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Fermentation and Crystallization of Honey

Elton J. Dyce

Study conducted under the direction of E. F. Phillips, of the Department of Entomology and Limnology

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THE MARKET QUALITY OF GRANULATED HONEY IS DIRECTLY INFLUENCED BY THE SIZE OF CRYSTALS. HONEY WHICH FORMS FINE CRYSTALS IS MORE PALATABLE, AND MORE SATISFYING TO THE PERSON WHO EATS IT, THAN HONEY WHICH CONTAINS COARSE, GRITTY CRYSTALS. ALL HONEY, TO BE MARKETED SUCCESSFULLY, SHOULD HAVE FINE CRYSTALS. RAPID CRYSTALLIZATION MAKES SMALL CRYSTALS AND BETTER HONEY.

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CONTENTS

	PAGE
Introduction	3
The fermentation problem	3
The granulation problem	6
Effect of methods of packing, on fermentation and granulation of honey	9
Material and methods used	10
Experiments with various methods of packing honeys (Experiments 1 to 11)	12
Experiments conducted at Chicago	51
Factors controlling crystal formation in honey	51
Experiments in the control of crystallization in honey (Experiments 12 to 21)	52
Development of a practical method of controlling crystallization (Experiments 22 to 27)	61
Formation of dextrose hydrate crystals in honey	68
Summary and conclusions	71
References cited	75

FERMENTATION AND CRYSTALLIZATION OF HONEY[1]

ELTON J. DYCE

INTRODUCTION

Fermentation and crystallization of honey are now problems of major concern to those interested in the production and marketing of this crop. In former years, when honey production had not attained its present magnitude, it was uncommon to hold the product in storage for a period of months before it reached the consumer; but during recent years, increased production and consumption have caused the marketing of the crop to be less seasonal. It is now often necessary, not only to store honey for a period of months, but also to hold it over from one year to the next. Honey is a perishable product, and the loss through spoilage when it is stored for a considerable time has become serious.

In order that the work reported in this paper may be properly understood in relation to the present status of honey problems, it is necessary, by way of introduction, to discuss two phenomena: honey fermentation, and honey granulation. Efforts have been made and are being made to control these two phenomena, and, since the work here reported has a bearing on the practical control of both, a brief report of earlier work is first presented.

THE FERMENTATION PROBLEM

Pugh (1927) gives some interesting data on the relation of the percentage of loss from fermentation of honey, to the length of time that the product is held in storage. He examined samples of the 1925 Ontario honey crop one year after production, and found that, if the original honeys had fermented to as great a degree as had the samples, a loss of 3.3 per cent of the year's crop would have resulted. Similar samples from the 1924 honey crop on the same basis showed a loss on storage for the two years of 26.4 per cent. In these cases it is of course to be remembered that much of this honey had been consumed before the samples were examined; yet the figures clearly indicate an increasing loss on prolonged storage.

It has been known for many years that fermenting honeys contain yeasts which have caused the fermentation, and several papers have been prepared

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[1]Also presented to the Faculty of the Graduate School of Cornell University, June, 1931, as a thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

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on the various phases of work on this subject. Nussbaumer (1910) gives the results of his own studies in this field, his work constituting one of the earlier scientific attacks on the problem. He concludes that heating the honey to 70° C. (158° F.) for thirty minutes destroys the yeasts and thus prevents fermentation. Because of the steadily increasing losses from the fermentation of honey, several investigators on this continent have more recently undertaken a study of the microorganisms causing such fermentation, among whom may be mentioned Fabian and Quinet (1928), Marvin (1927, 1928, 1930), Wilson and Marvin (1929, a and b, 1930, a and b, 1931), Lochhead and Heron (1929), and Lochhead and Farrell (1930, a and b). The work of Fabian and Quinet is especially important for the determinations of the sugar-tolerant yeasts causing honey fermentation. Those authors isolated bacteria, yeasts, and molds from honey, and found that bacteria and molds predominate on a 10-per-cent-honey agar, but when the concentration of the honey is increased to 30 per cent, yeasts predominate and no bacteria are found. Marvin has isolated five species of yeasts from fermenting honey, but has not given specific determinations for them. Lochhead and his coworkers have isolated and described four species of yeasts of the genus Zygosaccharomyces which are capable of fermenting honey. More recently Marvin and Lochhead and their coworkers have been interested in methods for preventing honey fermentation which are discussed in greater detail later in this bulletin.

Attention has been given to the method by which sugar-tolerant yeasts enter honey. Marvin (1928) suggests, without presenting conclusive evidence, that the mode of entrance is probably on pollen grains. Lochhead and Heron (1929) isolated eleven different sugar-tolerant yeasts from thirty-four species of nectar-bearing flowers. They find honey houses to be one possible source of contamination, and recommend cleanliness and sterilization of equipment. Lochhead and Farrell (1930 a), on making further investigations as to the source of the infection of honey by sugar-tolerant yeasts, isolated and classified one hundred and sixty-six cultures of such yeasts from apiary soil. These yeasts represent seven types, three of which have been found in fermented honey. On examining unripened honey from various hives, and also two hundred samples of unfermented honey from all parts of Canada, these authors conclude that normal honeys regularly contain sugar-tolerant yeasts capable of setting up fermentation under favorable conditions. Since this view has been expressed by other investigators also, it may be taken for granted that all honeys may contain sugar-tolerant yeasts which may cause fermentation whenever conditions become suitable for their growth.

The importance of high moisture content of honey in permitting the product to ferment has long been recognized, and it is well known that if honey is extracted before ripening is complete, fermentation usually results. Because of such experiences, beekeepers formerly attributed honey fermentation to improper ripening. With increased storage of honey for longer periods, however, it has become clear that this explanation is not satisfactory, since honeys of high concentration frequently ferment when stored. It has been claimed also that honeys from certain flowers tend to ferment more rapidly than do those from other flowers. Pugh (1927) found no correlation between the tendency of honey to

ferment, and specific gravity; nor did he find a correlation between fermentation and floral source, color, or climatic conditions at the time when the honey was produced.

Since liquid honeys rarely ferment, and since well-ripened honey seldom shows signs of fermentation for some time after extraction, it becomes important to know what are the changed conditions in honey after prolonged storage which bring about favorable conditions for the growth of yeasts. The well-known hygroscopic nature of honey has often been assumed to be the cause of this change. This is well illustrated by several experiments conducted by Fabian and Quinet (1928), and the following theory was given by them to explain why such a concentrated sugar mixture as honey may ferment: "Briefly stated the theory is that honey being hygroscopic absorbs sufficient water at the surface to lower the concentration of sugars there to a degree compatible with the life of certain yeasts. The yeasts present gradually become accustomed to the higher sugar concentration and eventually grow throughout the honey." Since honeys ferment when they are sealed hermetically, as is shown later in this bulletin, this theory of the cause of fermentation after storage cannot be accepted. While it is true that honeys exposed to a moist atmosphere may ferment quickly, this is by no means the explanation of the loss now experienced by beekeepers.

