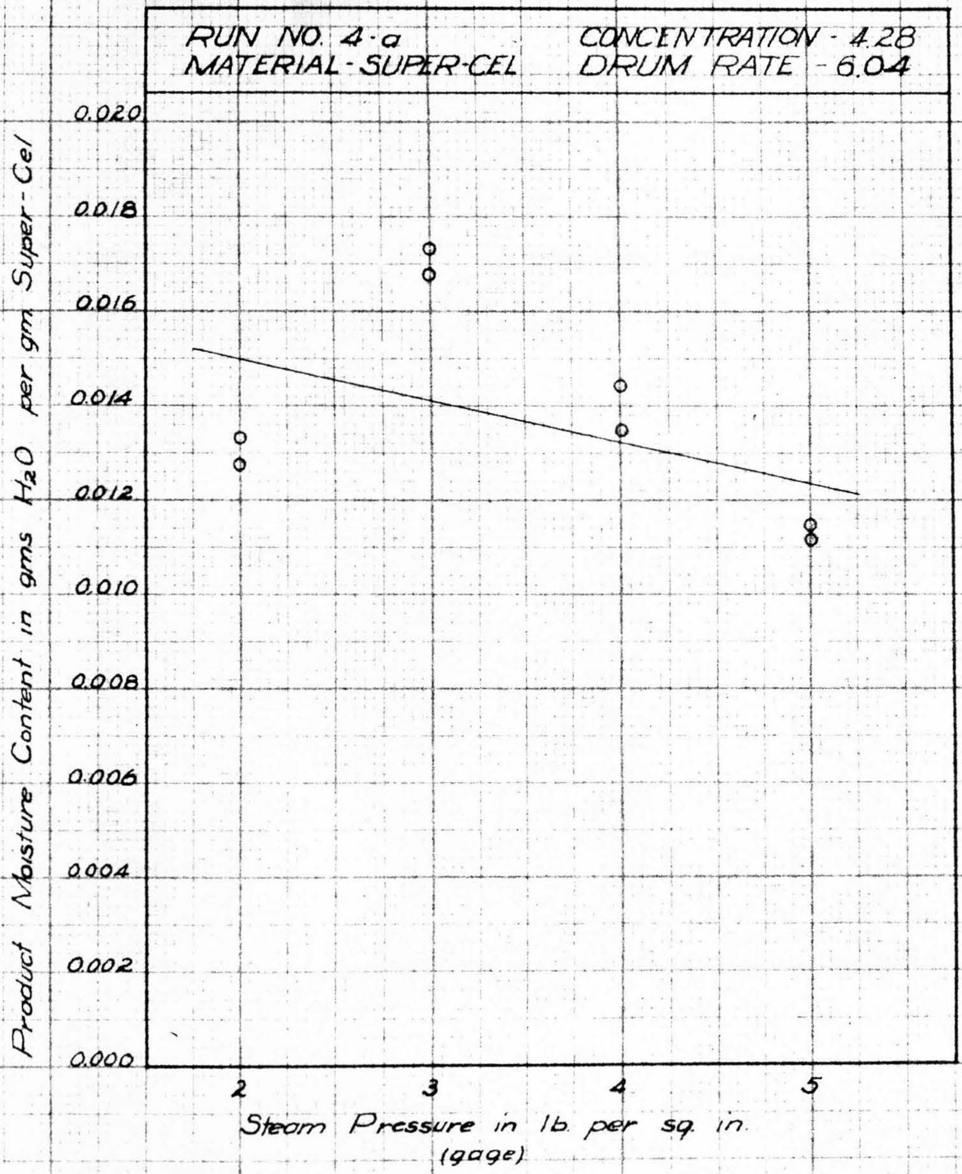


Figure 10 - EFFECT OF STEAM PRESSURE ON MOISTURE CONTENT OF THE PRODUCT

TABLE V

MOISTURE CONTENT OF MATERIAL BEING REMOVED

and of

THE SLURRY BEING DRIED

Run Number: 5-a
Material: Super-Cel

Date: April 1, 1940
Rate of Drum: 3.38 R.p.m.

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
63	Prod.	2 lb.	0.4255	0.0061	0.01431
64	Prod.	2	0.4165	0.0053	0.01271
65	Soln.	2	1.7944	7.8862	4.39000
66	Prod.	3	0.4306	0.0055	0.01276
67	Prod.	3	0.4450	0.0060	0.01349
68	Prod.	4	0.4935	0.0064	0.01297
69	Prod.	4	0.4658	0.0050	0.01072
70	Soln.	4	1.7808	7.3665	4.14000
71	Prod.	5	0.5930	0.0054	0.00914
72	Prod.	5	0.4522	0.0057	0.01260
73	Soln.	5	1.7903	7.8248	4.37000
74	Prod.	6	0.5403	0.0029	0.00536
75	Prod.	6	0.4742	0.0143	0.00302
76	Soln.	6	1.6854	7.5218	4.46000

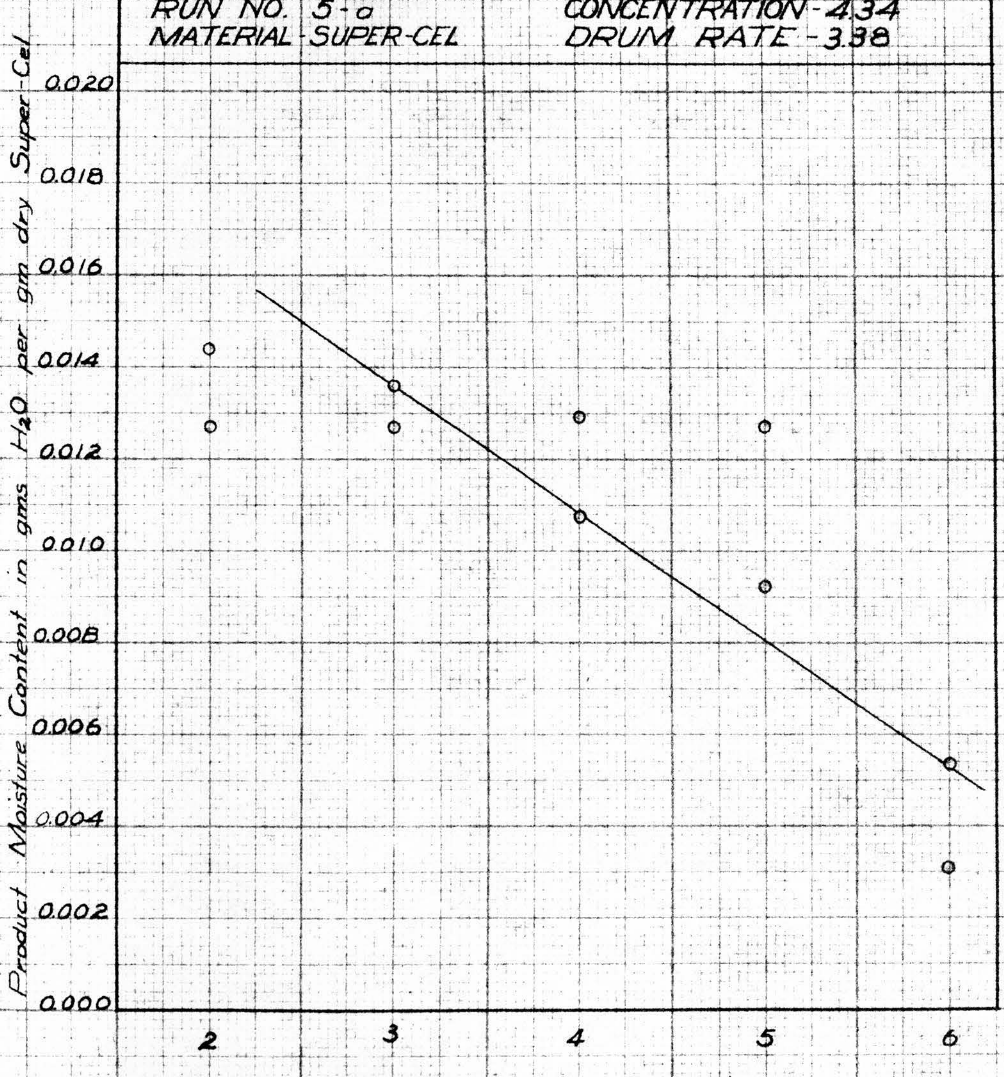


Figure 11 - Effect of Steam Pressure on Moisture Content of the Product

TABLE VI

MOISTURE CONTENT OF MATERIAL BEING REMOVED
and of
THE SLURRY BEING DRIED

Run Number: 6-a

Material: Super-Cel

Date: April 10, 1940

Rate of Drum: 3.38 R.p.m.

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
77	Prod.	5 lb.	0.4072	0.4335	1.0630
78	Soln.	5	2.5349	6.7945	2.6800
79	Prod.	6	0.5202	0.0888	0.1704
80	Soln.	6	2.1249	7.5938	3.5600
81	Prod.	6	0.5570	0.0699	0.1254
82	Prod.	6	0.3763	0.1359	0.5110
83	Soln.	6	2.1050	7.4787	3.5500
84	Prod.	4	0.4107	0.0163	0.0397
85	Prod.	4	0.3680	0.0074	0.0201
86	Soln.	4	1.9496	7.4892	3.8400
87	Prod.	6	0.3805	0.3805	0.0725
88	Prod.	6	0.4315	0.0494	0.1445
89	Soln.	6	2.0876	7.8424	3.7500

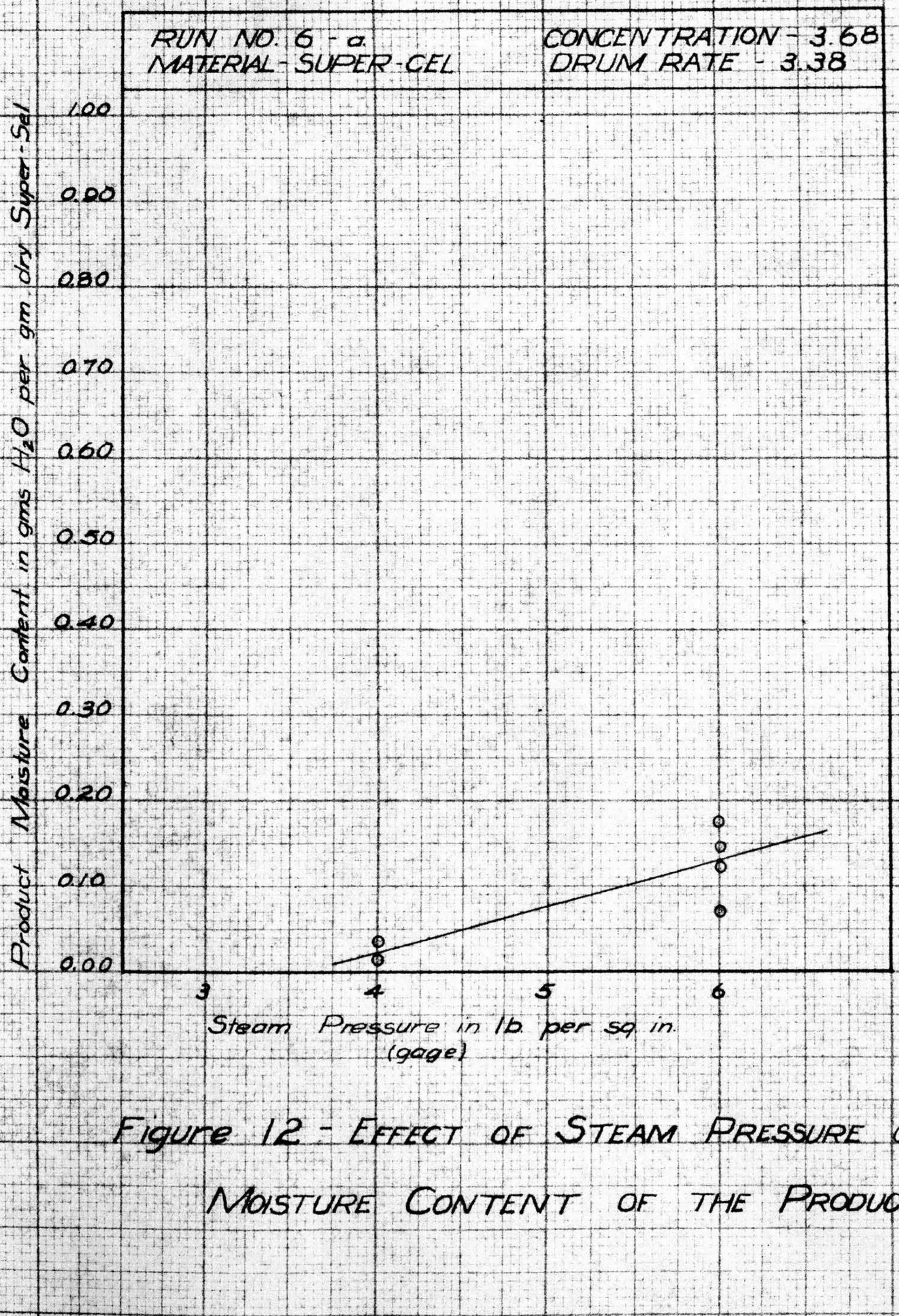


Figure 12 - Effect of Steam Pressure on Moisture Content of the Product

TABLE VII

MOISTURE CONTENT OF MATERIAL BEING REMOVED
and of
THE SLURRY BEING DRIED

Run Number: 7-a Material: Super-Cel

Date: April 10, 1940 Rate of Drum: 3.38 R.p.m.

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
90	Prod.	4 lb.	0.6275	0.8340	1.3280
91	Prod.	4	0.4914	0.7179	1.4600
92	Soln.	4	2.2392	7.3333	3.2700
93	Prod.	5	0.6434	0.4834	0.7500
94	Prod.	5	0.5206	0.2389	0.45800
95	Soln.	5	2.1947	7.3931	3.3700
96	Soln.	5	2.2187	7.5271	3.3900
97	Prod.	6	0.5977	0.5749	0.9620
98	Prod.	6	0.7349	0.9968	1.3560
99	Soln.	6	2.3701	7.6776	3.1900
100	Prod.	4	0.4518	0.0326	0.0719
101	Prod.	4	0.4682	0.0343	0.0733
102	Soln.	4	2.0234	7.4565	3.6900
103	Prod.	7	0.6188	0.6782	1.0980
1o4	Prod.	7	0.5490	0.5983	1.0890
105	Soln.	7	2.1679	7.4119	3.4200

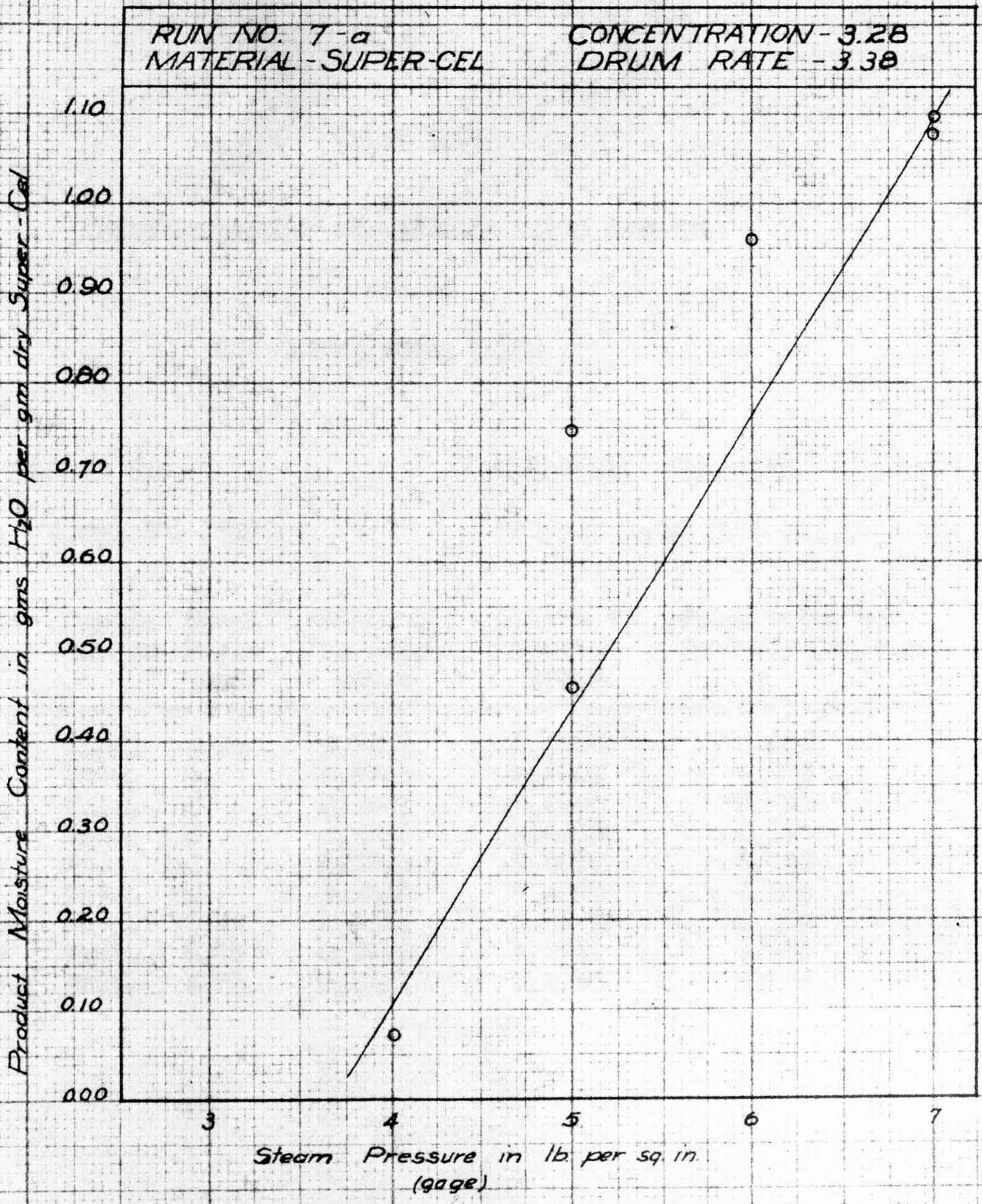


Figure 13 - Effect of Steam Pressure on Product Moisture Content

TABLE VIII

MOISTURE CONTENT OF MATERIAL BEING REMOVED

and of

THE SLURRY BEING DRIED

Run Number: 8-a Material: Super-Cel

Date: April 10, 1940 Rate of Drum: 2.06 R.p.m.

