and there is conversion of crystals from one polymorphic form to another. Variations in consistency and texture result if the fat is not tempered and is exposed to wide variations in temperature during the first 24-48 hours after the chilling operation.

REFERENCES

1. Bailey, Alton E., "Cottonseed," Interscience Publishers Inc., New York (1948).
2. Sanders, J. H., Oil & Soap, 2, 357-360 (1944).
3. Goss, Warren H., "History of Oilseed Processing," from "Proceedings of a Six-Day Short Course in Vegetable Oils," Aug. 16-21, 1948, sponsored by A.O.C.S. at University of Illinois, Urbana, Ill.

Some Factors Affecting the Hydraulic Extraction of Cottonseed Oil

G. H. HICKOX, Engineering Experiment Station, University of Tennessee, Knoxville, Tennessee

FOR the last four years the University of Tennessee has been engaged in a study to determine the effects of cooking and pressing variables on the residual oil content of cottonseed meal. The work has been done in the Engineering Experiment Station of the university under a contract with the Department of Agriculture. In addition to determining the effects of the processing variables on the amount of residual oil, recommendations were made to oil mill operators for the modification of their practices so that the potential additional oil yield could be realized.

A search of the literature on this subject revealed that very little information was available. In addition to Bailey's well known work (1), only two papers were found: one by Koo (2) and one by Baskervill and others (3). The results presented in these papers were not conclusive and, in some respects, were conflicting. They did however indicate certain trends which guided the experimental work.

Experimental Equipment

When the work was begun, the university was operating a pilot plant press room. It was soon found that it was impossible to control the variables satisfactorily on large scale equipment, and special apparatus was soon developed for the needs of the investigation. As finally set up, the equipment included a standard huller and five-high roll. The greatest change was made on the cooker. Instead of a stack cooker, or the pressure cooker which had been developed previously at the University of Tennessee, it was found necessary to use a small cooker composed of a glass jar immersed in an oil bath. Figure 1 shows the cooker disassembled. The meats were stirred during cooking by a rotating agitator with variously tilted blades attached as shown in the illustration. Projecting down from the cover of the jar were two other rods, which served to break up the meats adhering to the blades. One of these projections was hollow and served as a thermometer well for determining the temperature of the meats while cooking. The capacity of this cooker was approximately 500 g. of meats.

Because the meats were cooked at temperatures well above their surroundings, it was found necessary to heat the cooker lid in order to prevent heat loss by radiation. This was done by making the lid of a thick aluminum block and inserting two electric heaters as shown in the illustration. A reflux condenser was attached to the lid of the cooker so that the moisture content of the meats would remain unchanged while they were cooked at atmospheric pressure. Figure 2 shows the cooker assembled and operating in the oil bath. The oil bath was heated by a thermostatically controlled heater. A small propeller in the bath outside the cooking jar insured circulation of the oil and even distribution of temperature. By preheating the cooker lid, it was found possible with this equipment to raise the temperature of the meats from room temperature to 220°F. in approximately 15 minutes.

The presses used were standard Carver Laboratory presses arranged as shown in Figure 3. The pressing chambers were enclosed in jackets through which oil from a constant temperature reservoir was circulated for the purpose of maintaining a constant temperature in the cakes during pressing. It was found necessary to manifold the pressure chambers of these presses in order that pressure might be applied at the same rate in all presses simultaneously. The rate of application of pressure was found to be a critical factor in determining oil yield, and the desired uniformity could not be maintained by hand application of load to individual presses. Apparatus for determining moisture and oil content and other chemical tests was standard analytical equipment.

Since the tests were made on such small-scale equipment, it seemed desirable to make checks on a mill scale in order to establish the validity of the laboratory work. Such tests were accordingly made with the cooperation of the Perkins Oil Company at Memphis, Tenn. Figure 4 shows how electric strip heaters were placed in two grates of a standard box press so that one of the boxes might be heated from both above and below in order to maintain a pressing temperature at any desired level. Slots were milled in the grates to accommodate the strip heaters as shown. Figure 5 shows the heated grates inserted in a standard 15-box press with electric power connections attached.