It is known that the application of sufficient heat lessens or removes the susceptibility of honey to ferment. This is well shown by the fact that honeys which have been heated to 71.11° C. (160° F.) in preparation for bottling, practically never ferment. Marvin (1928) suggests heating honey to 160° F. for this purpose, but does not specify the length of time necessary for the destruction of the yeasts at this temperature. Fabian and Quinet (1928) conducted experiments to determine the thermal death-point of honey-fermenting yeasts, and conclude that heating honey to 62.5° C. for thirty minutes will prevent it from spoiling. They determined the thermal death-point of both vegetative cells and spores, and found the spores more resistant. Their determinations were made in honey which was only slightly diluted with broth. Lochhead and Heron (1929) found that little or no growth of yeasts occurs above 40° C. (104° F.), their tests being made at various dilutions of honey. Rahn (1928), and other workers (some of whom are cited by Fabian and Quinet), have shown that the presence of sugars makes it necessary that higher temperatures be applied for the sterilization of foods, so that in determining the thermal death-point of sugar-tolerant yeasts in fermenting honey it is essential that tests be made in honey or in an equally dense solution of simple sugars rather than in dilute solutions of honey. The results of both Fabian and Quinet, and Lochhead and Heron, support this view completely. The minimum requirements of time and temperature for controlling honey fermentation have not been definitely ascertained, and in any event it would not be safe to apply minimum sterilization. The spoiling of honey by overheating is a common occurrence and is to be avoided. The effect of heating on crystal formation is discussed later.

Since the quality of honey is greatly impaired by the method of heating now in use, other means of controlling fermentation are being investi-

gated. Marvin (1928) suggests that since yeasts are incapable of growth at temperatures below 52° F., fermentation might be controlled by keeping the honey in cold storage. The expense involved would obviously be the chief limiting factor in this practice, and it is doubtful, under present market conditions, whether cold storage is a practicable means of controlling fermentation.

Lochhead and Farrell (1930 b) tried various preservatives as a means of controlling fermentation. They selected chemicals of low toxicity, which are permitted in foods under most laws for the control of foodstuffs on the market. Of the materials used, sodium benzoate, sodium sulfite, and sodium bisulfite were considered the most promising. While it might be possible under existing laws to use such materials without declaration of their presence on the labels of honey containers, the well-known opposition of beekeepers to anything in the nature of food adulteration will probably prevent this means of preserving honey from coming into common use. This is all the more to be expected in view of the fact that, as is shown later, there are better methods for this purpose.

No practicable method other than the application of heat has been advanced to control fermentation. The simplest method, then, is to heat the honey and sell it in the liquid form. Beekeepers have followed the path of least resistance in this respect, and have offered their honey reduced in quality owing to the almost universal practice of overheating the product.

THE GRANULATION PROBLEM

Browne (1908) gives averages of the amount of the several carbohydrates found in honey, based on analyses of 92 samples of American honeys, as follows: levulose, 40.50 per cent; dextrose, 34.02 per cent; sucrose, 1.90 per cent; dextrin, 1.51 per cent. Many other analyses of honey give comparable results, so that it is unnecessary to discuss these in detail. Levulose usually predominates in normal honeys. It forms crystals only under very special conditions, and probably never forms crystals in granulated honey. It is the sugar in honey which most readily breaks down on heating, and its sweetness surpasses that of any of the other common sugars. Dextrose in some honeys exceeds levulose, but is present in smaller amounts in most honeys, as the average shows. Dextrose forms crystals readily from a water solution, and in the granulation of honey it forms the solid phase which serves as a supporting structure, giving to many granulated honeys an appearance of solidity. Sucrose is present in such small amounts that sucrose crystals probably never form in granulated honey. From examinations of granulated honeys, it is proper to assume that these sugars behave in honey as they do in similar mixed solutions in water.

Dextrose hydrate crystals form in most honeys sooner or later. To this phenomenon the beekeeper usually applies the term *granulation,* and in this paper the words *granulation* and *crystallization* are used interchangeably. Some honeys granulate within a few days after extraction from the combs, while others, such as sage and tupelo honeys, may remain liquid for months or years. The size of the dextrose hydrate crystals formed also varies greatly, some honeys granulating with a fine, smooth grain while others form large, coarse crystals. It is well known that

the size of crystals in granulated honey largely determines the quality of the product from the standpoint of human consumption, as the same honey in fine or in coarse crystallization has a very different flavor. The type of crystals formed is therefore of primary importance in the sale of honey.

Dextrose, when it is the only sugar present, remains in solution in water to an amount about equal to the amount of water at ordinary temperatures, so that on this basis honey appears to be a supersaturated dextrose solution. Jackson and Silsbee (1924) have shown, however, that the presence of levulose with dextrose in a water solution increases the solubility of dextrose. To cite a single example from their tables, at 30° C. a solution of dextrose and levulose is saturated with respect to dextrose when 34.85 per cent of each sugar is present. This figure is selected because it agrees closely with the average amount of dextrose in honeys as given by Browne. It thus appears that at temperatures lower than 30° C. an average honey is supersaturated with respect to dextrose, which explains the fact that average honeys form crystals at ordinary temperatures. Analyses show that quickly granulating honeys usually have a higher content of dextrose than do average honeys, while the non-granulating types are high in levulose. Jackson and Silsbee, in discussing crystallization of honey, offer "a possible empirical relation to predict granulation in honey," and state:

> Since, at ordinary temperatures, one part of water holds in solution approximately one part of dextrose, the percentage of dextrose in the honey minus the percentage of water represents the per cent of supersaturated dextrose. This tendency to granulate would be roughly proportional to this quantity. This tendency is inversely proportional to some function of the levulose and we have selected arbitrarily the percentage of levulose itself. Thus
>
> $$\text{Granulation tendency} = \frac{D-W}{L}$$
>
> in which D, W, and L represent the percentage of dextrose, water, and levulose, respectively. The formula is very evidently a measure of instability.

Honeys in granulated form ferment more readily than does liquid honey, whether or not the honey has been heated to keep it liquid. As has already been stated, fermentation does not occur for some time after extraction, which means that fermentation does not get under way until granulation has progressed considerably. The explanation of the more ready fermentation of granulated honeys lies in the fact that when dextrose hydrate crystals are formed in honey the liquid phase of the honey has a higher water content than the entire honey had while it was still liquid. When dextrose forms crystals in a water solution, the composition of the crystals is that of dextrose hydrate, and the water of crystallization amounts to only 9.09 per cent of the material in solid form. Since the average water content of honey is about 17 to 19 per cent, this means that when a portion is removed in solid form containing a lower percentage of water the remaining liquid phase has an increased water content. Fabian and Quinet (1928) have shown that a slight increase in water content permits the growth of sugar-tolerant yeasts, and this is what occurs when honeys ferment. Only a slight increase over the original water content of the honey is required to permit fermentation to proceed, and, as has already been stated, the yeasts are always present

and ready to grow whenever the water content of the liquid phase of a honey becomes sufficiently high.

It has sometimes been assumed that fermentation of honey begins or occurs more readily at or near the surface. This theory is hypothesized because of the well-known tendency of honeys to absorb moisture from a moist atmosphere. While it sometimes happens that the moisture content of honey, whether or not the honey is granulated, is slightly higher near the top of the container than elsewhere, the important change in water content is that due to granulation. As a matter of fact, fermentation occurs throughout the entire container in most cases in which this phenomenon is observed. The anaerobic nature of the yeasts makes it unnecessary that fermentation should occur at or near the surface.

It has also been erroneously stated by Marvin (1930) that fermentation occurs after separation of honey into solid and liquid layers. Apparently this author has been confused by the fact that there is a change in water content due to granulation, and has failed to observe that this change occurs throughout the honey. At any rate, it is a matter of common knowledge that fermentation usually begins while the honey is completely granulated throughout, and not after separation has occurred. Usually separation is an indication that fermentation has been going on for some time, and it is a sign of fermentation rather than a condition favorable to it.