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
106	Prod.	4 lb.	0.7201	0.4204	0.584
107	Prod.	4	0.8745	0.8554	0.979
108	Soln.	4	2.5477	7.3662	2.890
109	Prod.	6	0.7629	0.4425	0.580
110	Prod.	6	0.9566	0.6321	0.660
111	Soln.	6	2.3049	7.3957	3.200
112	Prod.	6.75	0.8571	0.2244	0.262
113	Prod.	6.75	0.7876	0.2352	0.298
114	Soln.	6.75	2.2649	7.3351	3.240

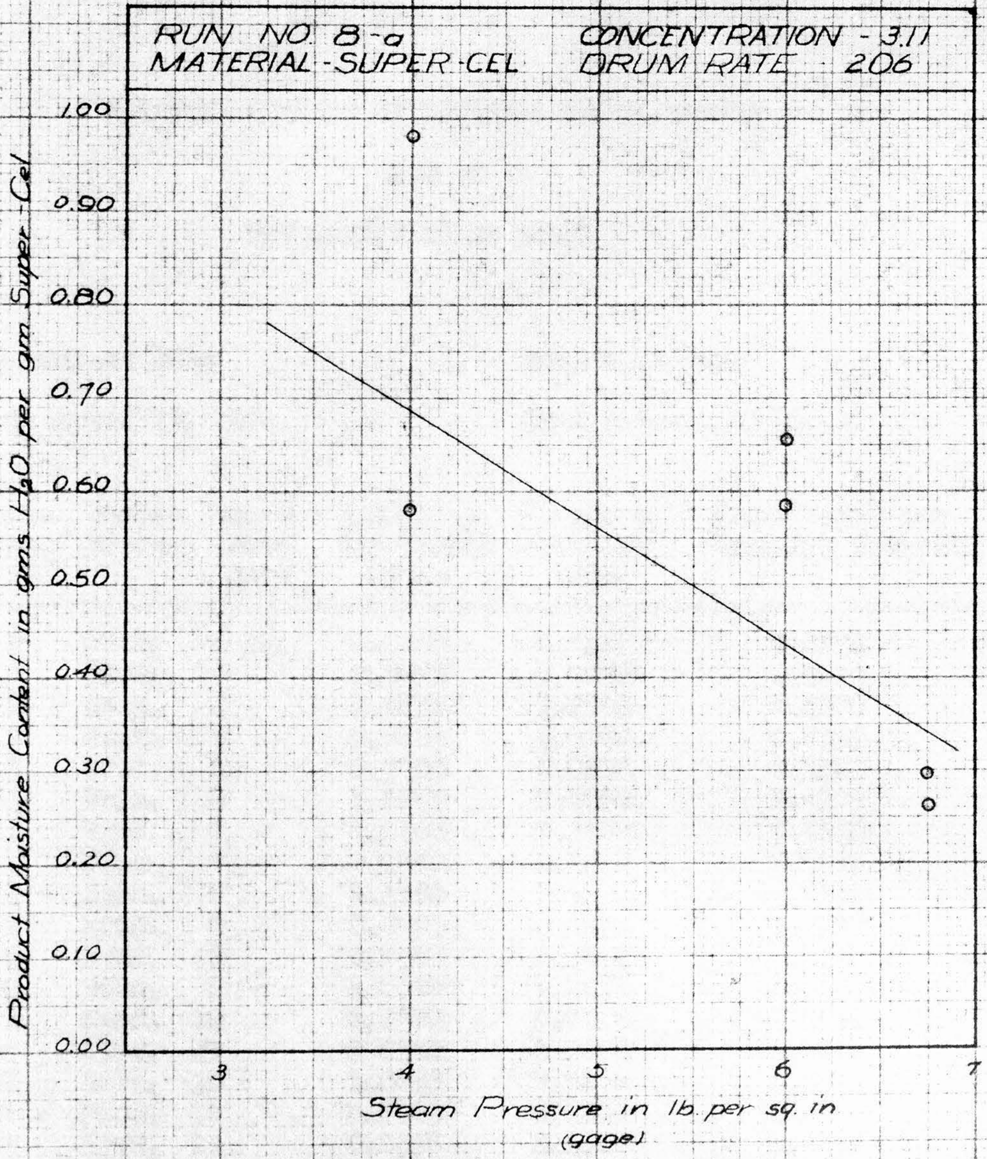


Figure 14 - EFFECT OF STEAM PRESSURE ON MOISTURE CONTENT OF THE PRODUCT

TABLE IX

MOISTURE CONTENT OF MATERIAL BEING REMOVED

and of

THE SLURRY BEING DRIED

Run Number: 10-a — Material: Soap

Date: April 17, 1940 — Drum Rate: 2.06 R.p.m.

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture gram	Grams Water per Gram Dry Material
115	Prod.	8 lb.	0.8921	0.0309	0.0346
116	Prod.	8	0.5445	0.0225	0.0404
117	Soln.	8	1.0756	7.0708	6.5600
118	Prod.	8	0.6421	0.0250	0.0389
119	Prod.	8	0.7785	0.0436	0.0560
120	Soln.	8	1.0977	7.0266	6.4000
121	Prod.	7	1.1192	0.1823	0.1525
122	Prod.	7	0.7470	0.0602	0.0806
123	Soln.	7	1.1190	7.3921	6.6100
124	Prod.	9	0.3986	0.0268	0.0675
125	Prod.	9	0.7492	0.0370	0.0495
126	Soln.	9	1.0899	7.2498	6.6600
127	Prod.	10	0.9989	0.0613	0.0664
128	Prod.	11	0.7122	0.0636	0.0879
129	Soln.	10	1.0895	7.3625	6.6600
130	Prod.	11	0.7422	0.0330	0.0445
131	Prod.	11	0.5635	0.0267	0.0413
132	Soln.	11	1.0852	7.2428	6.6700

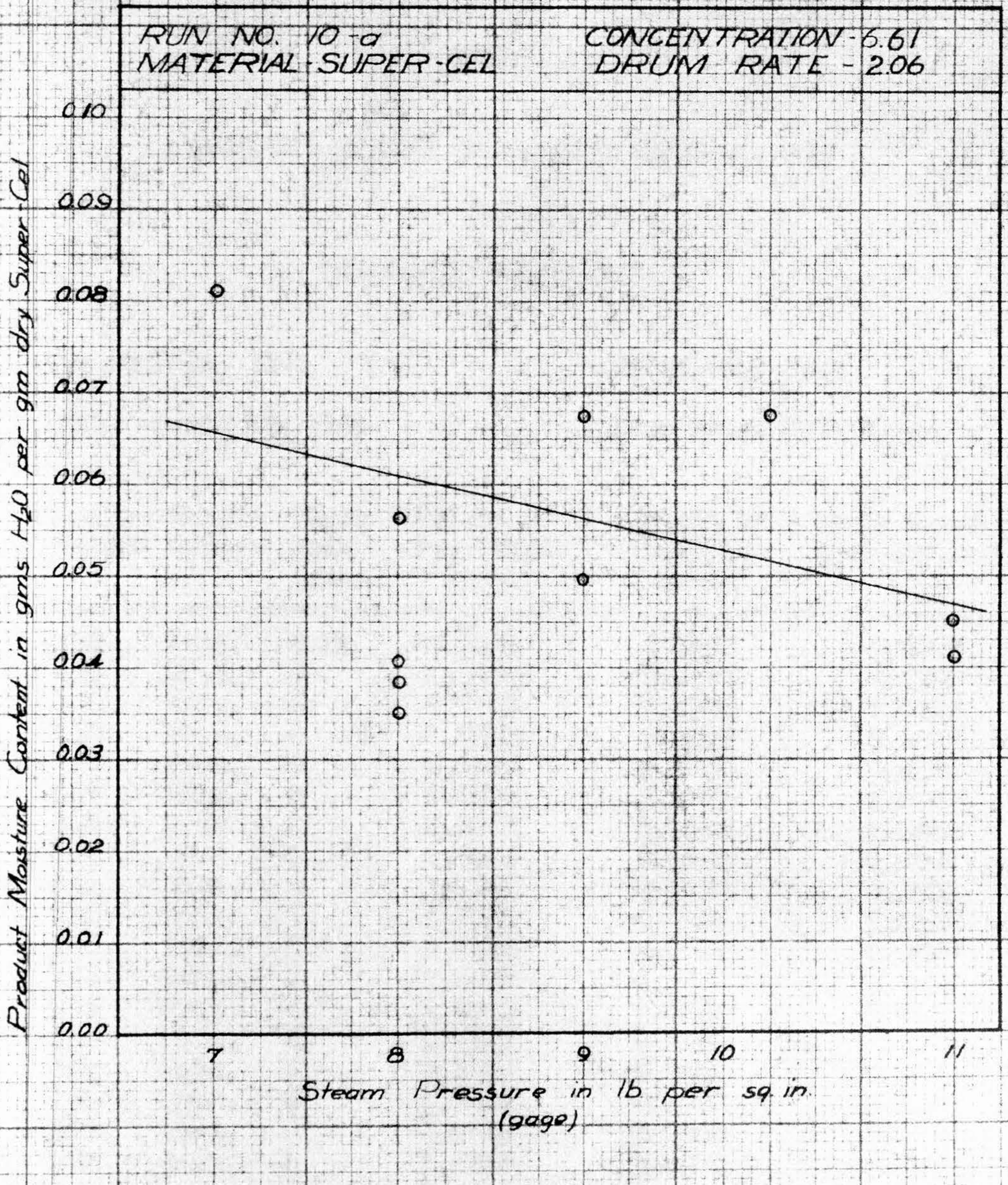


Figure 15 - Effect of Steam Pressure on Moisture Content of the Product

TABLE X

MOISTURE CONTENT OF MATERIAL BEING REMOVED

and of

THE SLURRY BEING DRIED

Run Number: 11-a

Material: Soap

Date: April 18, 1940

Drum Rate: 2.06 R.p.m.

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
133	Prod.	8 lb.	0.7001	0.0262	0.0375
134	Prod.	8	0.7155	0.0279	0.0390
135	Soln.	8	0.7155	7.4745	7.7400
136	Prod.	8	0.9288	0.0277	0.0335
137	Prod.	8	0.9087	0.0343	0.0392
138	Soln.	8	1.0580	7.2731	6.8800
139	Prod.	8	2.3606	0.1024	0.0434
140	Prod.	8	1.8054	0.0841	0.0466
141	Soln.	8	1.0732	7.0327	6.5500
142	Prod.	8	1.3326	0.0651	0.0489
143	Prod.	8	1.2938	0.0605	0.0467
144	Soln.	8	1.1336	6.9969	6.1700
145	Prod.	8	1.5003	0.0992	0.0661
146	Prod.	8	1.7857	0.1472	0.0835
147	Soln.	8	1.1300	6.8873	6.0800
148	Prod.	8	1.5484	0.2783	0.1800
149	Prod.	8	0.9989	0.0958	0.0960
150	Soln.	8	1.2243	6.8603	5.5200

TABLE XI

MOISTURE CONTENT OF MATERIAL BEING REMOVED

and of

THE SLURRY BEING DRIED

Run Number: 12-a Material: Soap

Date: April 18, 1940 Drum Rate: 2.06 R. p. m.

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
151	Prod.	8 lb.	1.2765	0.0396	0.0310
152	Prod.	8	1.7253	0.1126	0.0652
153	Soln.	8	1.1700	6.7564	5.7800
154	Prod.	8	1.7588	0.0590	0.0334
155	Prod.	8	1.7062	0.0552	0.0324
156	Soln.	8	1.1491	7.0542	6.1500
157	Prod.	8	1.4209	0.0520	0.0366
158	Prod.	8	1.5006	0.0714	0.0475
159	Soln.	8	1.1893	7.1624	6.0300
160	Prod.	8	0.9195	0.0428	0.0466
161	Prod.	8	1.0133	0.0523	0.0516
162	Soln.	8	1.1028	6.9339	7.1300
163	Prod.	8	0.4103	0.0209	0.0509
164	Prod.	8	0.5201	0.0268	0.0515
165	Soln.	8	0.9958	7.7696	7.8000
166	Prod.	8	0.9542	0.0366	0.0384
167	Prod.	8	0.9249	0.0271	0.0434
168	Soln.	8	0.9034	7.1275	7.9000

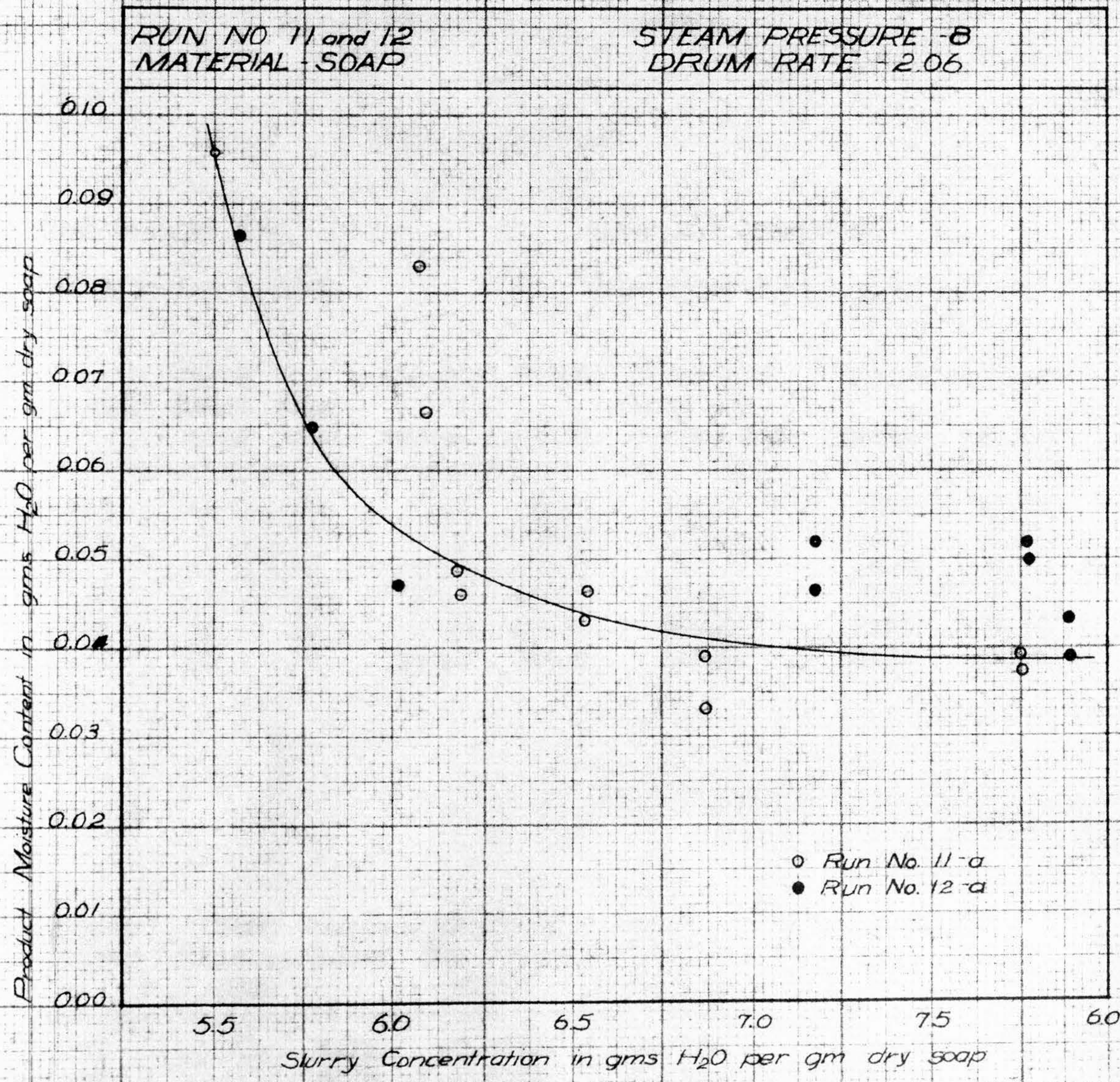


Figure 16 - Effect of Slurry Concentration on Moisture Content of the Product

TABLE XII

SLURRY CONCENTRATION, CAPACITY and STEAM CONSUMPTION

Run Number: 1-b
Material: Super-Cel

Date: March 21, 1940
Drum Rate: 6.04 R.p.m.