A wide range of variables was investigated during the laboratory study. Cooking time ranged from 30 to 120 minutes and cooking temperature from 220° to 250°F. Pressing time ranged up to 2 hours, the total pressure varied from 2,000 to 4,000 lb. p.s.i., and the rate of application of pressure from 67 lb. p.s.i. per minute to 500 lb. p.s.i. per minute. Pressing was performed at temperatures of 140°, 170°, 210°, and 230° F. Hull contents were 29, 43.5, and 54%. Normally hull content is slightly less than 29%, but a lower value could not readily be attained with the equipment available in the laboratory. The cake moisture ranged from 4 to 15%. Cake thickness varied from ¼ to 2½ inches.

A standard cooking and pressing procedure was adopted for most of the tests. The meats were raised

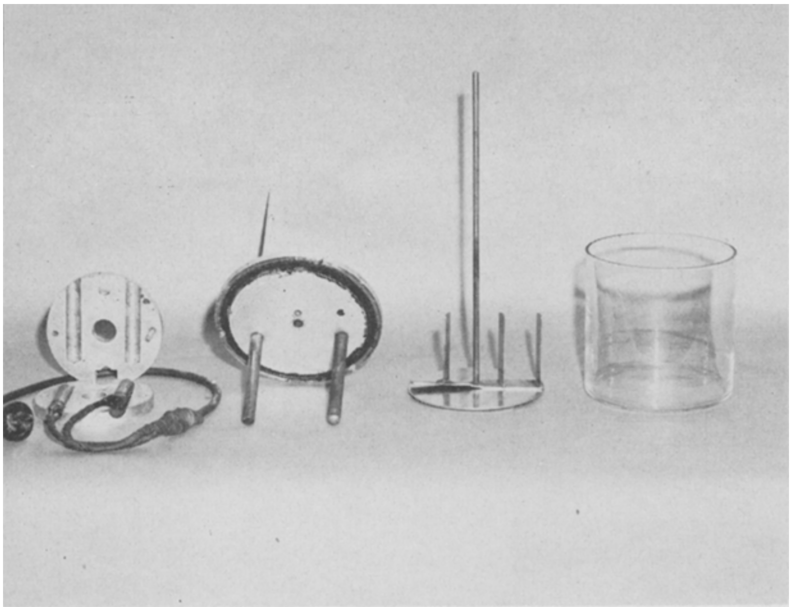

FIG. 1.

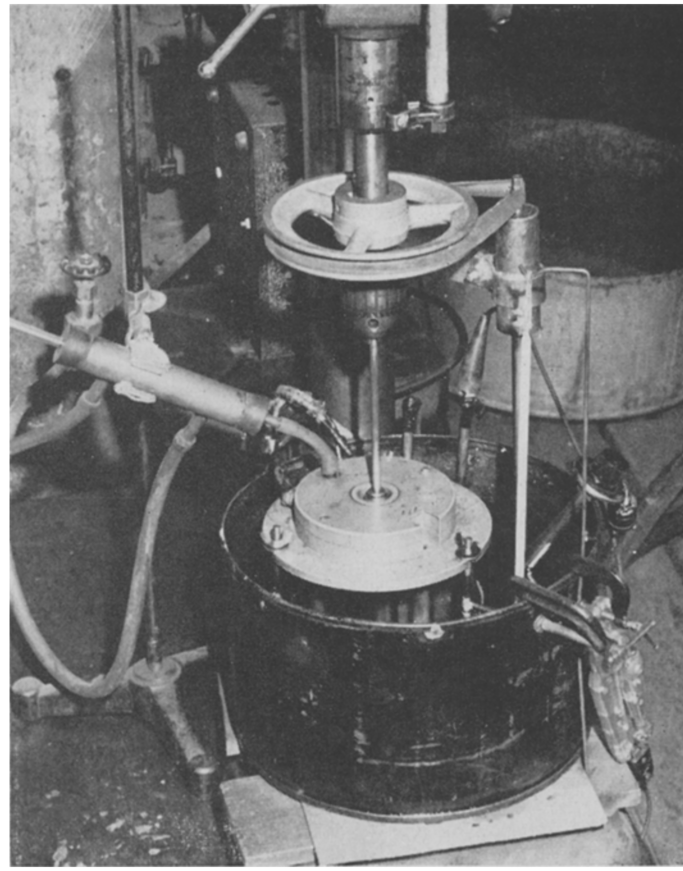

FIG. 2.

FIG. 1. Laboratory cooker, disassembled.

FIG. 2. Laboratory cooker, assembled for operation.

FIG. 3. Carver laboratory presses, manifolded for simultaneous operation.