Since the quality of granulated honey is influenced by the size of crystals, the problem of control of crystal size becomes of vital importance. Most of the foods analogous to honey offered in trade are highly refined and standardized. Consumers of honey, in common with consumers of other foods, desire a uniform product of superior quality. If inferior honey is purchased, the consumer's faith in the product is lost and other foods of known uniformity are chosen. It is therefore highly desirable that a method be devised for bringing about a uniform, finely crystallized product which will not ferment.

Investigators, recognizing the fact that large crystals in honey impair the flavor and that fine crystallization gives a better flavor, have attempted to bring about a condition of small crystals, or pieces of crystals, by grinding the honey in a suitable mill after rough crystallization has been allowed to become complete. This product now appears on the market under various trade names, such as Honey Cream or Cream of Honey. In grinding honey it is inevitable that myriads of minute air bubbles will become incorporated in it. If these bubbles are large enough, they rise to the top and some of them may escape; but, because of the high viscosity of honey and the added density due to crystal formation, it is found that most of the air bubbles remain in the honey. Some of the larger bubbles rise to the top but do not escape, forming an undesirable scum. While the flavor of this product is excellent (better than that of the same honey in liquid form), the objectionable scum detracts from its appearance and salability. This combination of conditions has been kept in mind in the processes described later, in the hope that an equally good or a better product may be obtained which will lack the undesirable features of the product now marketed.

Honey which has been heated to control fermentation or for other reasons invariably forms large crystals of dextrose hydrate, which in trade are decidedly objectionable. Should the honey not be consumed before these crystals are formed, the producer or the bottler may be put to the expense of reheating the honey in order that the crystals may be redissolved. It is well known that excessive heating retards the formation of the crystals, and it is a common practice to overheat the honey, thus impairing its quality, in order that these objectionable crystals may be prevented or sufficiently delayed in their formation so that the honey will probably be consumed before they appear.

It is known also that crystals present in honey hasten further crystallization, roughly in proportion to their quantity, or number. Extracted honey usually granulates more rapidly than does comb honey, and this is attributed to the fact that extracted honey contains more crystals. The agitation which honey undergoes during extraction, and especially in violent pumping, also is a factor. As is shown later, the honey left on combs after extraction, which partially crystallizes before the combs are again used, is doubtless another factor in the more rapid granulation of extracted honey.

Temperature also influences the rate of crystallization, and it is usually stated in beekeeping literature that fluctuating temperatures hasten granulation. As it shown later, this common opinion with regard to temperatures affecting granulation is incorrect.

As already stated, honeys in crystalline form are more susceptible to fermentation than are liquid honeys. Since the application of heat to control fermentation causes the formation of objectionable crystals, some modification of methods for preventing fermentation in crystallized honey should be devised. The method should be as economical as possible and should be of such a nature as not to injure the quality of the honey, and no preservative should be used if it can possibly be avoided. The method should also be of such a nature as to permit honeys to be stored over long periods without spoilage.

Since the fermentation and the crystallization of honey are at present inadequately controlled, the following investigational work was conducted with the object of contributing toward a better understanding of these problems and in an effort to overcome their complications. The two problems are obviously complicated and interrelated, and no satisfactory solution seems possible for one that does not automatically involve the solution of the other.

EFFECT OF METHODS OF PACKING, ON FERMENTATION AND GRANULATION OF HONEY

Retail packages of honey are usually closed by the use of either friction-top lids for tin packages or screw-top lids for bottles. The former type of container is closed by pressing a tightly fitting lid into the top. The bottles are closed by screwing the lids on as tightly as possible. In the larger bottling establishments other methods of closing the bottles are used, but for the local trade the screw-top lids are in commonest use. Neither the friction-top can nor the screw-top bottle is hermetically sealed. Wholesale packages for honey are usually 60-pound cans with

screw tops of various sizes. These are rarely air-tight. Although the area of the honey exposed to atmospheric changes is greatly reduced in these larger containers, if absorption or drying affect honey these conditions are possible in the ordinary large tins. It is well known that honey absorbs moisture from the atmosphere, or dries out when placed in an atmosphere of low relative humidity. Evidently any sealing which is not tight may permit absorption of moisture or drying-out, so that the common methods of packing honey do not prevent effects of humidity in the air. This is well shown by the appearance of honey packages that have stood for some time after packing.

As no definite information was available on the keeping qualities of honeys when packed in the usual ways, it was considered desirable to conduct some experiments on the subject. For purposes of comparison, identical honeys were packed by different methods. The main purpose when the work was begun was to determine the effect of the method of sealing on fermentation, but as the study progressed it became evident that the problem of granulation also was intimately involved. By selecting a wide range of floral sources, density, methods of production, and methods of extraction, it was hoped that some information might be derived as to the benefits of suitable packing, and at the same time some much-needed information obtained on the phenomena of fermentation and granulation.

As the work progressed it became evident that a satisfactory solution of these two important problems could not be obtained from a study of methods of packing alone, and from the earlier experiments reported in this section suggestions were obtained which led to the planning of the work reported in the latter part of this paper. There are, however, many things of importance to be learned from methods of packing, and, while this study did not give the results for which some hope was entertained, it seems to be of adequate economic importance to justify reporting it in some detail. Certain series of samples are not reported here fully, since they served chiefly to substantiate results obtained in the series reported more in detail.

MATERIAL AND METHODS USED

The honey used in the experiments was placed in containers which were closed by the following methods: (1) vacuum sealing of tin containers; (2) hermetic sealing of tin containers; (3) friction tops for tin containers; (4) screw tops for glass containers.

In sealing the honey under vacuum, sanitary tins 2 inches in height by 3⅜ inches in diameter, holding nearly one pound of honey, were used. A standard vacuum machine, such as is used in the canning industry, was employed. To insure efficient operation, frequent inspections of the vacuum machine were made by a specialist from the company furnishing the equipment. The machine was motor-driven and was capable of drawing and sealing under 30 inches of vacuum; but in all of these experiments 25 inches of vacuum was used, this figure being more or less standard in the canning industry. In order to insure that there would be no leakage of air, the containers were so made as to have five layers of tin with a sealing compound between them at the point of union, or

seam, of the lid and the container. In this manner the containers were made tight, and were found to be capable of retaining a high vacuum under proper conditions of sealing.

The same containers as were used in the vacuum series were used to seal the honey in tins hermetically. The method of sealing was identical with that of the vacuum series, except that no vacuum was drawn. This was accomplished by leaving the door of the vacuum chamber open.

The friction-top tins used in the experiments were made on exactly the same plan as are the metal containers commonly used in honey packing, except that they were smaller, being about 3¾ inches in height by 3⅛ inches in diameter, holding nearly one pound of honey.

Glass jars about 7 inches in height by 2½ inches in diameter, holding more than one pound of honey, were used for the fourth series. In the screw top were inserted disks of both cardboard and oiled paper. The jars were identical with those commonly used in the honey trade, except as to size.

When the containers were closed, each series was divided into three approximately equal portions, one-third being stored at Ithaca, New York, one-third at Guelph, Ontario, and one-third at Chicago, Illinois. The place of storage and the dates of examination are shown in the tabulated results of the various experiments. The three locations represent different, but normal, storage conditions for honey. It will be noticed in the tabulated results that some series were not sent to Chicago. It will be noticed also that certain experiments were conducted at Chicago in which the writer took no active part except for supplying the honey. These experiments were, however, a part of the whole plan drawn up at the beginning of the study, and were carried out under the exact conditions set forth at that time. They are therefore reported briefly.