Sample Number	Steam Press gage	Run Time min.	Material Dried grams	Material Dried grs/hr	Grams per Hour per Square Foor	Condensed Steam grams	Condensed Steam gms/hr
169	5	15	45.5	182.0	145.0	4489	13,556
170	3	15	34.4	148.6	118.0	2219	8,856
171	2	15	24.2	96.8	77.2	1726	6,904
172	1	15	32.7	130.8	104.0	1783	7,132
173	4	15	34.0	136.0	108.0	2237	8,947
174	4	15	42.2	168.8	135.0	2823	11,252

Sample Number	Steam Press. gage	Sample Source	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
169	5	Soln.	0.5530	5.6677	10.23
170	3	Soln.	0.5984	5.1006	8.53
171	2	Soln.	0.6268	6.1777	9.85
172	1	Soln.	0.8219	6.4721	7.88
173	4	Soln.	0.7270	6.7283	9.26
174	4	Soln.	0.8313	8.1589	9.82

TABLE XIII

SLURRY CONCENTRATION, CAPACITY and STEAM CONSUMPTION

Run Number: 1-c | Material: Super-Gel

Date: March 22, 1940 | Drum Rate: 6.04 R.p.m.

Sample Number	Steam Press gage	Run Time min.	Material Dried grams	Material Dried gms/hr	Grams per Hour per Square Foot	Condensed Steam grams	Condensed Steam gms/hr
175	3	30	19.8	39.6	32.6	2003	4,006
176	3	15	20.0	80.0	63.8	2062	8,248
177	4	15	36.0	144.0	115.0	2921	11,684
178	5	15	40.3	161.2	129.0	29.86	11,944

Sample Number	Sample Source	Steam Press gage	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
176	Soln.	3	0.8942	7.7385	8.66
177	Soln.	4	0.9429	7.8229	8.31
178	Soln.	5	0.8749	8.1378	8.30

TABLE XIV

CAPACITY and STEAM CONSUMPTION

Run Number: 2-b **Material:** Super-Cel

Date: March 25, 1940 **Drum Rate:** 6.04 R.p.m.

Sample Number	Steam Press gage	Run Time min.	Material Dried grams	Material Dried gms/hr	Grams per Hour per Square Foot	Condensed Steam grams	Condensed Steam gms/hr
19	1	15	50.0	200.0	159	3104	12,416
22	2	15	47.4	189.6	151	2081	8,324
25	3	15	64.0	254.0	202	2411	9,644
28	4	15	102.5	410.0	327	2881	11,424
31	5	15	97.0	388.0	309	2942	11,768
32	1	15	33,0	132.0	105	2278	9,112
34	4	15	63.0	252.0	202	2750	11,000

TABLE XV

CAPACITY and STEAM CONSUMPTION

Run Number: 3-b　　Material: Super-Cel

Date: March 30, 1940　　Drum Rate: 10 R.p.m.

Sample Number	Steam Press gage	Run Time min.	Material Dried grams	Material Dried gms/hr	Grams per Hour per Square Foot	Condensed Steam grams	Condensed Steam gms/hr
37	2	15	279	730	633	2507	10,028
41	3	15	216	684	592	3037	12,148
45	4	15	179	716	621	3155	18,620
48	5	15	197	784	679	3380	13,320
50	6	15	211	844	730	3621	14,484

TABLE XVI

CAPACITY and STEAM CONSUMPTION

Run Number: 4-b **Material:** Super-Cel

Date: March 30, 1940 **Drum Rate:** 6.04 R. p. m.

Sample Number	Steam Press gage	Run Time min.	Material Dried grams	Material Dried gms/hr	Grams per Hour per Square Foot	Condensed Steam grams	Condensed Steam gms/hr
53	2	20	106	318	276	2979	8,937
56	3	15	89	356	308	2164	8,656
59	4	15	114	456	395	2563	10,252
62	5	15	126	504	436	2771	11,084

TABLE XVII

CAPACITY and STEAM CONSUMPTION

Run Number: 5-b **Material:** Super-Cel

Date: April 1, 1940 **Drum Rate:** 3.38 R. p. m.

Sample Number	Steam Press gage	Run Time min.	Material Dried		Grams per Hour per Square Foot	Condensed Steam	
			grams	gms/hr		grams	gms/hr
65	2	20	54	162	140	3955	15,820
68	3	15	32	96	83	3270	13,080
70	4	15	39	117	101	2335	9,340
73	5	15	63	189	164	2406	9,624
76	6	15	70	210	182	2528	10,112

TABLE XVIII

CAPACITY and STEAM CONSUMPTION

Run Number: 6-b **Material:** Super-Cel

Date: April 10, 1940 **Drum Rate:** 3.38 R.p.m.

Sample Number	Steam Press gage	Run Time min.	Material Dried grams	gms/hr	Grams per Hour per Square Foot	Condensed Steam grams	gms/hr
78	5	15					
80	6	15					
83	6	15					
86	4	10	143	833	722	2090	12,540
89	6	10	336	1820	1575	2770	14,620

TABLE XIX

CAPACITY and STEAM CONSUMPTION

Run Number: 7-b **Material:** Super-Cel

Date: April 10, 1940 **Drum Rate:** 3.38 R. p. m.

Sample Number	Steam Press gage	Run Time min.	Material Dried		Grams per Hour per Square Foot	Condensed Steam	
			grams	gms/hr		grams	gms/hr
92	4	5					
95	5	6					
99	6	6	745	3530	3060	1930	19,300
105	7	6	702	3350	2906	1655	16,550

TABLE XX

CAPACITY and STEAM CONSUMPTION

Run Number: S-b	Material: Super-Cel
Date: April 10, 1940	Rate of Drum: 3.11 R. p. m.

Sample Number	Steam Press gage	Run Time min.	Material Dried		Grams per Hour per Square Foot	Condensed Steam	
			grams	gms/hr		grams	gms/hr
108	4	6	437	2450	2122	1563	15,630
111	6	6	318	1961	1700	1603	16,030
114	6.75	6	318	2485	2150	1917	19,170

TABLE XXI

CAPACITY and STEAM CONSUMPTION

Run Number: 10-b **Material:** Soap

Date: April 17, 1940 **Drum Rate:** 2.06 R. p. m.

Sample Number	Steam Press gage	Run Time min.	Material Dried grams	Material Dried gms/hr	Grams per Hour per Square Foot	Condensed Steam grams	Condensed Steam gms/hr
115	8	15	53	221	184	1797	7188
119	8	15	57	228	198	1953	7812
121	7	15	57	228	198	1970	7880
125	9	15	56	224	194	2074	8296
127	10	15	47	188	163	1889	7556
132	11	15	53	212	184	2788	7152

TABLE XXII

CAPACITY and STEAM CONSUMPTION

Run Number: 11-b

Date: April 18, 1940

Material: Soap

Drum Rate: 2.06 R. p. m.

Sample Number	Steam Press gage	Run Time min.	Material Dried grams	Material Dried gms/hr	Grams per Hour per Square Foot	Condensed Steam grams	Condensed Steam gms/hr
134	8	15	25	100	86.9	1484	5,536
137	8	15	40	160	139	1572	6,288
140	8	15	60	240	208	1560	6,240
143	8	15	76	304	264	1514	6,056
146	8	15	83	332	288	1519	6,076
149	8	15	71	284	246	1374	5,496

TABLE XXIII

CAPACITY and STEAM CONSUMPTION

Run Number: 12-b **Material:** Soap

Date: April 18, 1940 **Drum Rate:** 2.06 R. P. M.

Sample Number	Steam Press gage	Run Time min.	Material Dried		Grams per Hour per Square Foot	Condensed Steam	
			grams	gms/hr		grams	gms/hr
152	8	15	67	268	232	1o74	4,296
155	8	15	66	264	229	1459	5,936
158	8	15	67	268	232	1622	6,488
161	8	15	42	168	146	1574	6,296
164	8	15	37	148	148	1694	6,776
167	8	15	26	104	90.2	1626	5,704

TABLE XXIV

GRAMS OF STEAM CONDENSED

per

GRAM H_2O EVAPORATED

(Super-Cel)

Run Number	Concentration of the Slurry	Steam Press	Drum R. p. m.	Grams Steam Condensed per	
				gm. H_2O evap.	gm. dry
1 - b	10.23	5	10	9.12	74.5
	8.53	3	10	8.81	59.6
	9.85	2	10	9.09	71.4
	7.88	1	10	8.69	54.6
	9.26	4	10	8.94	65.8
	9.82	4	10	8.50	66.7
1 - c	8.76	2	6.06	14.43	101.1
	8.31	4	6.06	12.20	81.0
	9.30	5	6.06	9.96	74.0
	8.66	3	6.06	14.90	103.0
2 - b	5.69	1	6.06	13.75	62.1
	5.27	2	6.06	10.45	43.9
	5.47	3	6.06	8.73	37.9
	5.39	4	6.06	6.50	27.9
	6.39	5	6.06	7.06	30.3
	5.36	4	6.06	10.16	43.7
3 - b	4.68	2	10	3.39	13.7
	4.72	3	10	4.34	17.7
	5.03	4	10	5.96	26.0
	4.70	5	10	4.17	17.0
4 - b	4.30	2	6.06	7.51	28.1
	4.26	3	6.06	6.60	24.3
	4.25	4	6.06	6.10	22.5
	4.29	5	6.06	5.92	22.0
5 - b	4.39	2	3.38	26.80	97.7
	4.14	3	3.38	22.30	79.8
	4.37	4	3.38	13.42	51.0
	4.46	5	3.38	12.48	48.2
8 - b	2.89	4	2.06	25.5	6.38
	3.20	6	2.06	29.5	8.17
	3.24	6.75	2.06	27.5	7.71