FIG. 4. Electric strip heaters in press grate.

FIG. 5. Electrically heated box installed in press.

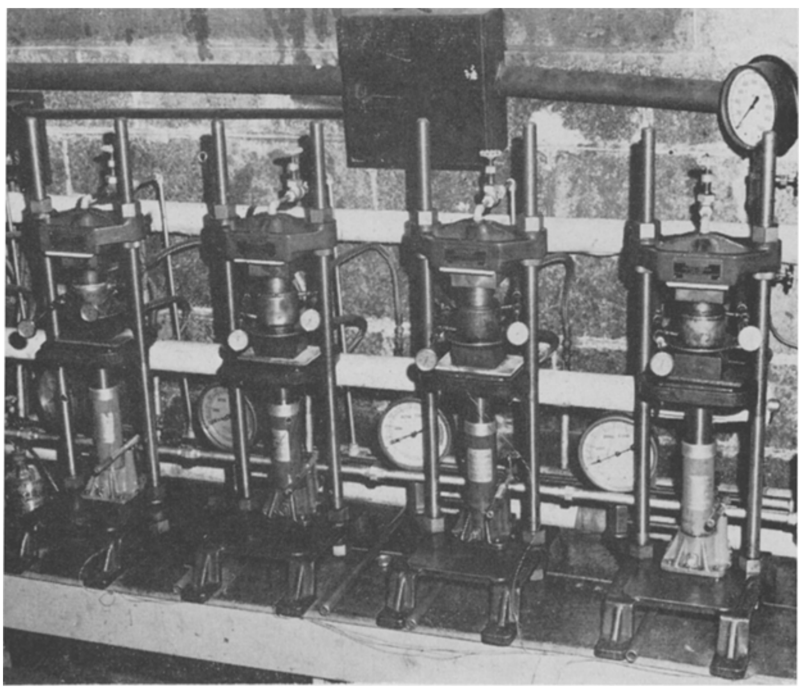

FIG. 3.

FIG. 4.

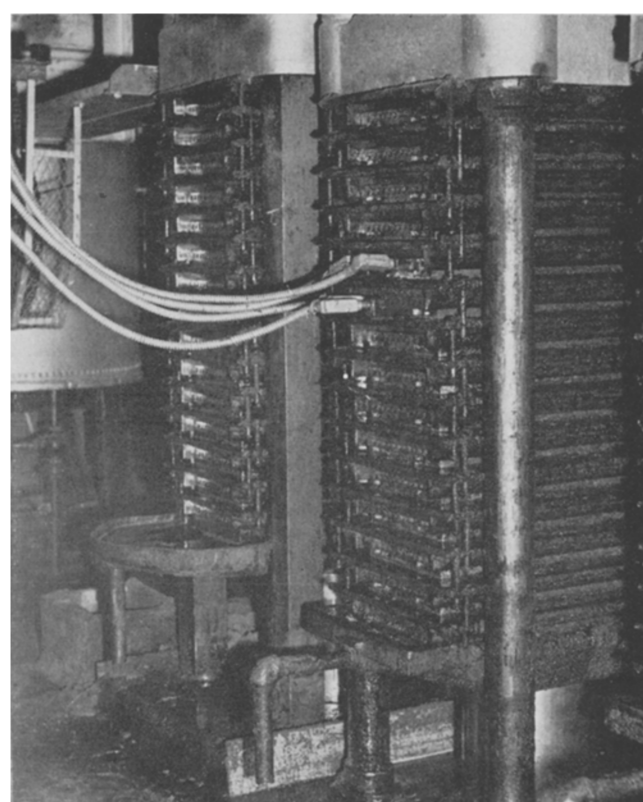

FIG. 5.

to a temperature of 220°F. as rapidly as possible, usually in about 15 minutes, and held at that temperature for a total elapsed time of 30 minutes. A measured volume of cooked meats was loaded into each press as soon as the cooker was opened. The moisture content of the cake was lowered when desired, by allowing moisture to evaporate from the meats before loading the press. The pressing time was 60 minutes at a total pressure of 2,000 lb. p.s.i.

Results of Laboratory Tests

Cooking. It was found that the time and temperature of cooking had little effect on the amount of residual oil in the cake, provided that the temperature of the meats was raised to a point where coagulation of the protein and breaking down of the cell walls occurred. Additional cooking time, or an increase in temperature above this point, seemed to have little effect.