At Ithaca the honeys were kept from November 1, 1929, to May 23, 1930, in the apiculture laboratory of the State College of Agriculture. The room in which they were stored is low in humidity and usually has a temperature ranging between 80° and 90° F. From May 23, 1930, to October 16, 1930, the honeys were stored in an unused cold-storage room which also was low in humidity and in which a temperature of about 75° F. was maintained. On October 16, 1930, the honeys were moved into the newly established honey laboratory at the College, and they remained there until the final examination in February, 1931. Owing to the amount of steam and water used in the work with honey in this room, the humidity as well as the temperature is often unusually high.

At Guelph the samples were stored in the basement of the Apiculture Building of the Ontario Agricultural College. The temperature was usually between 70° and 80° F. Owing to the location and the structure of the building, the humidity was rather high.

At Chicago the honeys were kept under normal storage conditions in a special room of the research laboratories of the American Can Company. The temperature remained at about 70° F. and the humidity was never extremely high or extremely low.

Each experiment is divided into series, and the four types of sealing are reported under each series. To cite an example, experiment 1 is divided into series A–D, E–H, and I–L. The first letter in each series

(A, E, I) indicates that the honey is sealed under vacuum; the second letter (B, F, J) indicates hermetic sealing; the third letter (C, G, K) indicates friction-top tins; and the fourth letter (D, H, L) indicates screw-top glass jars.

Under vacuum for each series of each experiment, 48 tins were filled with identical honey and sealed. An equal number of tins were used for the hermetic sealing. The reason for using a large number of containers was to permit frequent examination over a long period of storage. Since examinations could be made of the honey in the friction-top tins and the screw-top glass jars without harmful results, only 6 containers were used for each series with these containers.

Examinations were made as shown in the tables presenting the results of each series. It is extremely difficult to judge accurately the percentages of fermentation, crystallization, separation, and other phenomena. In anticipation of such difficulties an effort was made to set up standards for each characteristic, and the writer has tried to attain at least accuracy for comparisons. In the case of a sample the results of which were somewhat doubtful, two or more containers were opened. When this occurred under the vacuum series, the average number of inches of vacuum was recorded.

The examination of the samples at Chicago made on March 14, 1930, was conducted by members of the Research Division of the American Can Company, Dr. E. F. Phillips of Cornell University, and the writer. The data were tabulated by an employee of the Research Division of the Can Company, and, unfortunately, certain inaccuracies occurred which were due largely to different methods of expressing results. All doubtful tabulations are omitted from this paper.

The number of inches of vacuum was determined by inserting a standard vacuum gauge through the lid of each container just before opening. This gauge is constructed so as to give an accurate reading of vacuum without loss of air at the point of insertion.

The following rather indefinite terms are used as descriptions of size of crystals in the honey samples: very fine; fine; medium coarse; coarse; very coarse.

EXPERIMENTS WITH VARIOUS METHODS OF PACKING HONEYS

In order to determine what effect various methods of packing may have on fermentation and granulation of honeys, a series of experiments was planned to give as wide a variation of conditions as was practicable. The details of the honeys, and the methods used, are set forth in the following tabulations.

Experiment 1[2]

Series A–D of experiment 1 was a honey from White Dutch and alsike clover, sp. gr. 1.420, produced in the apiary of the Ontario Agricultural

[2]Definitions of terms used in descriptions of honeys here and elsewhere in this bulletin are as follows:

Wet combs are combs that are stored until the following season, immediately after extraction, without allowing the bees to remove the film of honey adhering to the cell walls.

Dry combs are combs that have been returned to the bees after extraction, in order that they may remove any honey which is still adhering to the cell walls.

A *honey pump* is a centrifugal pump used to convey honey from the extractor to large storage tanks.

College, Wellington County, Ontario. It was extracted from wet combs and run through a honey pump on August 17, 1929. This honey was unheated and totally liquid at the time of canning, August 17, 1929.

Series E–H, also from White Dutch and alsike clover, sp. gr. 1.434, was likewise produced in the apiary of the Ontario Agricultural College, Wellington County, Ontario. This honey was extracted on August 19, 1929, from dry combs which were completely capped, and was not pumped. It was gathered at the same time and in the same apiary as the honey used in series A–D. The honey was unheated and totally liquid at the time of canning, August 19, 1929.

Series I–L was the same honey as was used in series A–D. Prior to the date of canning, the honey was totally crystallized and was liquefied by heating to 130° F. for thirty minutes. The honey was canned while it was still warm, on September 24, 1929.

Discussion

Fermentation was encountered only in series A–D. Since the honey was abnormally high in water content, fermentation might have been expected. When fermentation was advanced, it was present under the four methods of packing. Under moist conditions at Guelph, the honey in glass and in friction-top tins showed more advanced fermentation as compared with the same honey sealed hermetically or under vacuum. At Ithaca the honey in glass and in friction-top tins showed a little less fermentation, owing possibly to the dried surface of the honey. No fermentation was present in the honey used in series I–L at the time of the last examination. This honey was identical with the honey used in series A–D, except that it was heated to 130° F. for thirty minutes. In this case, apparently this treatment was sufficient to destroy the sugar-tolerant yeasts, thereby preventing fermentation or at least delaying it for a considerable length of time. The honey used in series E–H also showed no signs of fermentation. This honey was produced in the same apiary and at the same time as the honey used in series A–D, but had a lower water content. The results are shown in table 1.

The size of crystals and the rapidity of crystallization were uniform within each series of experiment 1, but varied greatly between the three different series. In series A–D the honey was totally crystallized early in September, 1929, and the crystals formed were small. In series E–H the honey was not totally crystallized until the middle of November, 1929, and the crystals formed were large and coarse. The heated honey used in series I–L was only about 50 per cent crystallized by February, 1931, and the crystals formed were extremely coarse.

The data from experiment 1 indicate that small crystals are formed under conditions of rapid crystallization, but that when crystallization is retarded the crystals formed are larger and coarser. Evidently the rapidity at which honey crystallizes directly influences the size of crystals formed.