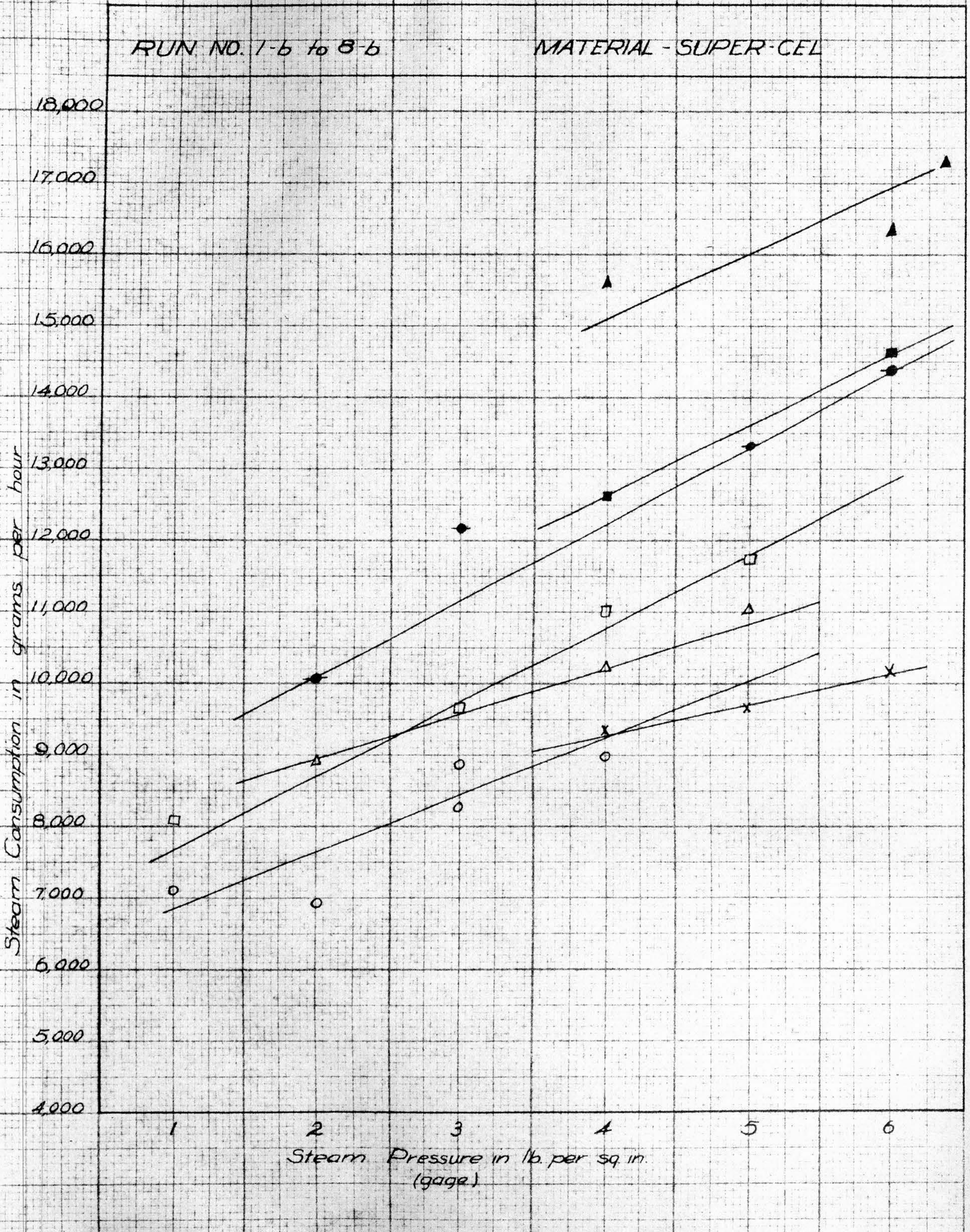


Figure 17 - Variation of Steam Consumption with Steam Pressure

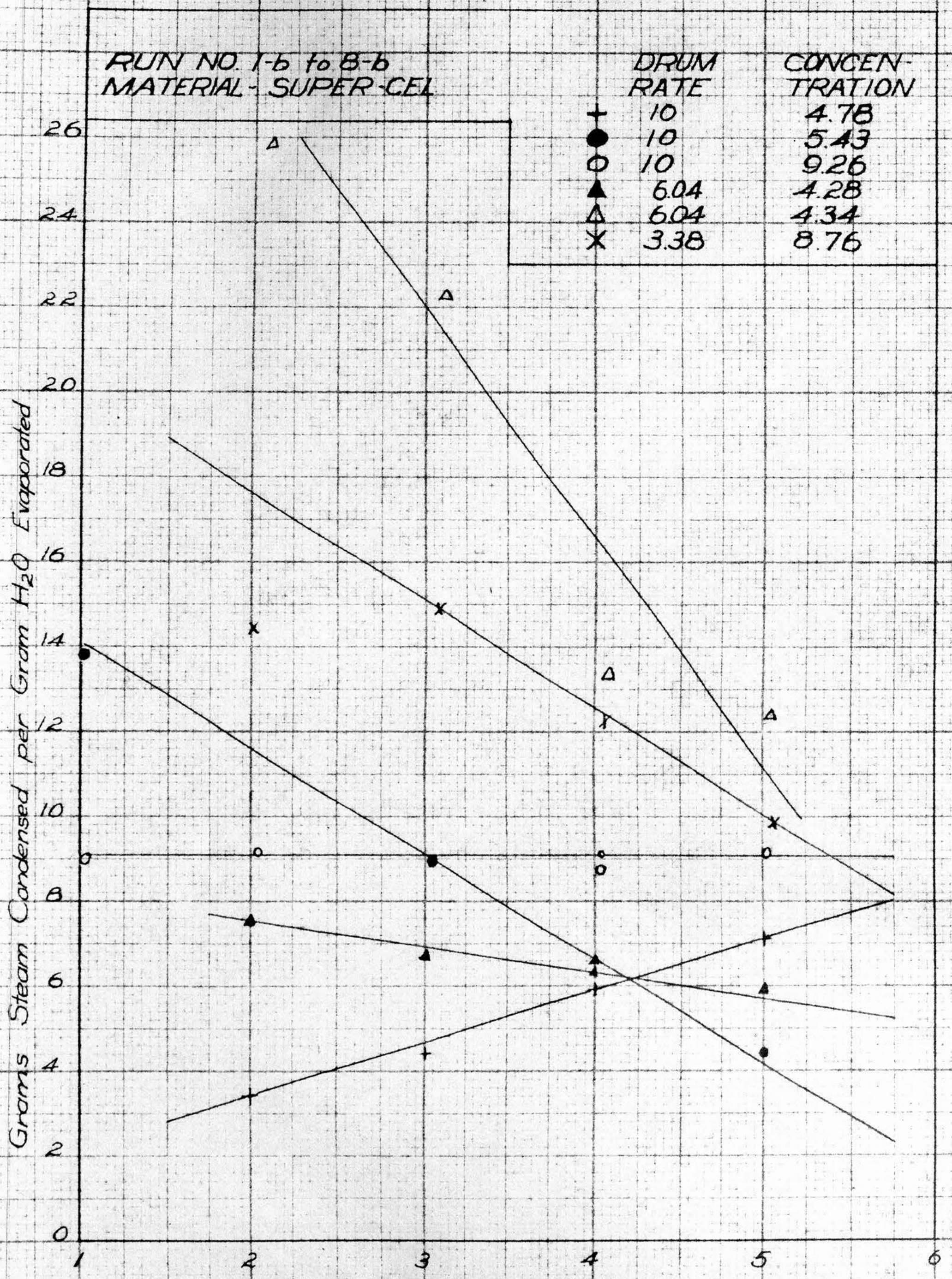


Figure 18 - Effect of Steam Pressure on Ratio of Grams Steam Condensed per Gram H_2O Removed

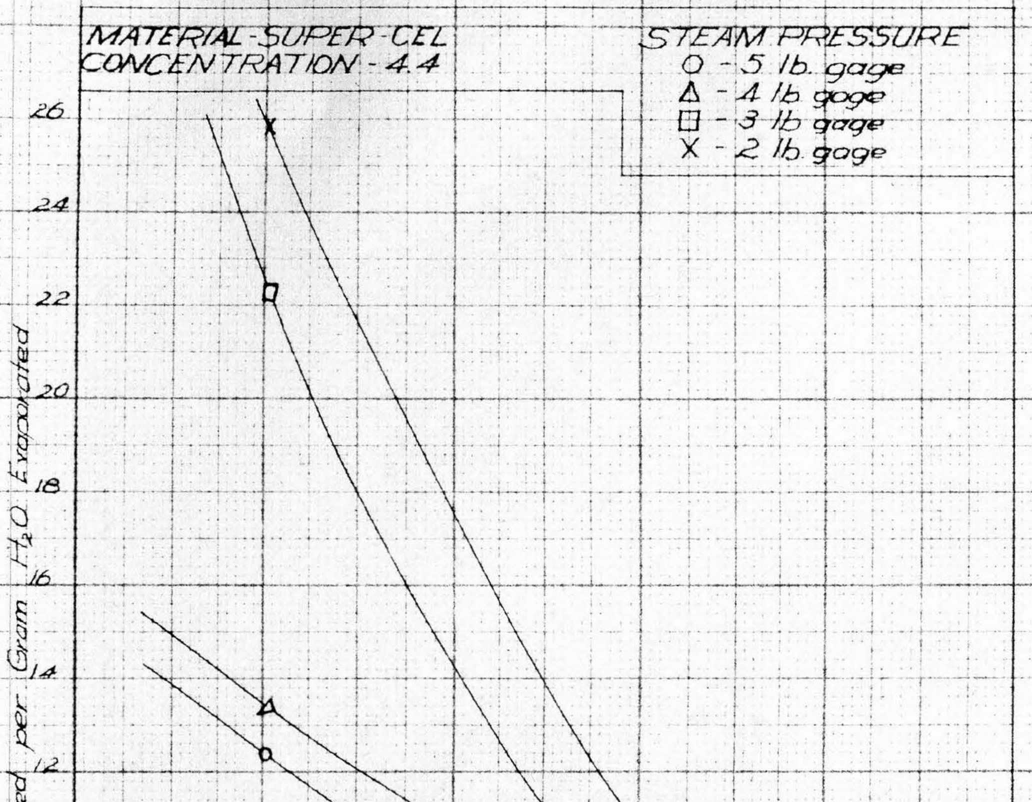


Figure 19 - Effect of Rate of Drum Revolution on Grams Steam Condensed per Gram H_2O Evaporated

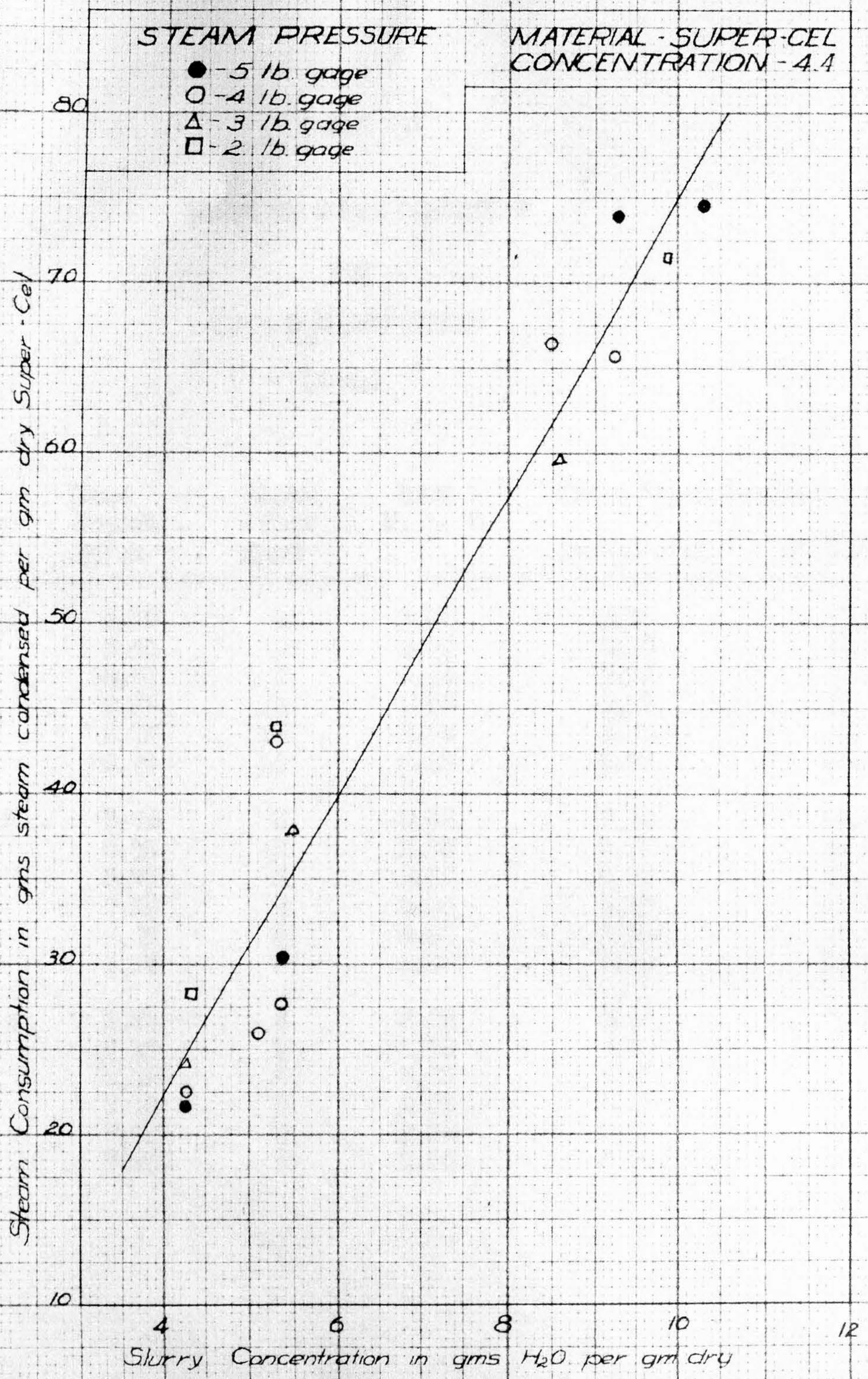


Figure 20 - Effect of Slurry Concentration on the Steam Consumption

TABLE XXV

GRAMS OF STEAM CONDENSED

per

GRAM H_2O EVAPORATED

(Soap)

Run Number	Feed Concen. gm/gm	Steam Press gage	Drum R. p. m.	Grams Steam Condensed per	
				gm H_2O evap.	gm dry soap
10 - b	6.56	8	2.06	5.15	33.8
	6.40	8	2.06	5.35	34.2
	6.61	7	2.06	5.21	34.5
	6.66	9	2.06	5.55	37.0
	6.76	10	2.06	5.95	40.2
	6.76	11	2.06	5.06	33.8
11 - b	7.74	8	2.06	7.15	55.4
	6.88	8	2.06	5.71	39.3
	6.55	8	2.06	3.97	26.0
	6.17	8	2.06	3.23	19.9
	6.08	8	2.06	3.01	18.3
	5.52	8	2.06	3.49	19.3
12 - b	5.78	8	2.06	2.76	16.0
	6.15	8	2.06	3.65	22.4
	6.03	8	2.06	4.01	24.2
	7.18	8	2.06	5.21	37.4
	7.80	8	2.06	5.86	45.7
	7.90	8	2.06	6.95	54.9

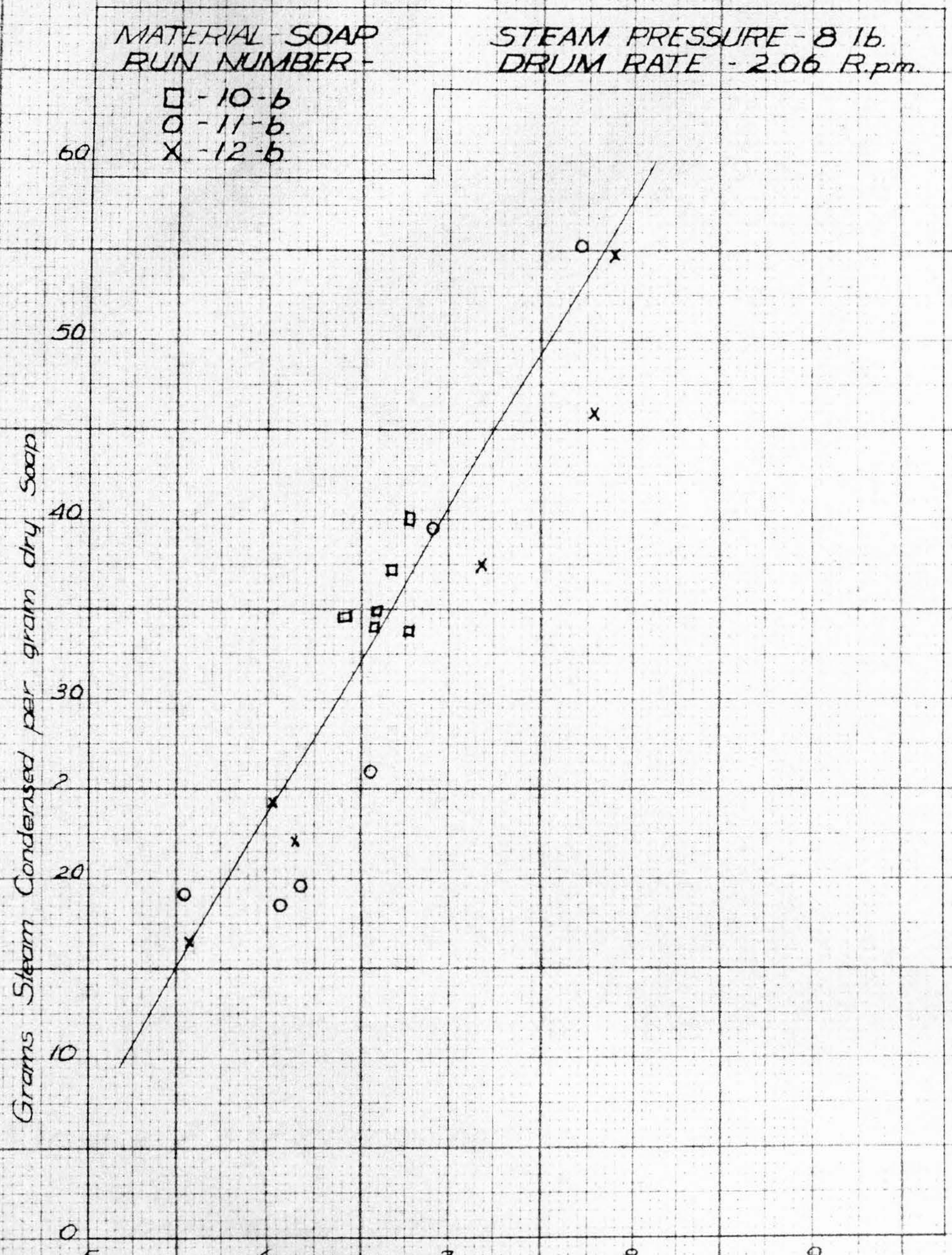


Figure 21 - Effect of Slurry Concentration on Steam Consumption

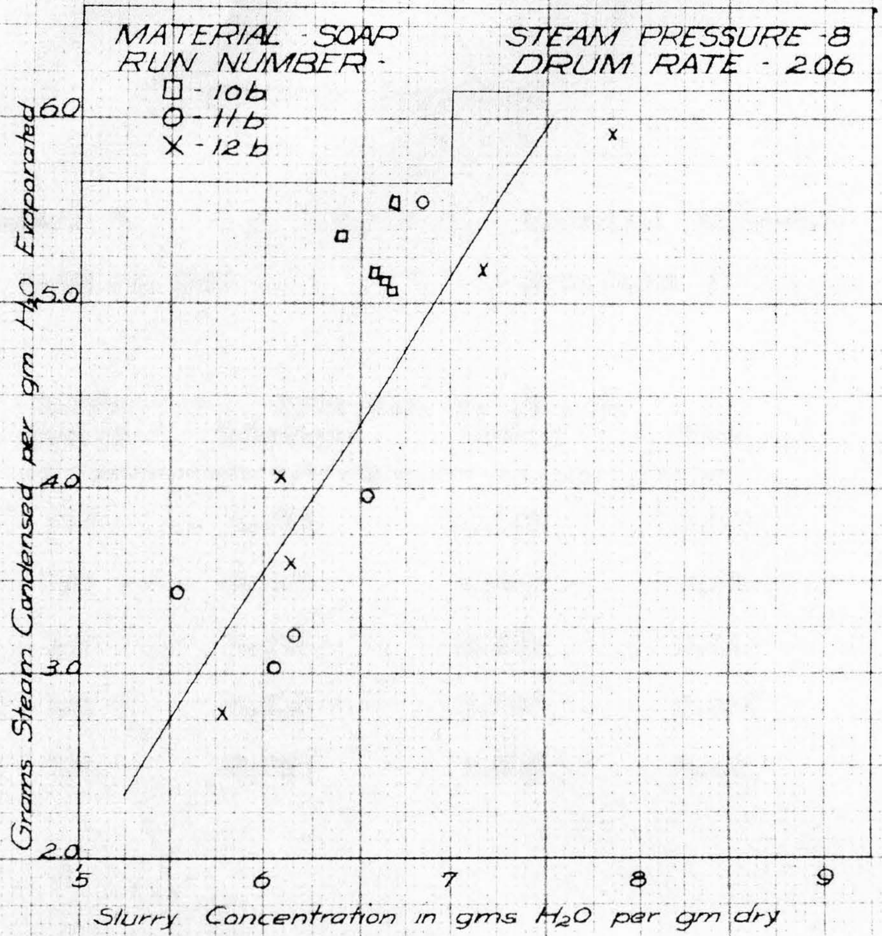


Figure 22 - Effect of Slurry Concentration on Steam Consumption

TABLE XXVI

EFFECT OF LIQUID LEVEL

Run Number: 9 **Material:** Super-Cel

Date: April 13, 1940 **Drum Rate:** 6.04 R.p.m.