Pressing Time. Figure 6 shows the effect of pressing time on residual oil for one set of cooking conditions and hull content. It may be seen that after a pressing time of 45 minutes to one hour little advantage is gained by further pressing. Only 0.1% oil is extracted after the first hour. It is probable that the most economical pressing time is between 45 and 60 minutes.

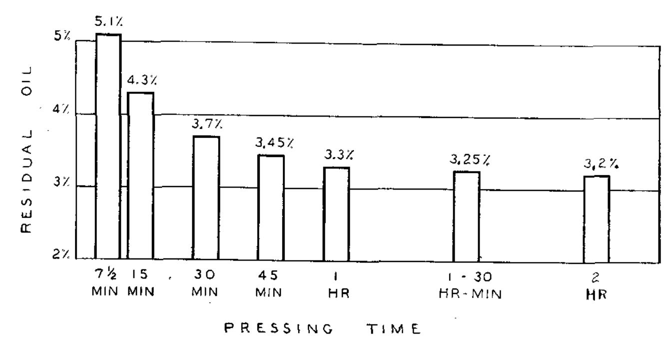

FIG. 6. Effect of pressing time on residual oil.

Bases for Oil and Moisture Content. It was found undesirable to use the standard commercial bases for expressing moisture and oil content. This is illustrated by Figure 7, which shows for 100 lb. of cottonseed cake the total amounts of meat, hull, moisture, and oil. The average values for 100 lb. of cake are 62 lb. of meat, 25 lb. of hull, 8 lb. of moisture, and 5 lb. of oil. On the basis of the total weight of the cake the moisture content is 8% and the oil content is 5%. This basis is not satisfactory for comparative purposes as may be seen if the moisture content is raised to 16 lb. The total weight is then 108 lb., and the oil content becomes 4.6%. It thus appears that the addition of moisture has reduced the residual oil although the actual amount is unchanged. In order to avoid such misleading conclusions, it was necessary to calculate the oil and moisture percentages on a base that remained unchanged. Such a base is the weight of the dry, oil-free, and hull-free meats in the cake, and the percentage of oil has been expressed on this basis. Moisture has been assumed to have the same value in both the meats and the hulls, and moisture has been expressed on the basis of dry oil-free material in the cake. These bases are illustrated in Figure 7, which shows that the 8 lb. of water becomes 9.2% and the 5 lb. of oil becomes 8.1%. Each of these values remains constant, regardless of how the other components are changed. The percentages referred to in the rest of this report are on this basis until the final conclusions are reached, when they are changed back to the customary commercial basis for purposes of comparison with current practice.

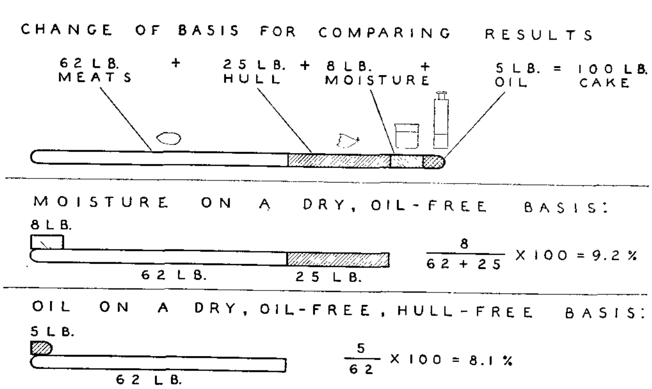

FIG. 7. Basis for expressing oil and moisture percentages.

Moisture Content. Figure 8 shows the effect of moisture content in the cake on residual oil for one set of pressing and cooking conditions. The open areas show the residual oil for different moisture contents at a pressing temperature of 170°F. It may be seen that the minimum residual oil of 6% occurred at a moisture content of 10%. The shaded areas represent the situation for a pressing temperature of 210°F. Here also it may be seen that the residual oil varies with the moisture content but that the minimum residual oil is considerably less and occurs at a different moisture content. This chart indicates that the effects of moisture and temperature are interrelated. More attention will be paid to this later.