The honeys used in series A–D and E–H were identical, except that the former was extracted from wet combs and run through a honey pump, while the latter was extracted from dry combs and was not pumped. The honey in series A–D crystallized rapidly, while the honey in series

TABLE 1. CONDITION OF HONEYS UNDER VARIOUS METHODS OF PACKING AFTER VARIOUS TIME INTERVALS, EXPERIMENT 1

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				I. Series A–D				
October 26, 1929....	A	Vacuum...	2	100.....	Very fine..	No.....	Moist.....	Guelph
October 26, 1929....	B	Hermetic..	.....	100.....	Very fine..	No.....	Moist.....	Guelph
October 26, 1929....	C	Friction...	.....	100.....	Very fine..	No.....	Moist.....	Guelph
October 26, 1929....	D	Glass.....	.....	100.....	Very fine..	No.....	Moist.....	Guelph
November 26, 1929..	A	Vacuum...	1	100.....	Very fine..	No.....	Moist.....	Ithaca
November 26, 1929..	B	Hermetic..	.....	100.....	Very fine..	No.....	Moist.....	Ithaca
November 26, 1929..	C	Friction...	.....	100.....	Very fine..	No.....	Moist.....	Ithaca
November 26, 1929..	D	Glass.....	.....	100.....	Very fine..	No.....	Moist.....	Ithaca
November 28, 1929..	A	Vacuum...	0	100.....	Very fine..	No.....	Moist.....	Guelph
November 28, 1929..	B	Hermetic..	.....	100.....	Very fine..	No.....	Moist.....	Guelph
November 28, 1929..	C	Friction...	.....	100.....	Very fine..	No.....	Moist.....	Guelph
November 28, 1929..	D	Glass.....	.....	100.....	Very fine..	No.....	Moist.....	Guelph
December 29, 1929..	A	Vacuum...	1	100.....	Very fine..	No.....	Moist.....	Ithaca
December 29, 1929..	B	Hermetic..	.....	100.....	Very fine..	No.....	Moist.....	Ithaca
December 29, 1929..	C	Friction...	.....	100.....	Very fine..	No.....	Dry.....	Ithaca
December 29, 1929..	D	Glass.....	.....	100.....	Very fine..	No.....	Moist.....	Ithaca
February 14, 1930...	A	Vacuum...	0	100.....	Very fine..	No.....	Moist.....	Ithaca
February 14, 1930...	B	Hermetic..	.....	100.....	Very fine..	No.....	Moist.....	Ithaca
February 14, 1930...	C	Friction...	.....	100.....	Very fine..	No.....	Dry.....	Ithaca
February 14, 1930...	D	Glass.....	.....	100.....	Very fine..	No.....	Moist.....	Ithaca
March 14, 1930.....	A	Vacuum...	0	100.....	Very fine..	No.....	Moist.....	Chicago
March 14, 1930.....	B	Hermetic..	.....	100.....	Very fine..	No.....	Moist.....	Chicago
March 14, 1930.....	C	Friction...	.....	100.....	Very fine..	No.....	Moist.....	Chicago
March 14, 1930.....	D	Glass.....	.....	100.....	Very fine..	No.....	Moist.....	Chicago
May 23, 1930.....	A	Vacuum...	0	100.....	Very fine..	Yes.....	Moist.....	Ithaca
May 23, 1930.....	B	Hermetic..	.....	100.....	Very fine..	Yes.....	Moist.....	Ithaca
May 23, 1930.....	C	Friction...	.....	100.....	Very fine..	Slightly...	Dry.....	Ithaca
May 23, 1930.....	D	Glass.....	.....	100.....	Very fine..	Slightly...	Dry.....	Ithaca
June 4, 1930.....	A	Vacuum...	0	100.....	Very fine..	Yes.....	Moist.....	Guelph
June 4, 1930.....	B	Hermetic..	.....	100.....	Very fine..	Yes.....	Moist.....	Guelph
June 4, 1930.....	C	Friction...	.....	100.....	Very fine..	Yes.....	Moist.....	Guelph
June 4, 1930.....	D	Glass.....	.....	100.....	Very fine..	Yes.....	Moist.....	Guelph
September 2, 1930...	A	Vacuum...	0	100.....	Very fine..	Yes.....	Moist.....	Guelph
September 2, 1930...	B	Hermetic..	.....	100.....	Very fine..	Yes.....	Moist.....	Guelph
September 2, 1930...	C	Friction...	.....	100.....	Very fine..	Yes.....	Moist.....	Guelph
September 2, 1930...	D	Glass.....	.....	100.....	Very fine..	Yes.....	Moist.....	Guelph
February 9, 1931....	A	Vacuum...	0	5% sep.*..	Very fine..	Yes.....	Moist.....	Guelph
February 9, 1931....	B	Hermetic..	.....	5% sep....	Very fine..	Yes.....	Moist.....	Guelph
February 9, 1931....	C	Friction...	.....	5% sep....	Very fine..	Yes.....	Moist.....	Guelph
February 9, 1931....	D	Glass.....	.....	5% sep....	Very fine..	Yes.....	Moist.....	Guelph
February 20, 1931...	A	Vacuum...	0	10% sep...	Very fine..	Yes.....	Moist.....	Ithaca
February 20, 1931...	B	Hermetic..	.....	10% sep...	Very fine..	Yes.....	Moist.....	Ithaca
February 20, 1931...	C	Friction...	.....	10% sep...	Very fine..	Yes.....	Moist.....	Ithaca
February 20, 1931...	D	Glass.....	.....	10% sep...	Very fine..	Yes.....	Moist.....	Ithaca

* Separation: a term applied to crystallized honey which shows a liquid layer on the surface.

TABLE 1 (*continued*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
			II. Series E–H					
October 26, 1929....	E	Vacuum...	12	80.....	Coarse....	No.....	Moist.....	Guelph
October 26, 1929....	F	Hermetic..	.....	80.....	Coarse....	No.....	Moist.....	Guelph
October 26, 1929....	G	Friction...	.....	80.....	Coarse....	No.....	Moist.....	Guelph
October 26, 1929....	H	Glass.....	.....	80.....	Coarse....	No.....	Moist.....	Guelph
November 26, 1929..	E	Vacuum...	18	100.....	Coarse....	No.....	Moist.....	Ithaca
November 26, 1929..	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
November 26, 1929..	G	Friction...	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
November 26, 1929..	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
November 28, 1929..	E	Vacuum...	8	100.....	Coarse....	No.....	Moist.....	Guelph
November 28, 1929..	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Guelph
November 28, 1929..	G	Friction...	.....	100.....	Coarse....	No.....	Moist.....	Guelph
November 28, 1929..	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Guelph
December 29, 1929..	E	Vacuum...	10	100.....	Coarse....	No.....	Moist.....	Ithaca
December 29, 1929..	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
December 29, 1929..	G	Friction..	.....	100.....	Coarse....	No.....	Dry.....	Ithaca
December 29, 1929..	H	Glass.....	.....	100.....	Coarse....	No.....	Drying....	Ithaca
February 14, 1930...	E	Vacuum...	13	100.....	Coarse....	No.....	Moist.....	Ithaca
February 14, 1930...	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
February 14, 1930...	G	Friction ..	.....	100.....	Coarse....	No.....	Dry.....	Ithaca
February 14, 1930...	H	Glass.....	.....	100.....	Coarse....	No.....	Dry.....	Ithaca
March 14, 1930.....	E	Vacuum...	5	100.....	Coarse...	No.....	Dry.....	Chicago
March 14, 1930.....	F	Hermetic..	.....	100.....	Coarse....	No.....	Dry.....	Chicago
March 14, 1930.....	G	Friction...	.....	100.....	Coarse....	No.....	Dry.....	Chicago
March 14, 1930.....	H	Glass.....	.....	100.....	Coarse....	No.....	Dry.....	Chicago
May 23, 1930.....	E	Vacuum...	9	100.....	Coarse....	No.....	Moist.....	Ithaca
May 23, 1930.....	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
May 23, 1930.....	G	Friction...	.....	100.....	Coarse....	No.....	Very dry..	Ithaca
May 23, 1930.....	H	Glass.....	.....	100.....	Coarse....	No.....	Very dry..	Ithaca
June 4, 1930.....	E	Vacuum...	3	100.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	G	Friction...	.....	100.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	E	Vacuum...	8	100.....	Coarse. ..	No.....	Moist.....	Guelph
September 2, 1930...	F	Hermetic..	.....	100.....	Coarse. ..	No.....	Moist.....	Guelph
September 2, 1930...	G	Friction...	.....	100.....	Coarse. ..	No.....	Very moist	Guelph
September 2, 1930...	H	Glass.....	.....	100.....	Coarse....	No.....	Very moist	Guelph
February 9, 1931....	E	Vacuum...	0	100.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	G	Friction...	.....	100.....	Coarse....	No.....	Moist.....	Guelpn
February 9, 1931....	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Guelph
February 20, 1931...	E	Vacuum...	0	100.....	Coarse....	No.....	Moist.....	Ithaca
February 20, 1931...	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
February 20, 1931...	G	Friction...	.....	100.....	Coarse....	No.....	Dry.....	Ithaca
February 20, 1931...	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Ithaca