Sample Number	Drum Area, sq. ft., as Submerged	Drying	Free
179	0.356	1.448	0.637
184	0.448	1.405	0.590
188	0.525	1.362	0.552
191	0.610	1.322	0.508
194	0.745	1.253	0.441

TABLE XXVII

MOISTURE CONTENT OF MATERIAL BEING REMOVED
and of
THE SLURRY BEING DRIED

Run Number: 9-a

Material: Super-Cel

Date: April 13, 1940

Drum Rate: 6.04 R.p.m.

Sample Number	Sample Source	Drying Area sq. ft.	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
179	Soln.	1.448	1.4159	7.5432	5.33000
180	Prod.	1.448	0.8328	0.0063	0.00755
181	Prod.	1.448	0.9706	0.0095	0.00979
182	Prod.	1.403	0.9565	0.0061	0.00637
183	Prod.	1.403	0.8966	0.0117	0.01303
184	Soln.	1.403	1.5904	7.5541	4.74000
185	Soln.	1.403	1.7631	7.9198	4.49000
186	Prod.	1.362	0.8383	0.0072	0.00859
187	Prod.	1.362	0.8839	0.0112	0.01260
188	Soln.	1.362	1.7087	7.7567	4.55000
189	Prod.	1.322	0.9817	0.0063	0.00643
190	Prod.	1.322	0.8338	0.0065	0.00780
191	Soln.	1.322	1.7912	7.9142	4.43000
192	Prod.	1.253	0.8765	0.0079	0.00900
193	Prod.	1.253	0.7457	0.0131	0.01755
194	Soln.	1.253	1.6827	7.8417	4.65000

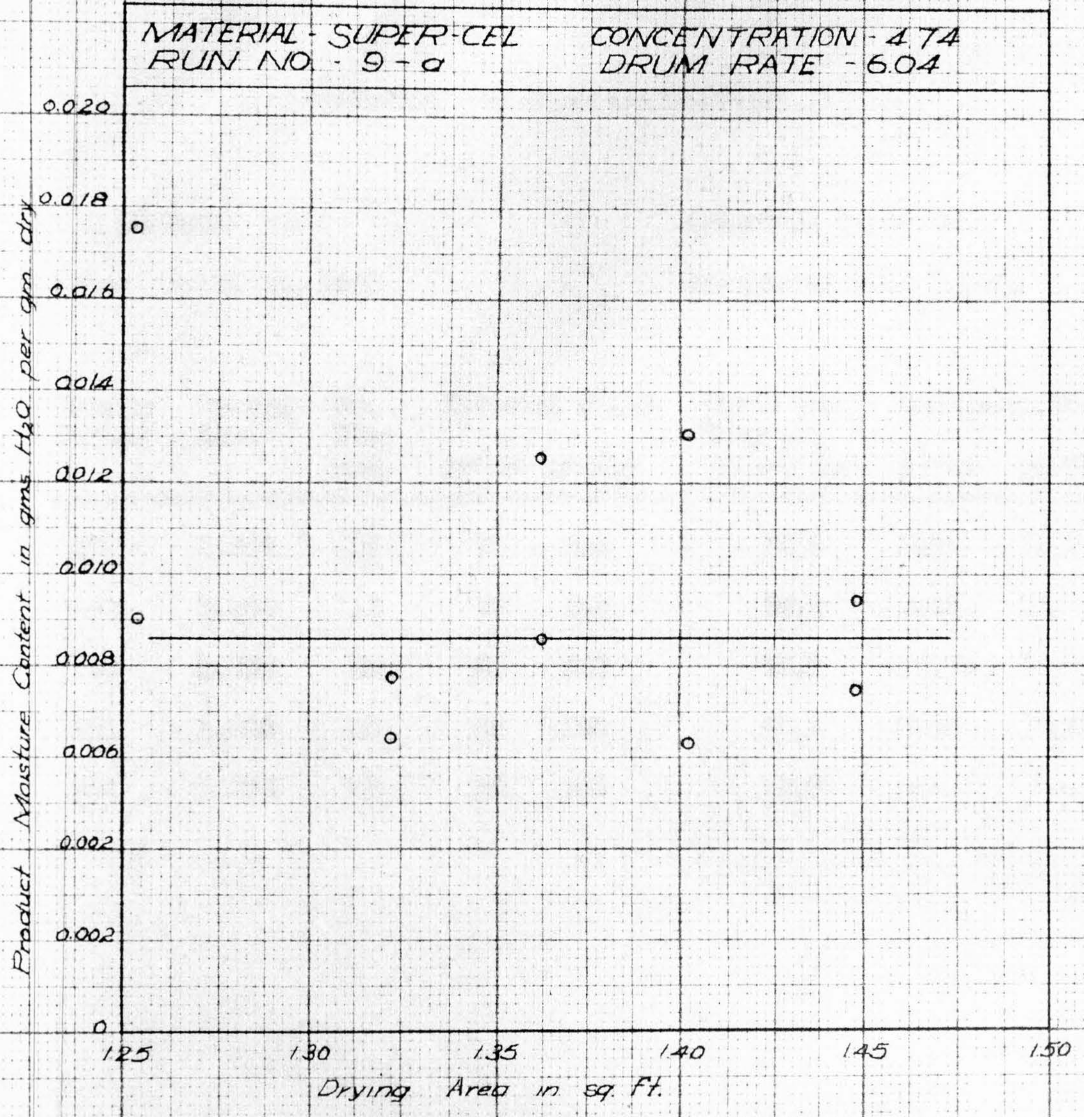


Figure 24 - EFFECT OF DRYING AREA ON PRODUCT MOISTURE CONTENT

TABLE XXVIII

CAPACITY and STEAM CONSUMPTION

Run Number: 9-b | Material: Super-Cel

Date: April 13, 1940 | Drum Rate: 6.04 R.p.m.

Sample Number	Drying Area	Run Time min.	Material Dried grams	Material Dried gms/hr	Grams per Hour per Square Foot	Condensed Steam grams	Condensed Steam gms/hr
179	1.448	15	75	300	85.0	3286	13,544
184	1.403	15	79	316	92.2	3243	12,969
188	1.362	15	60	240	72.1	32.38	12,962
191	1.322	15	49	196	60.6	3140	12,560
194	1.253	15	25	100	32.7	--	--

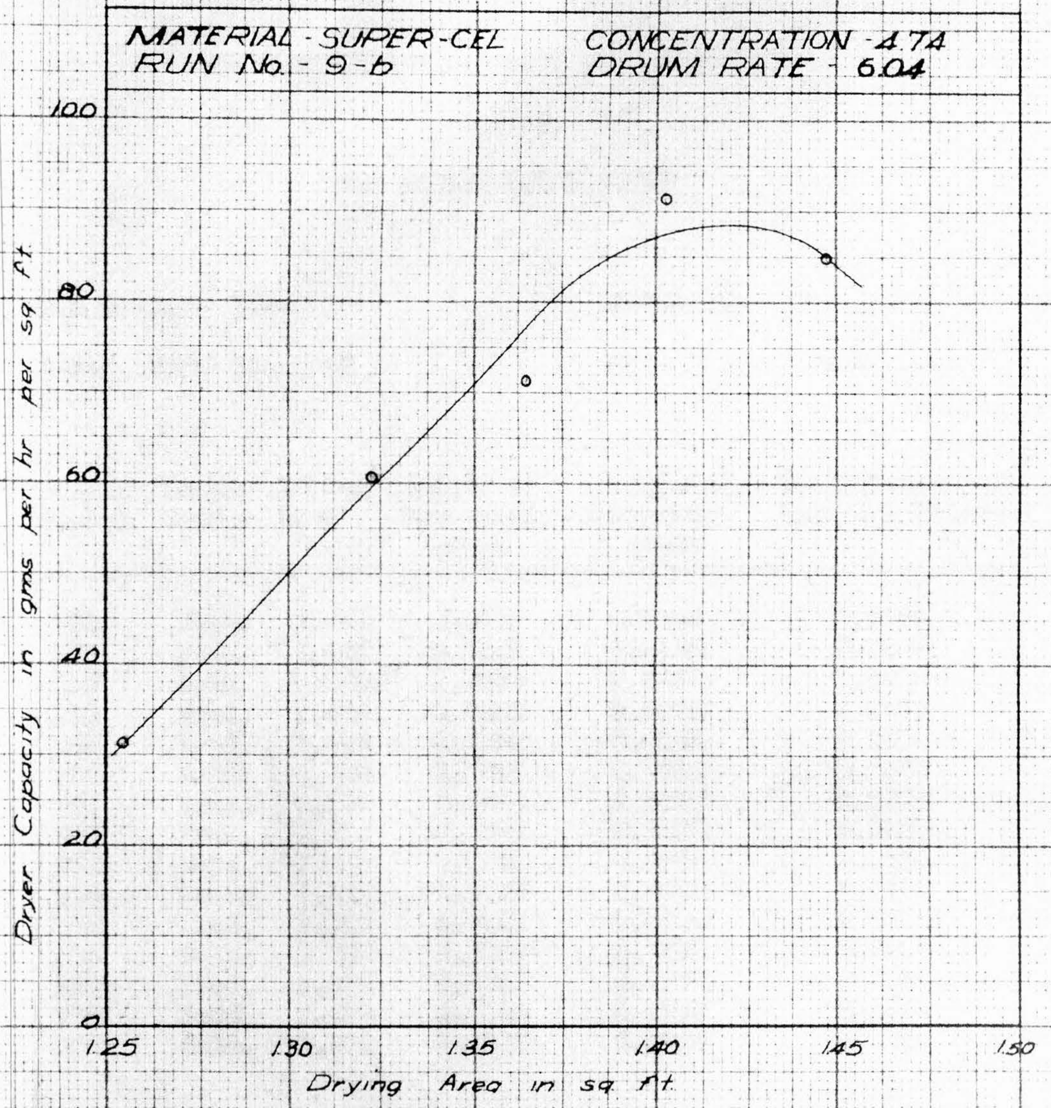


Figure 25 - EFFECT OF DRUM SUBMERGENCE ON DRYER CAPACITY

TABLE XXIX

MOISTURE CONTENT OF MATERIAL BEING REMOVED and of THE SLURRY BEING DRIED

Run Number: 13-a　　　Material: Soap

Date: April 25, 1940　　　Drum Rate: 2.06 R.p.m.

Sample Number	Sample Source	Drying Area	Weight of Dry Sample grams	Weight of Moisture grams	Grams Water per Gram Dry Material
195	Prod.	1.448	0.5712	0.0149	0.0261
196	Prod.	1.448	0.6429	0.0182	0.0283
197	Soln.	1.448	1.3008	6.6344	5.0800
198	Prod.	1.448	0.6326	0.0236	0.0374
199	Prod.	1.448	0.5392	0.0284	0.0527
200	Soln.	1.448	1.2371	6.2862	5.0800
201	Prod.	1.403	0.6554	0.0177	0.0300
202	Prod.	1.403	0.6008	0.0503	0.0838
203	Soln.	1.403	1.2431	6.4300	5.1700
204	Prod.	1.362	0.9649	0.0679	0.0704
205	Prod.	1.362	0.8567	0.0708	0.0826
206	Soln.	1.362	1.2843	6.8893	5.3600
207	Prod.	1.322	0.8815	0.0879	0.0996
208	Prod.	1.322	1.0041	0.0997	0.0994
209	Soln.	1.322	1.2216	6.5464	5.3500

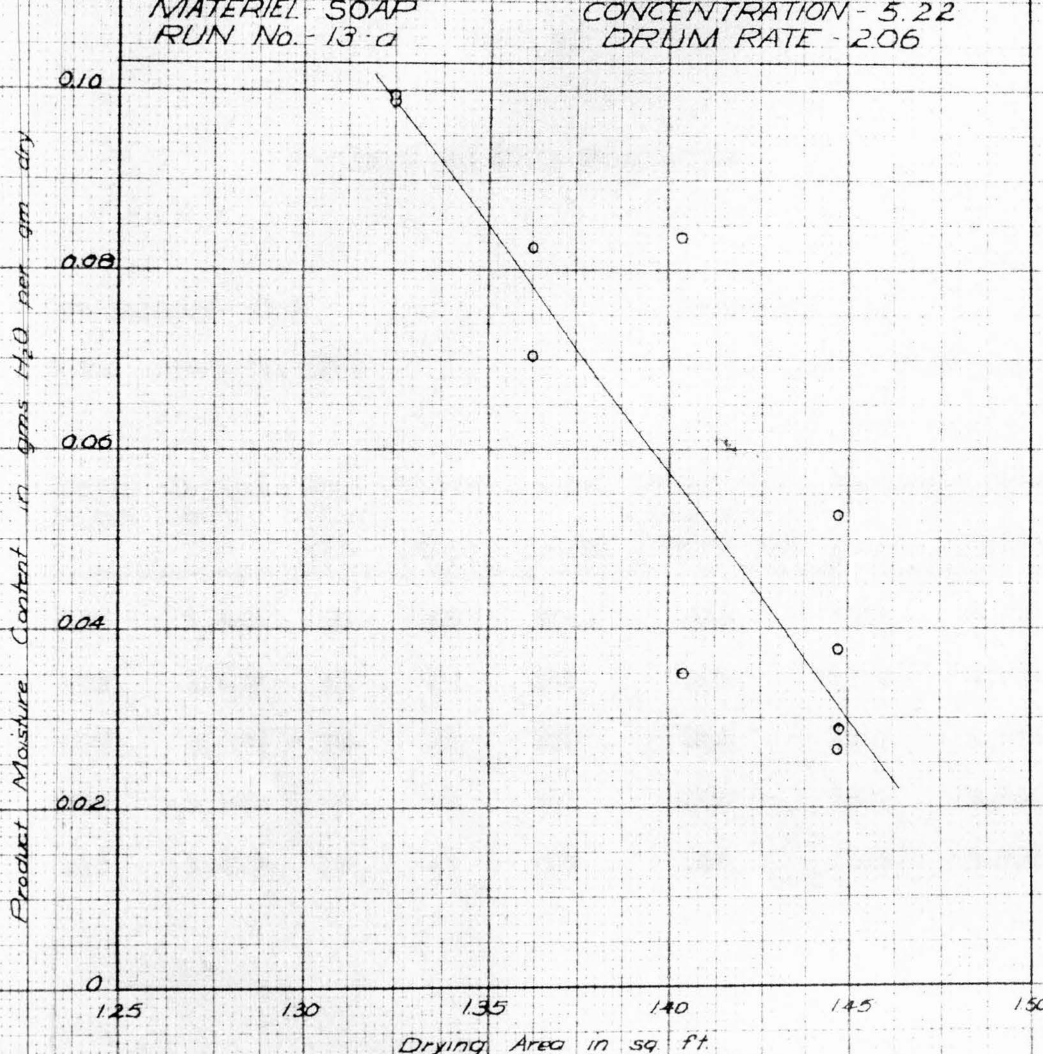


Figure 26 - Effect of Drum Submergence on Product Moisture Content

TABLE XXX

CAPACITY and STEAM CONSUMPTION

Run Number: 13-b | Material: Soap

Date: April 25, 1940 | Drum Rate: 2.04 R.p.m.