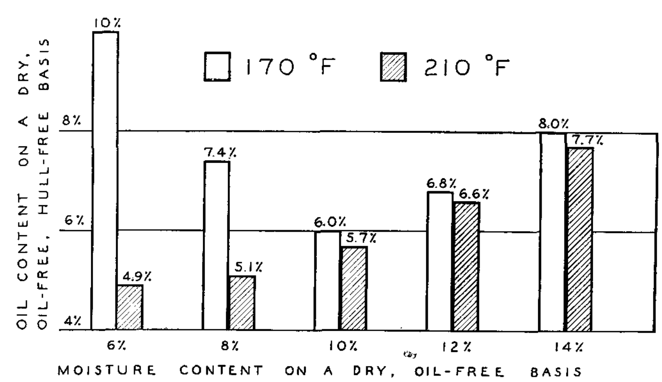

FIG. 8. Effect of moisture content on residual oil.

Hull Content. The effect of hull content is shown in Figure 9. The shaded areas in this figure show the minimum residual oil for each of three hull contents: 29, 43.5, and 54%. It will be seen that the lower hull content results in the least residual oil. The unshaded rectangles show the pressing temperature at which the minimum residual oil occurred, and it will be seen that for the higher hull content, higher pressing temperatures are required. The best result was obtained at a hull content of 29% and a pressing temperature of 205°F. These results indicate that pressing should be carried out with the minimum hull content.

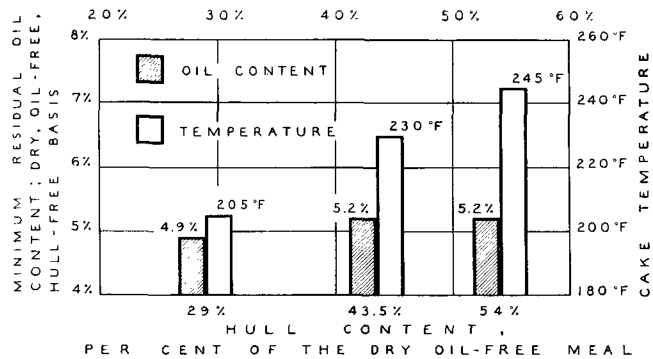

FIG. 9. Effect of hull content on residual oil.

Cake Thickness and Total Pressure. Figure 10 shows the effect of cake thickness on residual oil. The open rectangles show the results obtained at a pressure of 2,000 lb. p.s.i., and shaded rectangles show the results for a pressure of 4,000 lb. p.s.i. This figure shows that for both pressures the amount of residual oil increases as the cake thickness increases. For cake thicknesses up to one inch the pressure has no effect, but at thicknesses greater than one inch the higher pressure results in less residual oil. The reason for the curious behavior with respect to pressure at thicknesses of less than one inch is unknown. It appears that there is no advantage to be gained by increasing the pressure above 2,000 lb. p.s.i.

Rate of Pressure Application. The rate of application of pressure was found to be important with regard to the residual oil in the cake. Figure 11 summarizes the results of tests on this variable. The open rectangles show the minimum residual oil obtained

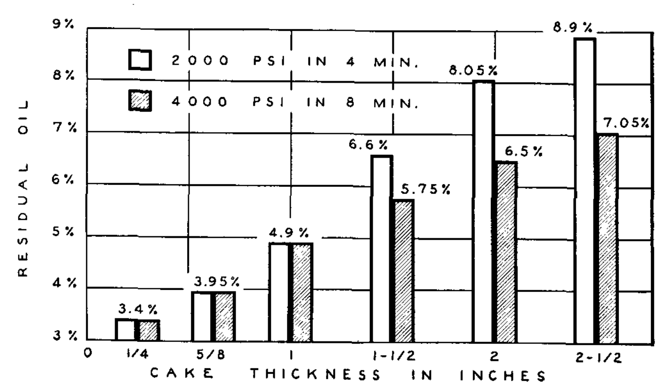

FIG. 10. Effect of cake thickness and total pressure on residual oil.

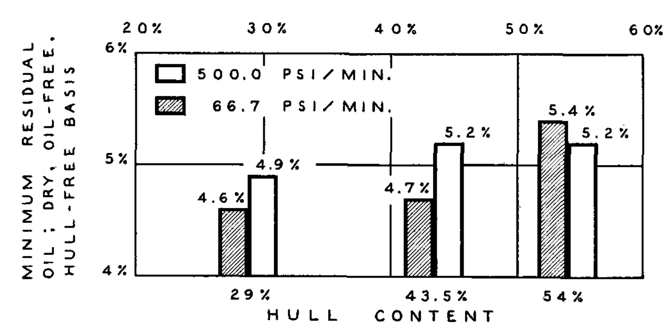

FIG. 11. Effect of rate of pressure application on residual oil.