TABLE 1 (*concluded*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
III. Series I–L								
October 26, 1929....	I	Vacuum...	21	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	K	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
November 26, 1929..	I	Vacuum...	8	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	K	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Ithaca
November 28, 1929..	I	Vacuum...	19	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	K	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
December 29, 1929..	I	Vacuum...	13	10.....	Very coarse	No.....	Moist.....	Ithaca
December 29, 1929..	J	Hermetic..	.....	10.....	Very coarse	No.....	Moist.....	Ithaca
December 29, 1929..	K	Friction...	.....	10.....	Very coarse	No.....	Drying....	Ithaca
December 29, 1929..	L	Glass.....	.....	10.....	Very coarse	No.....	Moist.....	Ithaca
February 14, 1930...	I	Vacuum...	16	20.....	Very coarse	No.....	Moist.....	Ithaca
February 14, 1930...	J	Hermetic..	.....	20.....	Very coarse	No.....	Moist.....	Ithaca
February 14, 1930...	K	Friction...	.....	20.....	Very coarse	No.....	Dry.....	Ithaca
February 14, 1930...	L	Glass.....	.....	20.....	Very coarse	No.....	Drying....	Ithaca
March 14, 1930.....	I	Vacuum...	22	Incomplete	Very coarse	No.....	Moist.....	Chicago
March 14, 1930.....	J	Hermetic..	.....	Incomplete	Very coarse	No.....	Moist.....	Chicago
March 14, 1930.....	K	Friction...	.....	Incomplete	Very coarse	No.....	Moist.....	Chicago
March 14, 1930.....	L	Glass.....	.....	Incomplete	Very coarse	No.....	Moist.....	Chicago
May 23, 1930.....	I	Vacuum...	20	30.....	Very coarse	No.....	Moist.....	Ithaca
May 23, 1930.....	J	Hermetic..	.....	30.....	Very coarse	No.....	Moist.....	Ithaca
May 23, 1930.....	K	Friction...	.....	30.....	Very coarse	No.....	Very dry..	Ithaca
May 23, 1930.....	L	Glass.....	.....	30.....	Very coarse	No.....	Dry.....	Ithaca
June 4, 1930.....	I	Vacuum...	19	30.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	J	Hermetic..	.....	30.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	K	Friction...	.....	30.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	L	Glass.....	.....	30.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	I	Vacuum...	18	40.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	J	Hermetic..	.....	40.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	K	Friction...	.....	40.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	L	Glass.....	.....	40.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	I	Vacuum...	18	50.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	J	Hermetic..	.....	50.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	K	Friction...	.....	50.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	L	Glass.....	.....	50.....	Very coarse	No.....	Moist.....	Guelph
February 20, 1931...	I	Vacuum...	16	50.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	J	Hermetic..	.....	50.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	K	Friction...	.....	50.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	L	Glass.....	.....	50.....	Very coarse	No.....	Moist.....	Ithaca

E–H crystallized rather slowly and the crystals were larger and coarser. It is rather difficult to account for the difference in crystallization between these two series. The honey used in series E–H had a high specific gravity, but it is known from other samples that highly concentrated honeys also may crystallize rapidly and form small crystals. The relative proportions of the different sugars in honeys may have an influence on the rapidity of crystallization, but the two lots of honey under discussion should be identical in this respect.

As already stated, the honey used in series A–D was extracted from wet combs and run through a honey pump, while the honey used in series E–H was extracted from dry combs and was not pumped. It is possible that the film of honey adhering to the cell walls of the wet combs after extraction, crystallized during the winter. This crystallized film of honey on the combs being filled again by the bees, and the honey extracted the following season, may have caused large numbers of small crystals to be incorporated in the honey, which should hasten crystallization. The breakage of the crystals present by the mechanical action of the honey pump also may have hastened crystallization.

In series A–D of experiment 1, a slight separation was present. The term *separation* is usually applied to crystallized honeys which have not been heated and which later show a liquid layer on the surface. The line of demarcation between the liquid layer and the crystal layer is usually clear and distinct. Heated honeys which have been so treated or processed as to cause the formation of small crystals, also may show such a separation, but untreated heated honeys rarely show a characteristic separation. The crystals in heated honeys are usually large, and settle to the bottom of the container or hang in flocculent curtains within the liquid honey, the line of demarcation between the liquid and the crystal parts rarely being distinct. In February, 1931, the samples of series A–D opened at Guelph showed a 5-per-cent separation, while at Ithaca a 10-per-cent separation was present. The honeys at Ithaca were kept at a higher temperature than were those at Guelph, and fermentation was further advanced. Since separation also was further advanced at Ithaca, it is suggested that separation may be correlated with fermentation, either as a contributing factor or as a result.

In series A and E the vacuum was either lost or greatly reduced. When fermentation occurs, a loss of vacuum is to be expected; but, since the vacuum was lost or greatly reduced shortly after the honey was sealed, and long before fermentation had commenced, a further explanation is necessary. Since the honeys used in series A and E were not heated and since the honey used in series I was heated, it would appear that the vacuum is lost or greatly reduced in unheated honeys while it is retained to a greater degree in heated honeys. In unheated honeys large numbers of small air bubbles may be present, but on heating the honey these bubbles are at least partly driven off. It is possible that the honeys used in series A and E contained a large number of small air bubbles when they were sealed, so that as time progressed these bubbles were gradually drawn to the surface, thereby causing a reduction or a total loss of vacuum.

A reduction of vacuum was noticed in the unheated samples of honey in November, 1929, and in order to check the efficiency of the vacuum machine 15 empty containers were sealed under 27 inches of vacuum. These containers were opened at Guelph in February, 1931, and it was found that 12 of the containers retained a vacuum of more than 20 inches while the remaining 3 containers retained a vacuum of more than 10 inches. Apparently the loss of vacuum was not entirely due to inefficiency of the vacuum machine or of the containers.

To determine the effect of vacuum in drawing air bubbles from cold unheated honey, the following experiment was conducted. Several samples of honey were placed in open containers under 27 inches of vacuum for various periods of time up to one hour. Just before subjecting the honeys to vacuum the depths of two or three conspicuous air bubbles in the honey were measured. It was found that these bubbles gradually rise to the surface but that their upward movement is slow. It would appear, then, that the loss of vacuum is due largely to rising air bubbles in the unheated honey, rather than to inefficiency of the vacuum machine or of the containers.

The results from experiment 1 indicate that the type of sealing has little or no effect on the rapidity or on the type of crystallization, and is of little importance in the control of fermentation except when the honey is stored under moist conditions. The hygroscopic property of honey was evident, and the samples in glass and in friction-top tins at Guelph, under moist conditions, showed a slight advance in fermentation as compared with the vacuum and the hermetically sealed honeys. The samples in glass and in friction-top tins stored at Ithaca, under dry conditions, showed considerable drying on the surface. This drying, although it tends to conceal apparent fermentation, caused the surface of the honey to become plastic and of an objectionable thick consistency.