Sample Number	Drying Area	Run Time min.	Material Dried grams	Material Dried gms/hr	Grams per Hour per Square Foot	Condensed Steam grams	Condensed Steam gms/hr
197	1.448	15	66	264	229	1890	7,560
200	1.448	15	52	208	180	1119	4,476
203	1.403	15	90	360	312	1731	6,924
206	1.362	15	83	332	288	1691	6,764
209	1.322	15	96	306	266	1625	6,600

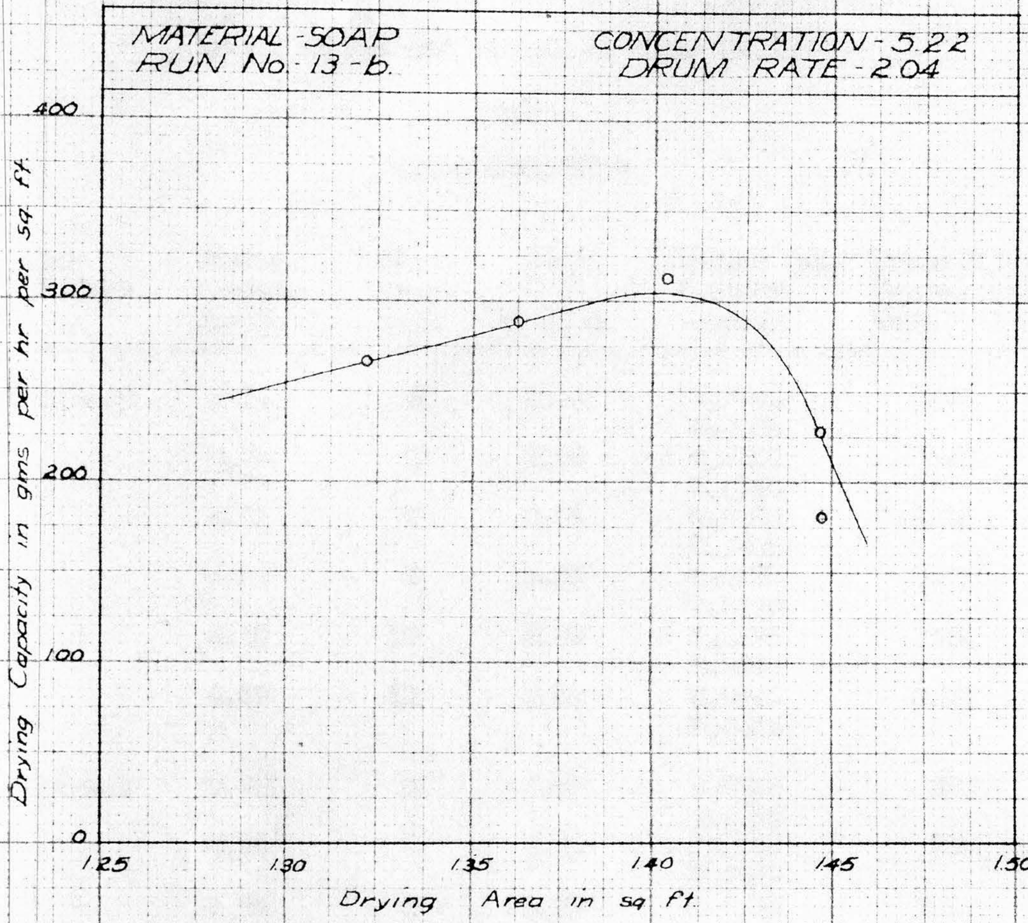


Figure 27 - Effect of Drum Submergence on Dryer Capacity

TABLE XXXII

RATE OF DRYING

(grams of H_2O evaporated per hour per square foot)

and

DRYING CONDITIONS

Run Number	Slurry Concen. gms/gm	Steam Press gage	Drum R. p. m.	Product H_2O Content gms/gm	Grams H_2O per Square Foot per Hour
10-a,b	6.56	8	2.06	0.0346 0.0404	1209
	6.40	8	2.06	0.0389 0.0560	1269
	6.61	7	2.06	0.0806 0.1525	1310
	6.66	9	2.06	0.0675 0.0495	1292
	6.76	10	2.06	0.0879 0.0674	1101
	6.67	11	2.06	0.0445 0.0413	1227
11-a,b	7.75	8	2.06	0.0374 0.0390	672
	6.88	8	2.06	0.0335 0.0392	957
	6.55	8	2.06	0.0434 0.0466	1362
	6.17	8	2.06	0.0489 0.0467	1630
	6.08	8	2.06	0.0661 0.0835	1751
	5.52	8	2.06	0.1800 0.0900	1358
12-a,b	5.79	8	2.06	0.0310 0.0652	1341
	6.15	8	2.06	0.0224 0.0324	1349
	6.03	8	2.06	0.0366 0.0475	1400

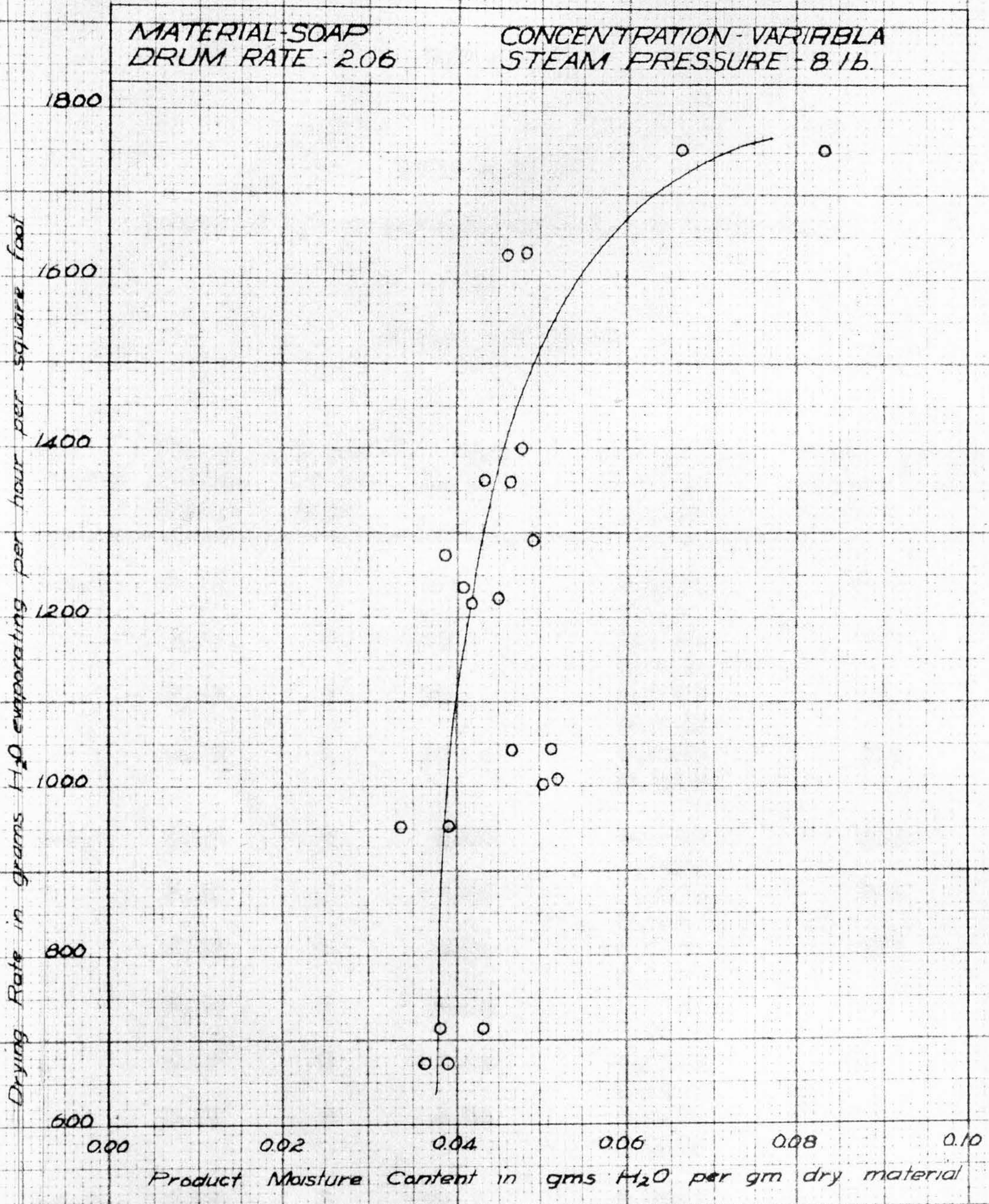


Figure 28 - VARIATION OF DRYING RATE WITH PRODUCT MOISTURE CONTENT

TABLE XXXI

RATE OF DRYING

(grams of H_2O evaporated per hour per square foot)

and

DRYING CONDITIONS

Run Number	Slurry Concen. gms/gm	Steam Press gage	Drum R. p. m.	Product H_2O Content gms/gm	Grams H_2O per Square Foot per Hour
1-a,b	8.58	5	10	0.1374 0.1222	1243
	6.66	3	10	0.0625 0.0262	787
	8.48	3	10	0.0522 0.0243	655
	7.93	1	10	0.0565 0.1008	825
2-a,b	5.68	1	6.04	0.0168 0.0207	903
	5.27	2	6.04	0.0173 0.0159	796
	5.47	3	6.04	0.0188 0.0192	1105
	5.39	4	6.04	0.0132 0.0107	1762
	5.39	5	6.04	0.0139 0.0107	1665
	5.36	3	6.04	0.0139 0.0103	1082
3-a,b	4.68	2	10	0.0562 0.0816	2960
	4.72	3	10	0.0924 0.0388	2795
	5.03	4	10	0.0611 0.0133	3130
	4.70	5	10	0.0076 0.0104	3190
	4.78	6	10	0.0082 0.0149	3490

TABLE XXXI

(Continued)

Run Number	Slurry Concen.	Steam Press	Drum R. p. m.	Product H_2O Content	Grams per Square Foot per Hour
4-a,b	4.30	2	6.04	0.01292 0.0132	1189
	4.26	3	6.04	0.0168 0.0174	1311
	4.25	4	6.04	0.0136 0.0145	1680
	4.29	5	6.04	0.0115 0.0114	1870
5-a,b	4.39	2	3.38	0.0143 0.0127	614
	4.28	3	3.38	0.0128 0.0135	356
	4.14	4	3.38	0.0130 0.0107	418
	4.37	5	3.38	0.0091 0.0126	719
	4.46	6	3.38	0.0054 0.0030	813
8-a,b	2.89	4	2.06	0.584 0.979	6150
	3.20	6	2.06	0.580 0.660	5430
	3.24	6.75	2.06	0.262 0.298	6960

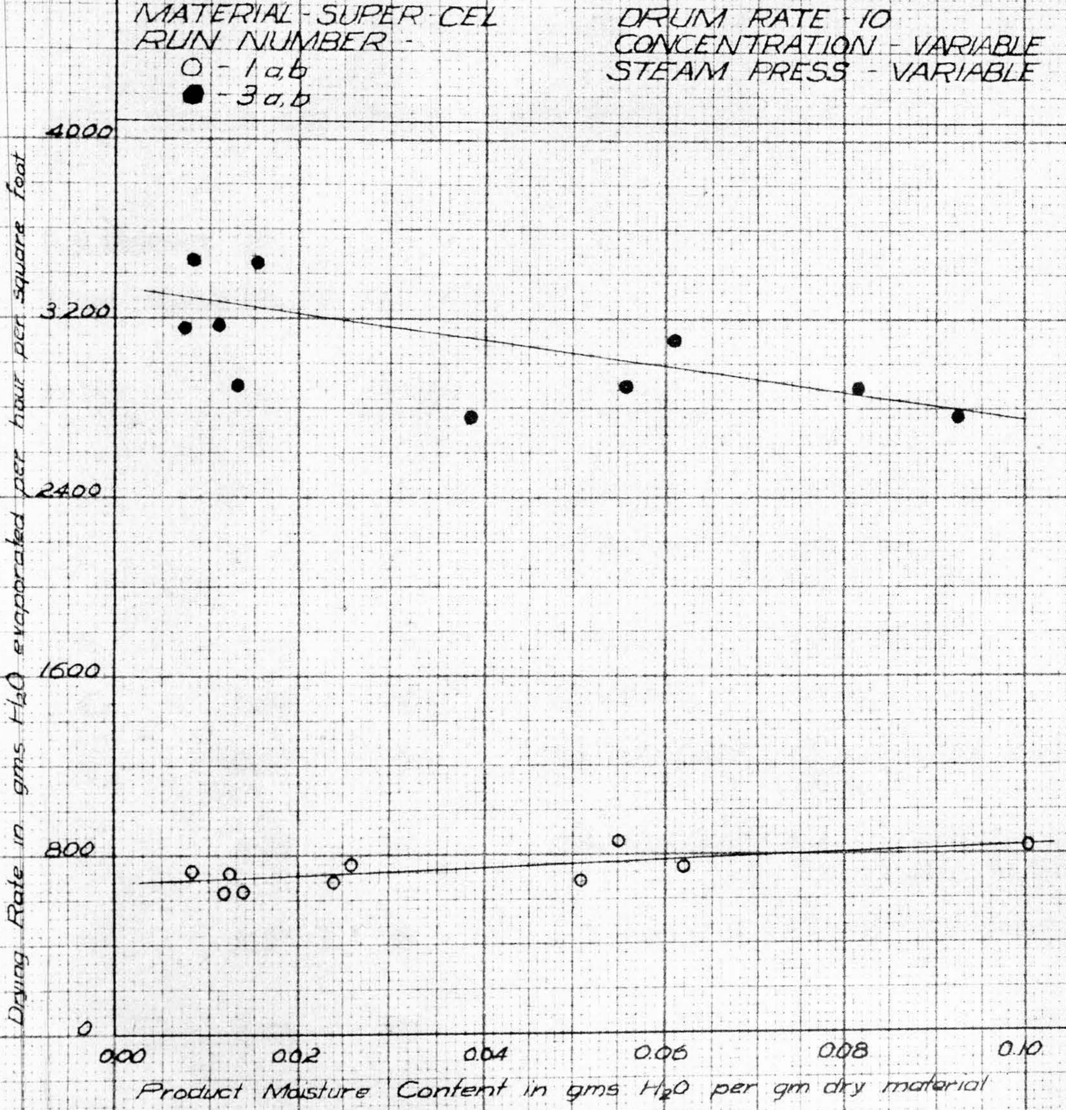


Figure 27 - VARIATION OF DRYING RATE WITH PRODUCT MOISTURE CONTENT

TABLE XXXIII

RESULTS WHEN DRYING A SODIUM SULPHATE SOLUTION

Run Number: 14

Date: March 14, 15, 16, 1940

Trial Number	Drum R. p. m.	Steam Press	Solution Concentration	Comment
1	10	4	Saturated	No visible drying
2	2.06	4	Saturated	Insufficient capacity for measuring.
3	2.06	6	Saturated	Soon glazed
4	2.06	12	Saturated	Glazed solidly
5	2.06	8	0.5 saturated	Glazed before data was taken.
6	6.04	10	0.5 saturated	Surface glazed, product incompletely dried.
7	2.06	10	0.3 saturated	Insufficient capacity, surface glazed
8	6.04	10	0.3 saturated	Incomplete drying, surface glazed.
9	6.04	3	0.3 saturated	Incomplete drying, eventually glazed.

TABLE XXXIV

RESULTS WHEN DRYING A SODIUM CARBONATE SOLUTION

Run Number: 16

Date: May 20, 22, 23, 1940

Run Number	Drum R. p. m.	Steam Press	Solution Concentration	Comment
1	10	5	Saturated	Incomplete drying
2	2.06	5	Saturated	Insufficient drying
3	2.06	10	Saturated	Surface glazed
4	2.06	10	0.5 saturated	Surface glazed
5	6.04	10	0.5 saturated	Surface glazed
6	3.38	5	0.5 saturated	Insufficient capacity, eventually glazed.

TABLE XXXV

RESULTS WHEN DRYING A SODIUM CHLORIDE SOLUTION

Run Number: 16

Date: May 27, 1940

Run Number	Drum R. p. m.	Steam Press	Solution Concentration	Comment
1	2.06	3	0.7 saturated	Insufficient capacity, glazed in spots.
2	6.04	7	0.7 saturated	Surface glazed
3	6.04	10	0.7 saturated	Surface glazed
4	2.06	10	0.7 saturated	Surface glazed
5	3.38	8	0.7 saturated plus a small amount of Super-Cel	Surface glazed
6	3.38	8	0.7 saturated plus a greater amount of Super-Cel	Surface Glazed, Super-Cel removed until glazing occurred.