for different hull contents when the pressure was raised to 2,000 lb. p.s.i. in 4 minutes, a rate of 500 lb. p.s.i. per minute. The shaded rectangles show the residual oil when the pressure was raised to 2,000 lb. p.s.i. in 30 minutes, a rate of 66.7 lb. p.s.i. per minute. The total pressing time in each case was 60 minutes. The difference in favor of the slower rate of pressure application is significant. Since mill practice agrees generally with the higher rate of application, it is suggested that improvement in oil yield might result by decreasing the rate of pressure application.

Cake Quality. A few observations on cake quality indicated that the soluble protein was not affected by any of the pressing or moisture conditions at temperatures below 210°F. The free gossypol content was apparently not affected by the pressing temperature.

Combined Effect of Cake Moisture and Pressing Temperature. The interrelationship between pressing moisture and pressing temperature has already been mentioned. Figure 12 is a chart that shows this relationship graphically. It is based on the data obtained in the laboratory tests and shows the residual oil in the cake for moisture contents ranging from 4 to 12%, and temperatures from 130° to 250°F. This chart is similar in appearance to a surveyor's contour map and may be interpreted in the same way. The heavy lines connect points of equal residual oil content. Inspection of the chart shows that there is one point where the residual oil is the lowest. This point is inside the 5% line and is estimated to be about 4.8% residual oil. The point at which this residual oil is reached corresponds approximately to 6.5% moisture, and about 208°F. pressing temperature. It will be seen that any departure from these conditions, either in moisture or temperature, will raise the residual oil.

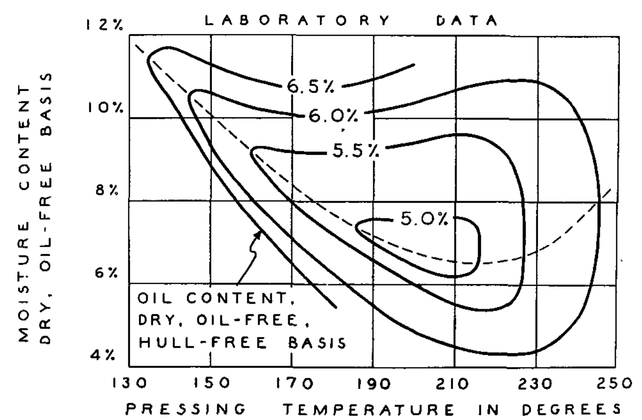

FIG. 12. Combined effect of cake moisture and pressing temperature on residual oil, laboratory data.

Results of Mill Tests

Figure 13 is a similar chart based on mill test data. Comparison of the two charts shows that the curves of residual oil are similarly shaped and that the points of lowest residual oil are in approximately the same position. The minimum residual oil in Figure 13 is estimated at about 5.8%, and it occurs at about 6.6% moisture and 205°F. pressing temperature. The actual amounts of residual oil are greater than for the laboratory tests, and this is explained in part by two factors. The cakes in the mill tests were much

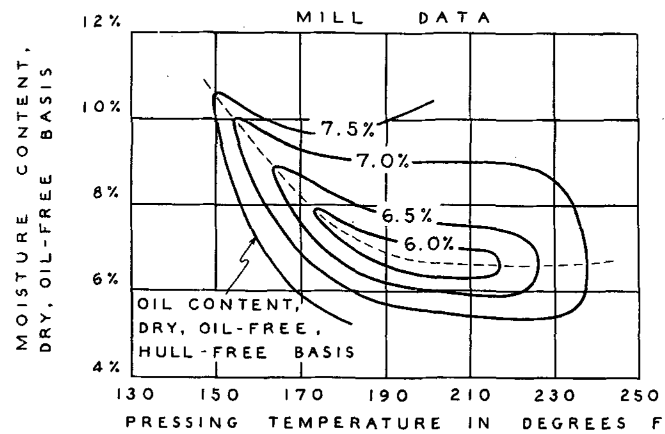

FIG. 13. Combined effect of cake moisture and pressing temperature on residual oil, mill data.

thicker than in the laboratory tests, and reference to Figure 10 will show that this addition of cake thickness should result in an increase in residual oil of several tenths per cent. Another factor contributing to the increase in residual oil found in the mill tests is the fact that the laboratory tests were conducted at a pressing time of one hour while the mill tests were conducted on a 45-minute cycle, which means a pressing time of approximately 40 minutes. This accounts for another one or two tenths per cent. When allowances are made for the differences in operating conditions between mill and laboratory, the agreement is found to be within a few tenths of 1%, which is very good indeed, considering the change in scale from the laboratory cooker and presses to a commercial stack cooker and the standard 15-cake box press.