Experiment 2

Series E–H of experiment 2, made from white sweet clover, sp. gr. 1.431, was produced in Simcoe County, Ontario. It was extracted from dry combs on September 2, 1929, and was not pumped. It was unheated and totally liquid at the time of canning, September 17, 1929.

Series M–P was the same honey as was used in series E–H. The honey was totally liquid, but was heated to 130° F. and held at that temperature for thirty minutes before canning on September 24, 1929.

Discussion

Experiment 2 was practically a duplication of experiment 1, except that white-sweet-clover honey, produced in a different locality, was used instead of White-Dutch-and-alsike-clover honey. The results from experiment 2 are almost identical with those from experiment 1, and are of value in supporting some of the conclusions tentatively drawn from experiment 1. The results are shown in table 2.

TABLE 2. CONDITION OF HONEYS UNDER VARIOUS METHODS OF PACKING AFTER VARIOUS TIME INTERVALS, EXPERIMENT 2

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
			I. Series E–H					
October 26, 1929....	E	Vacuum...	3	60.....	Coarse....	No.....	Moist.....	Guelph
October 26, 1929....	F	Hermetic..	.....	60.....	Coarse....	No.....	Moist.....	Guelph
October 26, 1929....	G	Friction...	.....	80.....	Coarse....	No.....	Moist.....	Guelph
October 26, 1929....	H	Glass.....	.....	60.....	Coarse....	No.....	Moist.....	Guelph
November 26, 1929..	E	Vacuum...	4	80.....	Coarse....	No.....	Moist.....	Ithaca
November 26, 1929..	F	Hermetic..	.....	80.....	Coarse....	No.....	Moist.....	Ithaca
November 26, 1929..	G	Friction...	.....	90.....	Coarse....	No.....	Moist.....	Ithaca
November 26, 1929..	H	Glass.....	.....	80.....	Coarse....	No.....	Moist.....	Ithaca
November 28, 1929..	E	Vacuum...	0	90.....	Coarse....	No.....	Moist.....	Guelph
November 28, 1929..	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Guelph
November 28, 1929..	G	Friction...	.....	100.....	Coarse....	No.....	Moist.....	Guelph
November 28, 1929..	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Guelph
December 29, 1929..	E	Vacuum...	2	100.....	Coarse....	No.....	Moist.....	Ithaca
December 29, 1929..	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
December 29, 1929..	G	Friction...	.....	100.....	Coarse....	No.....	Drying....	Ithaca
December 29, 1929..	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
February 14, 1930...	E	Vacuum...	0	100.....	Coarse....	No.....	Moist.....	Ithaca
February 14, 1930...	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
February 14, 1930...	G	Friction...	.....	100.....	Coarse....	No.....	Dry.....	Ithaca
February 14, 1930...	H	Glass.....	.....	100.....	Coarse....	No.....	Drying....	Ithaca
March 14, 1930.....	E	Vacuum...	0	100.....	Coarse....	No.....	Moist.....	Chicago
March 14, 1930.....	F	Hermetic.	.....	100.....	Coarse....	No.....	Drying....	Chicago
March 14, 1930.....	G	Friction...	.....	100.....	Coarse....	No.....	Drying....	Chicago
March 14, 1930.....	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Chicago
May 23, 1930.....	E	Vacuum...	1	100.....	Coarse....	No.....	Moist.....	Ithaca
May 23, 1930.....	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
May 23, 1930.....	G	Friction...	.....	100.....	Coarse....	No.....	Dry.....	Ithaca
May 23, 1930.....	H	Glass.....	.....	100.....	Coarse....	No.....	Dry.....	Ithaca
June 4, 1930.....	E	Vacuum...	0	100.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	G	Friction...	.....	100.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	E	Vacuum...	0	100.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	G	Friction...	.....	100.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	E	Vacuum...	0	100.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	G	Friction...	.....	100.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	H	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Guelph
February 20, 1931...	E	Vacuum...	0	100.....	Coarse....	No.....	Moist.....	Ithaca
February 20, 1931...	F	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Ithaca
February 20, 1931...	G	Friction...	.....	100.....	Coarse....	No.....	Dry.....	Ithaca
February 20, 1931...	H	Glass.....	.....	100.....	Coarse....	No.....	Dry.....	Ithaca

TABLE 2 (*concluded*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				II. Series M–P				
October 26, 1929	M	Vacuum	22	0		No	Moist	Guelph
October 26, 1929	N	Hermetic		0		No	Moist	Guelph
October 26, 1929	O	Friction		0		No	Moist	Guelph
October 26, 1929	P	Glass		0		No	Moist	Guelph
November 26, 1929	M	Vacuum	16	0		No	Moist	Ithaca
November 26, 1929	N	Hermetic		0		No	Moist	Ithaca
November 26, 1929	O	Friction		0		No	Moist	Ithaca
November 26, 1929	P	Glass		0		No	Moist	Ithaca
November 28, 1929	M	Vacuum	18	0		No	Moist	Guelph
November 28, 1929	N	Hermetic		0		No	Moist	Guelph
November 28, 1929	O	Friction		0		No	Moist	Guelph
November 28, 1929	P	Glass		0		No	Moist	Guelph
December 29, 1929	M	Vacuum	21	0		No	Moist	Ithaca
December 29, 1929	N	Hermetic		0		No	Moist	Ithaca
December 29, 1929	O	Friction		0		No	Drying	Ithaca
December 29, 1929	P	Glass		0		No	Moist	Ithaca
February 14, 1930	M	Vacuum	14	10	Very coarse	No	Moist	Ithaca
February 14, 1930	N	Hermetic		10	Very coarse	No	Moist	Ithaca
February 14, 1930	O	Friction		20	Very coarse	No	Dry	Ithaca
February 14, 1930	P	Glass		10	Very coarse	No	Moist	Ithaca
March 14, 1930	M	Vacuum	16	50	Very coarse	No	Moist	Chicago
March 14, 1930	N	Hermetic		Slight	Very coarse	No	Moist	Chicago
March 14, 1930	O	Friction		25	Very coarse	No	Moist	Chicago
March 14, 1930	P	Glass		25	Very coarse	No	Moist	Chicago
May 25, 1930	M	Vacuum	21	20	Very coarse	No	Moist	Ithaca
May 25, 1930	N	Hermetic		20	Very coarse	No	Moist	Ithaca
May 25, 1930	O	Friction		40	Very coarse	No	Dry	Ithaca
May 25, 1930	P	Glass		20	Very coarse	No	Moist	Ithaca
June 4, 1930	M	Vacuum	8	50	Very coarse	No	Moist	Guelph
June 4, 1930	N	Hermetic		50	Very coarse	No	Moist	Guelph
June 4, 1930	O	Friction		60	Very coarse	No	Moist	Guelph
June 4, 1930	P	Glass		60	Very coarse	No	Moist	Guelph
September 2, 1930	M	Vacuum	19	70	Very coarse	No	Moist	Guelph
September 2, 1930	N	Hermetic		70	Very coarse	No	Moist	Guelph
September 2, 1930	O	Friction		80	Very coarse	No	Moist	Guelph
September 2, 1930	P	Glass		80	Very coarse	No	Moist	Guelph
February 9, 1931	M	Vacuum	17	90	Very coarse	No	Moist	Guelph
February 9, 1931	N	Hermetic		90	Very coarse	No	Moist	Guelph
February 9. 1931	O	Friction		90	Very coarse	No	Moist	Guelph
February 9, 1931	P	Glass		90	Very coarse	No	Moist	Guelph
February 20, 1931	M	Vacuum	9	80	Very coarse	No	Moist	Ithaca
February 20, 1931	N	Hermetic		80	Very coarse	No	Moist	Ithaca
February 20, 1931	O	Friction		80	Very coarse	No	Moist	Ithaca
February 20, 1931	P	Glass		80	Very coarse	No	Moist	Ithaca