3. Derivation of the equation for predicting the capacity of the dryer:

1. Super-Cel. Using the data for the constant rate of 6.04 revolutions per minute for the drum, the capacity was plotted, Figure 28, against the concentration of the slurry for the different steam pressures. A semilogarithmic system of coordinates was used. The resulting straight lines may then be represented by the equation

$$Q = a\, b^{C} \text{ ------------(1)}$$

where, $Q =$ quantity of material dried, grams of dry material per hour per square foot of drying area

$a =$ a constant depending upon the pressure

$b =$ a constant depending upon the steam pressure

$C =$ concentration of the slurry in grams of water per gram of dry material

The two constants, a and b, were then determined for all of the points and the average of the values for each pair of points used in their determination were then plotted against the steam pressure. These two curves are shown in Figures 29 and 30.

The variation of b with the steam pressure was found to follow a curve, Figure 29, that could be represented by the equation

$$\frac{P}{b} = c\,P - d \text{ --------(2)}$$

where, $P =$ steam pressure in pounds per square inch gage

$b =$ the constant in equation (1)

$c =$ a constant

$d =$ a constant

c was found to be equal to 1.075 and d equal 1.050. Using these values, it was found that the value of b predicted by the equation

$$b = \frac{P}{1.075\,P - 1.050}$$

was less than one per cent in error.

In the same manner, the constant a was plotted, Figure 30, against the pressure and the equation

$$a = \frac{2470}{P} - 758$$

fitted the curve with an average error of about four per cent.

This gave the equation for predicting the capacity of the drum to be

$$Q = \left(\frac{2470}{P} - 758\right)\left(\frac{P}{1.075\,P - 1.050}\right)^{C} \text{------}(3)$$

for a constant rate of revolution of the drum of 6.04.

The logarithm of the rate of revolution of the drum was next plotted, Figure 31, against the capacity and was accurately fitted by the equation

$$Q = 1.25\,Q_o\,\frac{\log R}{\log R_o} \text{-----------}(4)$$

where, Q = capacity at the rate, R

Q_o = capacity at the rate, R_o

From Figure 24, the variation in capacity with changing depth of drum submergence is given by the term

$$Q = 125 - 58.33\,D$$

where, D = depth of drum submergence between 0.60 and 2.00 in inches.

In terms of drying area this becomes

$$Q = 178 - 196\,A$$

Combining this equation with equation (3) and (4) and letting R_o equal 6.04 and D equal 1.80 the final equation for predicting the capacity of the dryer results

$$Q = 160 \log R \left(\frac{2470}{P} - 758\right)(178 - 196\,A)\left(\frac{P}{1.075P - 1.050}\right)^{C}$$

where, Q = the capacity of the dryer in grams per hour per square foot drying area

R = rate of revolution of the drum in revolutions per minute

P = the steam pressure in pounds per square inch, gage

C = the concentration of the slurry in grams of water per gram of dry material

A = the drying area of the drum per revolution

The equation gives values of Q which are about ten per cent high for the very low values of the steam pressure and are about ten per cent low for the high steam pressures. The limits for all the terms are those used during the experiment.

2. Soap. As shown on the graphs for Run Nos. 11-b, 12-b, and 10-b the capacity of the drum varies only with the concentration of the solution. Therefore, the capacity may be predicted by the equation

$$Q = (725 - 82.0\,C)(372 - 91.66\,D)$$

where all the terms have the same meaning as previously given.

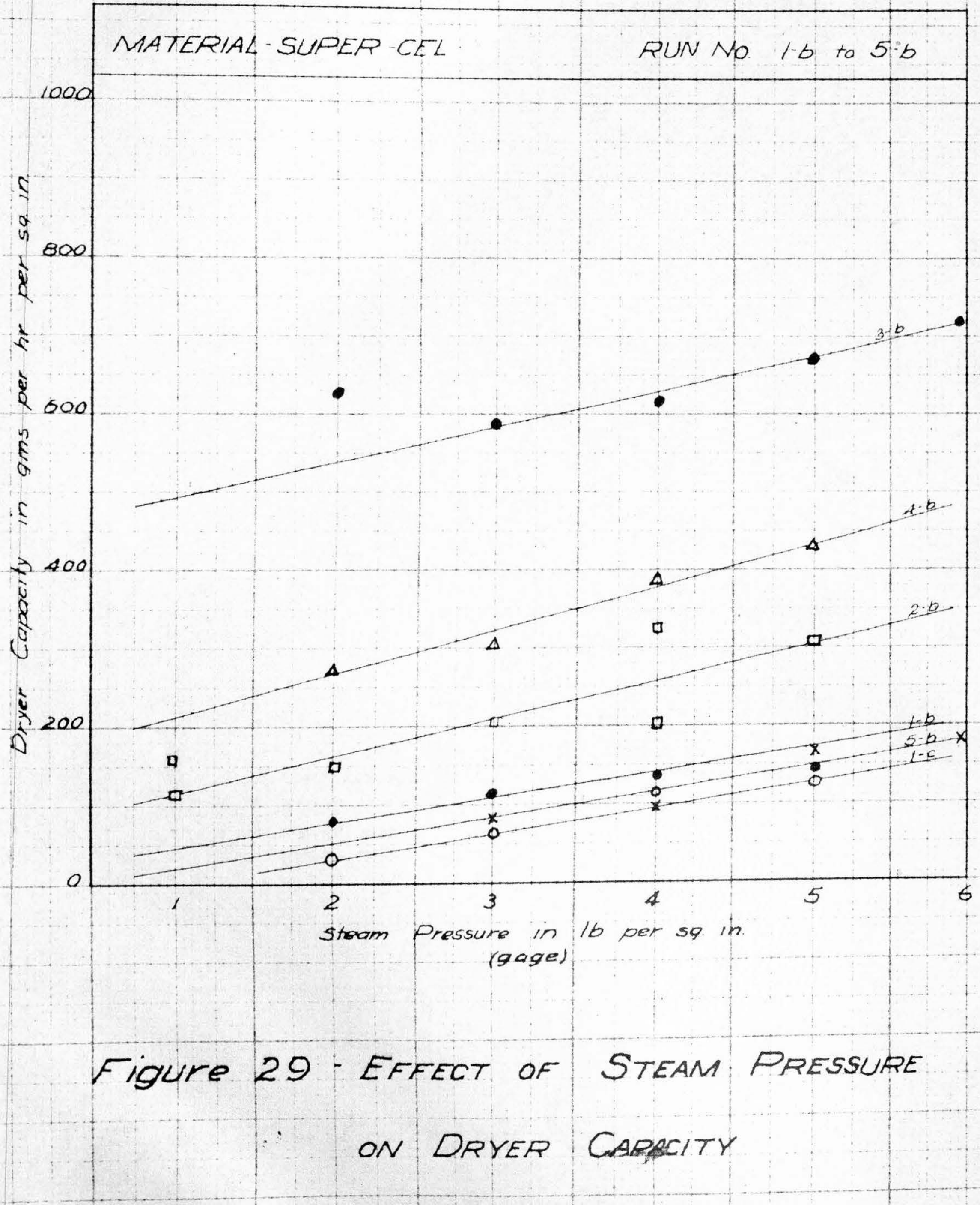


Figure 29 - EFFECT OF STEAM PRESSURE ON DRYER CAPACITY

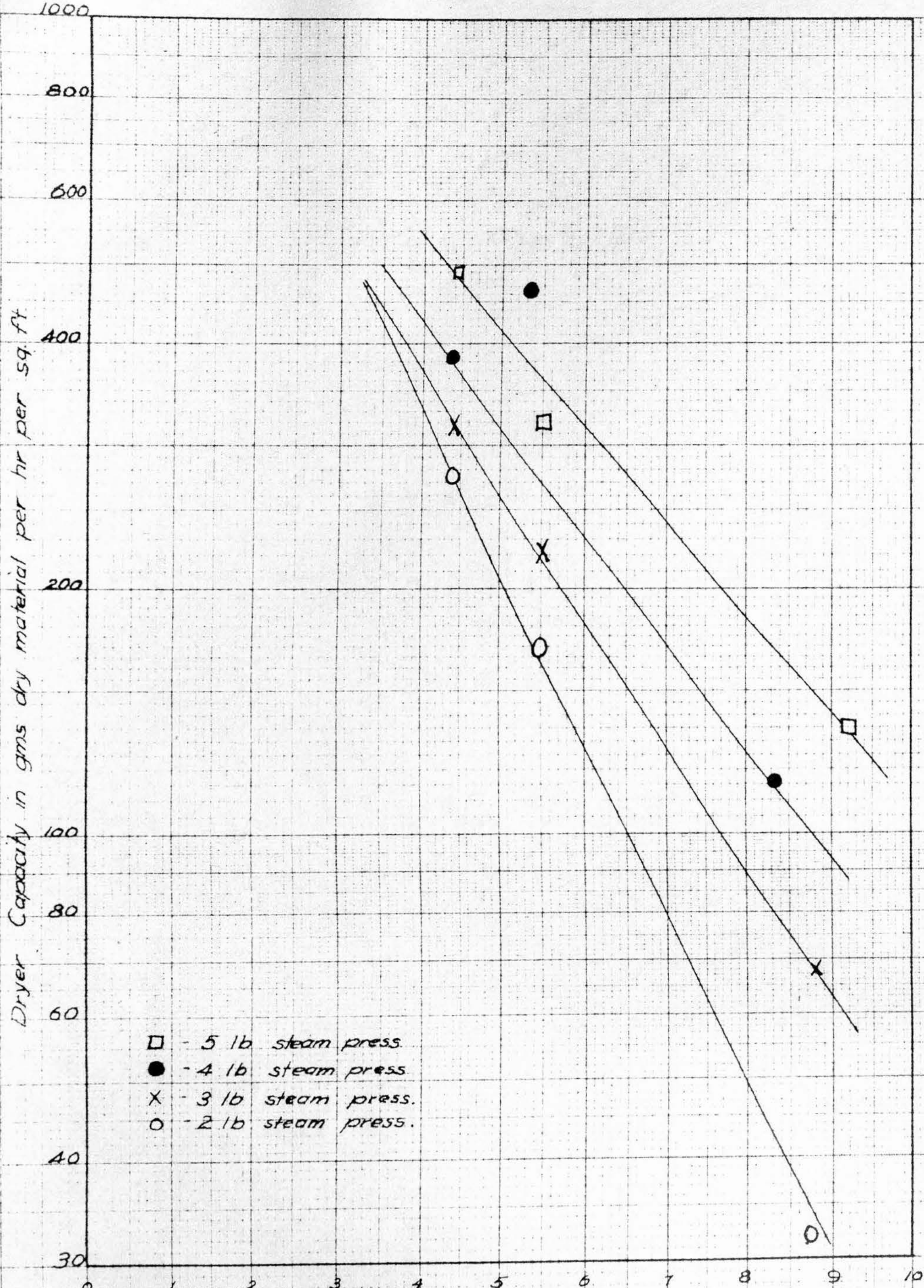


Figure 30 - EFFECT OF SLURRY CONCENTRATION ON DRYER CAPACITY

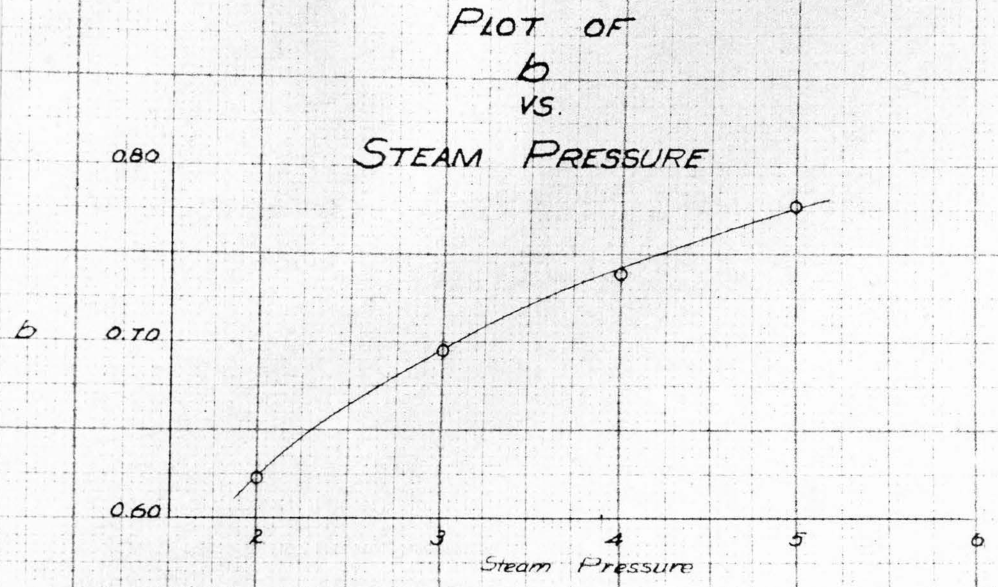


Figure 31

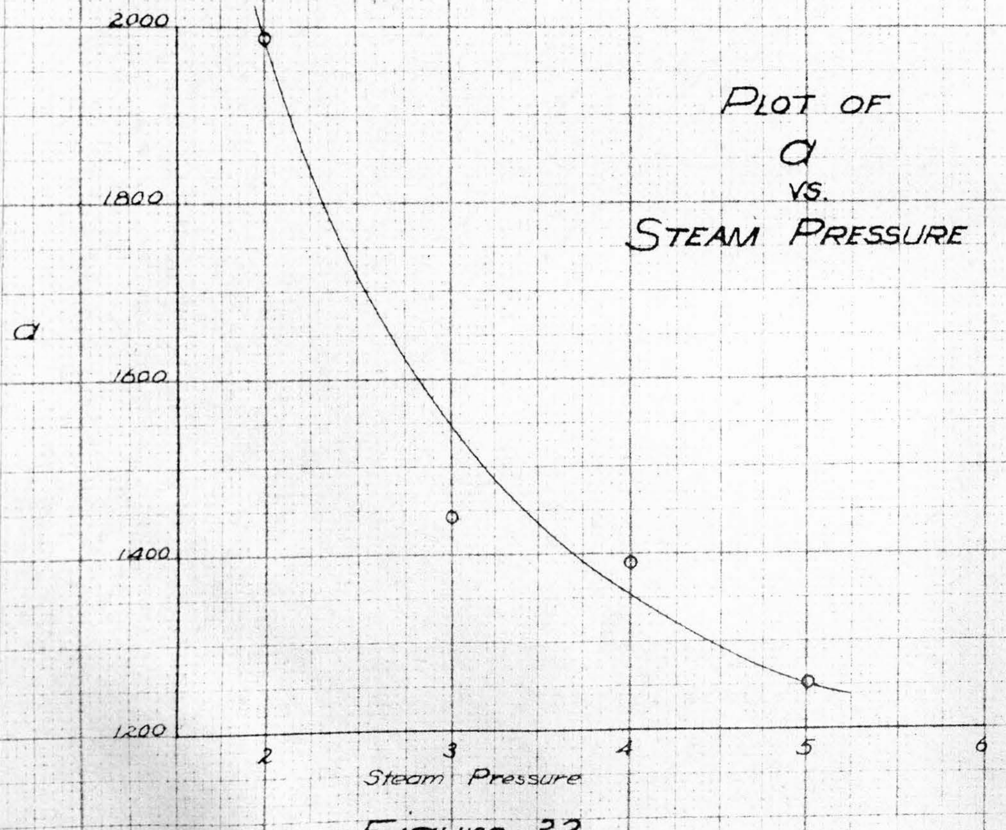
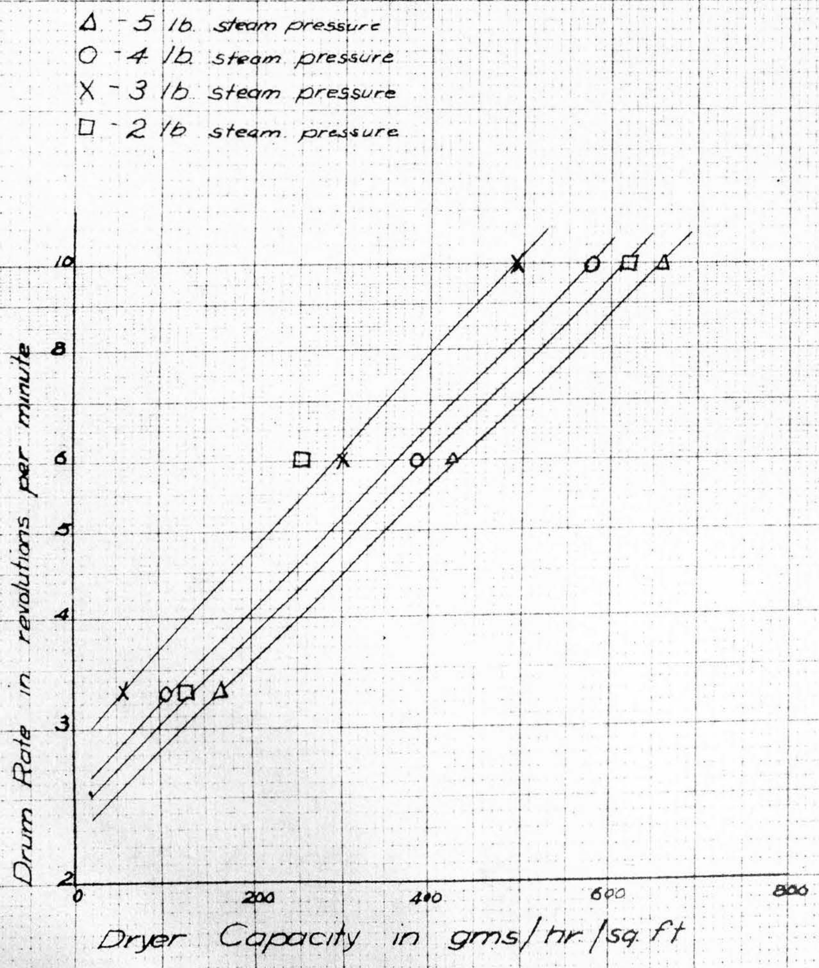