Conclusions

All the data up to this point have been expressed in terms of dry, oil-free, hull-free meats. Figure 14 is prepared from the same data as Figure 13 but on the standard commercial basis. Inspection of this

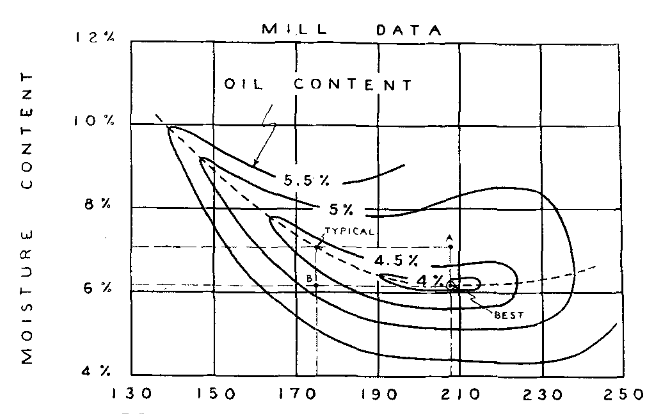

FIG. 14. Effect on residual oil of varying cake moisture and pressing temperature, mill operation.

chart shows that the best mill operation might be expected at a moisture content of 6.2% and a pressing temperature of 208°F. This point is indicated on the chart. Typical mill operation occurs at a pressing temperature of about 175°F. For this temperature the best residual oil which can be realized is approximately 4.3% at a moisture content of 7%, and this is the range in which the mill was operating at the time the tests were made.

This chart shows why various experiments to determine the effect of changing the temperature or the moisture from the typical operating conditions have resulted in conflicting conclusions. If a mill is operating at the point marked "typical," and an attempt is made to improve operation by heating the presses, leaving the moisture content at 7%, operation will be at point "A" in the diagram where the moisture is 7% and the temperature is 210°F. At this point the residual oil will be 4.7%, an increase of 0.4% and a condition not to be desired. On the other hand, if an attempt is made to improve operating conditions by reducing the pressing moisture from 7 to 6.2% without changing the temperature, operation will occur at point "B," where the residual oil is found to be 4.8%. This is also an undesirable condition. However it will be seen that if the moisture content is reduced and the temperature is increased at the same time, operation will be at the "best" point with a residual oil of 3.8%. It appears that earlier experimenters and mill operators were correct in their conclusions but did not carry their work far enough to arrive at the best combination of results because of the interrelated effect of the moisture and temperature variables.

Observations of cake temperatures at the Perkins Oil Company mill, made with thermocouples embedded in the cakes, showed that the temperature of the cakes in the press varied from the top to the bottom of the press. During a typical set of runs the temperature in the top cake was found to be 135°F., the middle cake 175°F., and the bottom cake 145°F. With all cakes having a moisture content of 7%, the effect on the residual oil due to the change in temperature can be seen by an inspection of Figure 14. The residual oil at 135°F. is probably in the neighborhood of 7%, and at 145°F. is about 5.8%. The lower temperatures of the top and bottom cakes are probably caused by conduction of heat away from the press boxes by the metal parts of the ram and the frame of the press. It seems that pressing conditions in the upper and lower cakes could be improved by paying careful attention to the insulation of these cakes from the frame of the press. The increase in oil yield from the upper and lower cakes would soon repay the time and cost of this work. The average increase in yield for a 15-box press would be about 0.2%, or about 4.5 lb. of oil per press for each cycle. With oil at 13c per lb. and a 45-minute operating cycle, this amounts to about $15 per press per month.

Further improvement in oil yield can be obtained by heating the entire press to 200° or 210°F. With a concurrent reduction in cake moisture this would result in a reduction in residual oil from 4.3 to 3.8%, or about 35 lb. of oil per press per day. At 13c per lb. this amounts to $4.50 per press per day, $135 per press per month, or about $50 per hundred tons of seed. Calculations on the cost of heating a press electrically indicate that the power cost would be in the neighborhood of $15 per press per month, or a net gain of $120 per press per month due to heating the presses. This increased income should soon pay for the cost of installing heating equipment.