Figure 32

Figure 33 - EFFECT OF DRUM RATE ON DRYER CAPACITY



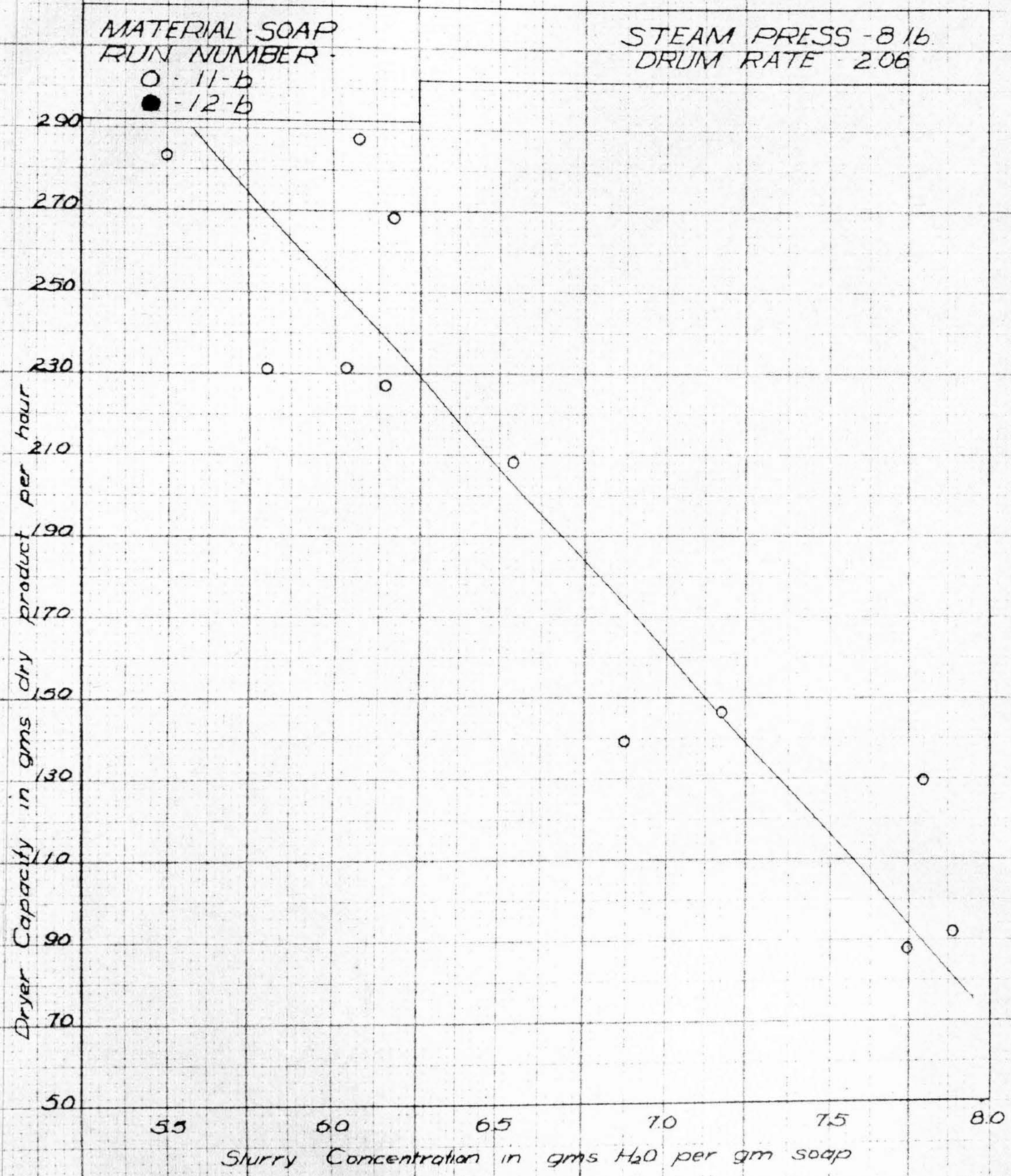


Figure 34 - Effect of Slurry Concentration on the Capacity of the Dryer

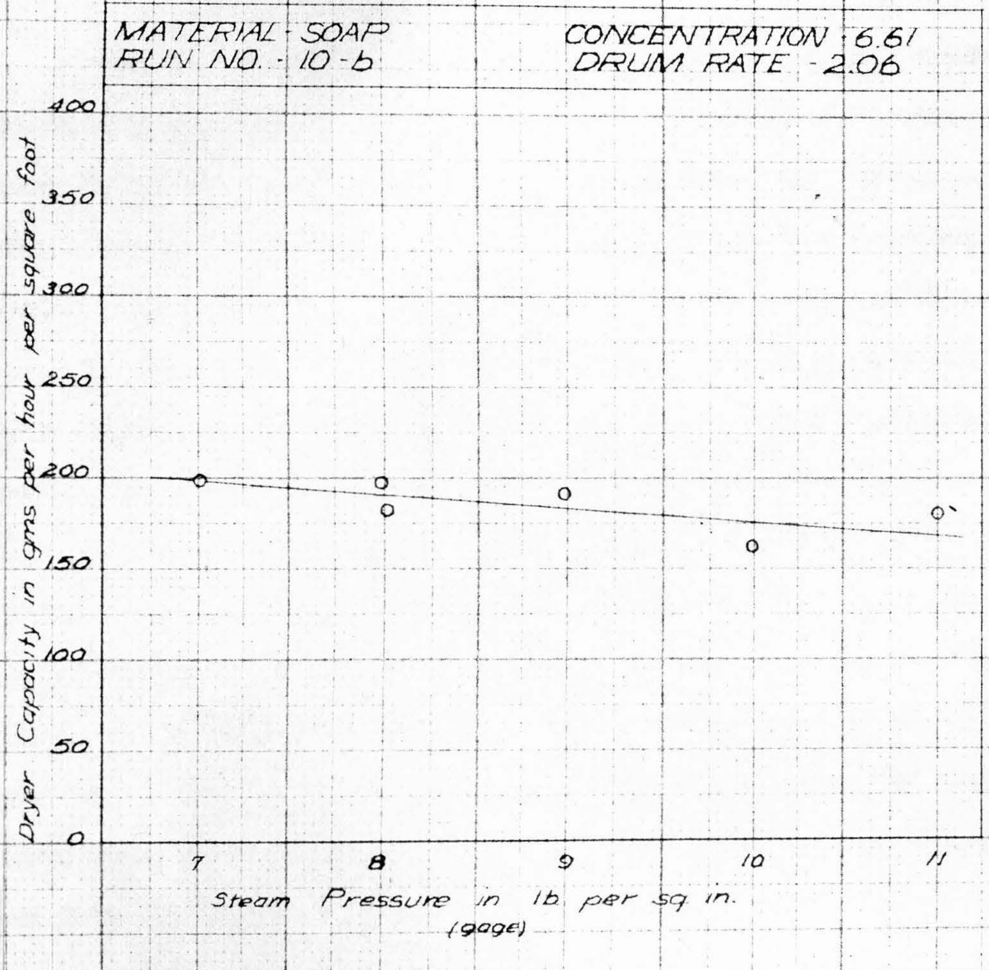


Figure 35 Effect of Steam Pressure on Dryer Capacity

IV. DISCUSSION OF RESULTS

The fundamental mechanism of drying used by the drum dryers is the vaporization of the liquid by heat and the diffusion of the vaporized solvent through the material being dried and then into the surrounding medium and its eventual removement. When the feed is introduced upon the heated surface of the drum it immediately begins to dry and deposit solids upon the drum face. These solids next to the drum face continually become drier until they finally lose as much moisture as it is possible to remove by the operating conditions of the drum. This dry layer near the drum face does not transfer heat as rapidly as the metal of the drum, and a correspondingly larger drop in temperature must exist throughout the drying material. It is this temperature drop through the material and the consequent difference in moisture content of the material that causes the greater part of the operating difficulties encountered. For instance, using the solutions the deposited salts would dry upon the drum surface and then, by continued heating, would glaze before the surface of the adhering solution would even dry beyond the fluid stage. This glazed portion would be so closely adhering to the drum face that it was impossible for the knife to remove it and all that would be removed would be the fluid, incompletely dried solution. The temperature drop through this glazed portion was so high that on the next revolution virtually no solution was picked up. This sampe phenomena resulted when drying the soap. For high steam pressures and a drum revolution of 3.38 r. p. m. the product showed this variation in drying very remarkable. The material next to the drum came off apparently perfectly dried while the other surface appeared to be as fluid as the feed solution.

From a consideration of the effect of depth of liquid upon the drum's capacity, it was noticed that after a definite drum submergence the amount of material picked up measured by the capacity, then depended only upon the temperature at which the drum face entered the solution. Roeser and Mueller[7] showed that the drum face greatly increased in temperature between the time it left the knife and entered the solution. By increasing the depth of the solution this time was lessened and the drum face did not reach as high a temperature as it would for lower liquid levels. This explanation also holds for the increase in drum capacity with increasing steam pressure, that is, higher face temperatures. A minimum depth of dip after which the capacity would fall off would be expected as there must be a definite time interval required for the material to become attached to the drum face sufficiently firmly to be carried away from the liquid. Roeser and Mueler also showed that the surface temperature of the drum dropped considerably in traveling through the feed solution and, therefore, if the drum enters at a lower temperature, it would also be expected to emerge at a lower temperature and thus dry the attached material less. This showed very clearly in the case of the soap where the product moisture content increased rapidly with an increase in the depth of drum submergence.

By the same line of reasoning it would appear that at the slower drum speed the amount of material dried per revolution should be greater than for the higher speeds. By dividing the capacity of the drier by its rate of revolution, this immediately becomes apparent.

The explanation for the product moisture content of the Super-Cel decreasing less than for the soap is that the layer of dried material next to the surface was a better insulator and allowed less heat to pass. Enlarging upon this, the explanation for the increase in moisture content of the product with decreasing rates of revolution of the drum is that at these slower rates the surface temperature is higher and the dried material next to the drum is both drier and comparatively thicker thus giving a larger screening effect and causing a higher temperature drop through the drying material. This was noticed even before being calculated as the surface temperature of the drying material changed enough with changing drum rates to be measured by merely touching it.

It is rather hard to draw conclusions from the steam consumption data. The data itself did not check very well, probably because all of the condensed water in the line may not have been removed by bleading and also to the fact that a change in room temperature or the presence of air drafts would change the amount of heat lost by convection. In general, the steam consumption figures indicate exactly what would be expected. The steam consumption increased when more water had to be evaporated and decreased when the pressure was increased. Increasing the pressure increases the heat content for the same weight and should thereby decrease the weight of steam required. The data on some of the runs would indicate otherwise, but in these cases it is assumed that the external conditions have changed and been the cause of these discrepancies.

✓

V. CONCLUSIONS

From the results of the experiment, it is concluded that:

1. Increasing the steam pressure results in an increase in the capacity of the dryer and in a decrease in the product moisture content for both the Super-Cel and the soap.

2. Decreasing the rate of revolution of the drum results in a lower total capacity for the dryer and decreases the steam requirement per gram of water evaporated.

3. The grams of steam condensed in evaporating one gram of water increases with increasing concentration of the slurry and but slightly with increasing steam pressure.

4. The depth to which the drum dips is a very important consideration in the operation of the drum. For increasing depths the capacity increases until a depth of 0.60 inches is reached after which the capacity falls off.

5. The product moisture content depends upon the steam pressure, the rate of revolution of the drum, the concentration of the feed, and the depth of dip of the drum.

6. When drying solutions the knife must fit the drum face very closely, the face itself must be absolutely smooth, and the solutions must be very nearly saturated.

7. The rate of drying varies with the moisture content of the drying material. The characteristic critical point was found for the soap.

VI. SUMMARY

The results of an equipment test upon a single roll atmospheric drum dryer are presented in the thesis. The data presented cover the runs made using a commercial grade of filter cell made by the Johns-Mansville Company and sold under the name of "Super-Cel" and a flake soap sold by Proctor and Gamble under the name of "Clean Quick." Runs were also made using solutions but these glazed and no satisfactory results could be obtained. No transfer coefficients are given.

The dryer was made in the laboratory and was made to be used in the test work with no attempt being made to duplicate any particular model of dryer in commercial use. A simple dip feed was used.

It was found that the more important variables in operation of the dryer were:

1. the steam pressure,
2. the rate of revolution of the drum,
3. the concentration of the feed,
4. the depth the drum dipped into the feed,

For Super-Cel these variables are connected to the capacity by the equation

$$Q = 160 \log R \left(\frac{2470}{P} - 758\right) (178 - 196\ A) \left(\frac{P}{1.075\ P - 1.05}\right)^{C}$$

and the equation

$$Q = (725 - 82.0\ C)\ (372 - 91.66\ D)$$

was found to predict the capacity when soap was being run. These terms have the following meaning:

Q = the capacity of the dryer in grams per hour per square foot drying area

R = the rate of revolution of the drum in revolutions per minute

P = the steam pressure in pounds per square inch gage

C = the concentration of the slurry in grams of water per gram of dry material

D = the surface area of the drum covered by the cake per revolution

VII. BIBLIOGRAPHY

1. Alliott, Eustace A. Some Factors Involved in Drying Operation. Chem. and Met. 21, 620 (1919)
2. Badger, W. L. and McCabe, W. L. Elements of Chemical Engineering, p. 294-296. McGraw-Hill Book Company, New York. (1936)
3. Devine, Graham Vacuum Drying. Chem. and Met. 29, 492 (1923)
4. Harcourt, G. N. Effective Drum Drying by Present Day Methods.Chem. and Met. 45, 179 (1938)
5. Harte, Charles R. Jr. Drum Dryers. Ind. Eng. Chem. 28, 7-10 (1936)
6. Perry, John H. Chemical Engineers' Handbook. p. 1237. McGraw-Hill Book Co., New York. (1934)
7. Roesser, Wm. F. and Mueller, E. F. Measurement of Surface Temperatures. Bureau of Standards Res. Paper No. 231 p. 800 (1930)
8. Stacey, A. E. Jr. Evaporation Rates of Moisture from a Wet Material and from a Free Water Surface. Ind. Eng. Chem. 30, 1385-1389 (1938)
9. Van Marle, D. J. Drum Drying. Ind. Eng. Chem. 30, 1006-8 (1938)
10. Walker, Wm. H., Lewis, W. K., McAdams, Wm. H. and Gilliland, E. R. Principles of Chemical Engineering. p. 628. McGraw-Hill Book Co., New York, (1937)
11. Weisselber, Arnold. Drying. Chem. and Met. 41, 250 (1934)
12. Hougen, O. A., Typical Dryer Calculations. Chem. and Met. 47, 15-17 (1940)

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