Recommendations

As a result of the laboratory tests and their verification in a full-scale mill, the following recommendations are made for the benefit of hydraulic press mill operators:

1. The hull content should be kept low during pressing when the final output is sold as meal. If the cake is sold as a final product and the nitrogen content must be adjusted before pressing, this benefit cannot be realized. The addition of hulls to the cake during pressing is undesirable because it reduces the throughput of the mill and also reduces the oil yield.
2. The rate of application of pressure should be reduced below that customarily used. The experiments showed that the residual oil was reduced a measurable amount when the pressure was increased to its maximum during a 30-minute period instead of the customary 4 or 5 minutes. It is suggested that the pressure be built up over a 20-minute period in order to take advantage of this effect.
3. The total pressure on the cake need not be increased above 2,000 lb. p.s.i. unless the final cake thickness is greater than 1 in. The tests indicated that, for thin cakes, increasing the pressure had no effect on the residual oil.
4. The cake should be kept as thin as economical considerations and the throughput of the mill will permit. This is a matter which will necessarily be governed by local conditions at each mill.
5. The moisture content of the cake should be controlled carefully in order to obtain the minimum residual oil. Examination of Figure 14 shows a change in moisture content of a few tenths of 1% will increase the residual oil an undesirable amount.
6. Since the top and bottom cakes in the press are cooler than the middle cakes, it is desirable to raise their temperature by insulating them from the body of the press in any manner that may be feasible.
7. If possible, the entire press should be heated so that pressing could be carried on at a temperature of approximately 205°F. This may be accomplished by inserting strip heaters as was done for the tests, or possibly by steam passed through copper or other pipes embedded in the grates. It is probable that a jacket around the presses would be helpful, particularly in cold weather.

Acknowledgments

The tests described in this paper were carried out at the University of Tennessee during the period June 1949 to August 1952. The project was supervised by R. M. Dowd until November, 1950, at which time the project was taken over by Clyde L. Carter. The entire project was under the direction of the writer. The work was done under contract with the U. S. Department of Agriculture and authorized by the Research and Marketing Act of 1946. The contract was supervised by the Southern Regional Research Laboratory of the Bureau of Agricultural and Industrial Chemistry. Special acknowledgment is due to E. A. Gastrock, head, Engineering and Development Division, Southern Regional Research Laboratory, for his unflagging interest and helpful suggestions in the progress of the work.

REFERENCES

1. Bailey, A. E., *et al.*, "Cottonseed and Cottonseed Products," Interscience Publishers Inc., New York, pp. 617-625 (1948).
2. Koo, E. C., *Industrial Research (China)*, *6*, 9-14 (1937).
3. Baskervill, W. H., *et al.*, Oil Mill Gazetteer, *51*, 56-63 (1947).

History and Latest Development in Expeller and Screw Press Operations on Cottonseed

J. W. DUNNING, The V. D. Anderson Company, Cleveland, Ohio

A DISCUSSION of the extraction of oil from cottonseed by means of mechanical screw presses may be divided into two broad phases. One phase concerns the mechanics of oil extraction while the other phase concerns the chemistry of oil extraction. Although these two phases will be discussed separately, it must be borne in mind that they are inseparable in practice.

J. W. Dunning

The mechanical screw press oil mill of today is quite unlike the oil mill of centuries ago when the ancient Egyptians, Phoenicians, and Chinese produced some form of crude oil and meal. These early mills were very primitive and are illustrated by a photograph (Figure 1), taken by Frank Anderson not many years ago, of an oil mill in the Orient. The basic unit of equipment in this mill is called a stump press. It consists of a burned-out stump with a heavy pole driven by an ox to macerate the seed and thus free some of the oil. From the days of the Greek and Roman empires to the 17th century the stump press and its ancient equivalents were modified to impose more pressure on the seed being milled to give a better separation of oil from meal. The manual screw press (1) (Figure 2) may be cited as an example of this development. The vegetable seed was wrapped in some form of cloth and placed between the platens of the press. A single screw was then manually turned to impose a pressure on the seed, thus expressing some oil.

FIG. 1. Oriental stump press.

Many mechanical improvements in mill equipment appeared during the 17th and 18th centuries. It might be said that this early developmental stage was