As in experiment 1, the samples in glass and in friction-top tins were inferior to those sealed hermetically or under vacuum. In Guelph, under moist conditions, the samples in glass and in friction-top tins absorbed moisture, while in Ithaca, where low humidity prevailed, drying took place on the surface of the honey. Not all of the friction-top and the glass containers showed absorption and evaporation of moisture, but in most cases the method of sealing was not sufficiently tight to obviate the effect of changes in atmospheric humidity.

In experiment 2, as in experiment 1, heating the honey retarded crystallization, which caused the crystals to become larger and coarser. The unheated honey used in series E–H was totally crystallized by December, 1929, but the rate of crystallization was comparatively slow and the crystals formed were coarse. The honey used in series M–P was the same as was used in series E–H, except that it was heated, the crystals formed being large and coarse.

The vacuum was lost also in the unheated samples of series E, while the heated honey of series M held several inches of vacuum. These results substantiate those from experiment 1, and should add further evidence to the theory that air bubbles are gradually drawn out of unheated honey, thereby causing a reduction of vacuum.

The fact that the white-sweet-clover honey used in experiment 2 behaved almost identically as did the White-Dutch-and-alsike-clover honey used in experiment 1, would suggest a similarity of physical behavior, especially with relation to crystallization.

Experiment 3

Series A–D of experiment 3 was a buckwheat honey, sp. gr. 1.414, produced in Norfolk County, Ontario. The honey was extracted from wet combs on September 20, 1929, and was not pumped. It was unheated and totally liquid at the time of canning, September 23, 1929.

Series I–L was the same honey as was used in series A–D. Prior to the date of canning, no crystallization was evident. The honey was heated to 130° F. for thirty minutes, and was canned on September 23, 1929, while it was still warm.

Discussion

The results from the use of the buckwheat honey used in experiment 3 showed great similarity to the results with the White-Dutch-and-alsike-clover honey used in experiment 1 and with the white-sweet-clover honey used in experiment 2. This further substantiates the theory that the physical properties of most honeys may be similar. The results are shown in table 3.

It will be noted that in experiment 3, also, the type of closure of the glass and the friction-top tins was inadequate to control the changes in humidity. The honey in these containers was inferior to the honey sealed hermetically or under vacuum.

Slight fermentation was encountered in the unheated honey used in series A–D, but was not present in the same honey used in series I–L which was heated to 130° F. for thirty minutes. Here again the amount of heating was sufficient to prevent fermentation.

TABLE 3. CONDITION OF HONEYS UNDER VARIOUS METHODS OF PACKING AFTER VARIOUS TIME INTERVALS, EXPERIMENT 3

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				I. Series A–D				
October 26, 1929	A	Vacuum	4	100	Fine	No	Moist	Guelph
October 26, 1929	B	Hermetic		100	Fine	No	Moist	Guelph
October 26, 1929	C	Friction		100	Fine	No	Moist	Guelph
October 26, 1929	D	Glass		100	Fine	No	Moist	Guelph
November 26, 1929	A	Vacuum	1	100	Fine	No	Moist	Ithaca
November 26, 1929	B	Hermetic		100	Fine	No	Moist	Ithaca
November 26, 1929	C	Friction		100	Fine	No	Moist	Ithaca
November 26, 1929	D	Glass		100	Fine	No	Moist	Ithaca
November 28, 1929	A	Vacuum	0	100	Fine	No	Moist	Guelph
November 28, 1929	B	Hermetic		100	Fine	No	Moist	Guelph
November 28, 1929	C	Friction		100	Fine	No	Moist	Guelph
November 28, 1929	D	Glass		100	Fine	No	Moist	Guelph
December 29, 1929	A	Vacuum	2	100	Fine	No	Moist	Ithaca
December 29, 1929	B	Hermetic		100	Fine	No	Moist	Ithaca
December 29, 1929	C	Friction		100	Fine	No	Moist	Ithaca
December 29, 1929	D	Glass		100	Fine	No	Moist	Ithaca
February 14, 1930	A	Vacuum	0	100	Fine	No	Moist	Ithaca
February 14, 1930	B	Hermetic		100	Fine	No	Moist	Ithaca
February 14, 1930	C	Friction		100	Fine	No	Dry	Ithaca
February 14, 1930	D	Glass		100	Fine	No	Drying	Ithaca
March 14, 1930	A	Vacuum	0	*	*	No	*	Chicago
March 14, 1930	B	Hermetic		*	*	No	Dry	Chicago
March 14, 1930	C	Friction		*	*	No	Dry	Chicago
March 14, 1930	D	Glass		*	*	No	Dry	Chicago
May 23, 1930	A	Vacuum	1	100	Fine	No	Moist	Ithaca
May 23, 1930	B	Hermetic		100	Fine	No	Moist	Ithaca
May 23, 1930	C	Friction		100	Fine	No	Dry	Ithaca
May 23, 1930	D	Glass		100	Fine	No	Dry	Ithaca
June 4, 1930	A	Vacuum	0	5% sep. †	Fine	No	Moist	Guelph
June 4, 1930	B	Hermetic		5% sep.	Fine	No	Moist	Guelph
June 4, 1930	C	Friction		5% sep.	Fine	No	Moist	Guelph
June 4, 1930	D	Glass		5% sep.	Fine	No	Moist	Guelph
September 2, 1930	A	Vacuum	0	5% sep	Fine	No	Moist	Guelph
September 2, 1930	B	Hermetic		5% sep	Fine	No	Moist	Guelph
September 2, 1930	C	Friction		5% sep	Fine	No	Moist	Guelph
September 2, 1930	D	Glass		5% sep	Fine	No	Moist	Guelph
February 9, 1931	A	Vacuum	0	5% sep	Fine	Slightly	Moist	Guelph
February 9, 1931	B	Hermetic		5% sep	Fine	Slightly	Moist	Guelph
February 9, 1931	C	Friction		5% sep	Fine	Slightly	Moist	Guelph
February 9. 1931	D	Glass		5% sep	Fine	Slightly	Moist	Guelph
February 20, 1931	A	Vacuum	0	10% sep	Fine	Slightly	Moist	Ithaca
February 20, 1931	B	Hermetic		10% sep	Fine	Slightly	Moist	Ithaca
February 20, 1931	C	Friction		10% sep	Fine	Slightly	Moist	Ithaca
February 20, 1931	D	Glass		10% sep	Fine	Slightly	Moist	Ithaca

*Incomplete.
† Separation: a term applied to crystallized honey which shows a liquid layer on the surface.

TABLE 3 (*concluded*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				II. Series I–L				
October 26, 1929....	I	Vacuum...	22	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	K	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
November 26, 1929..	I	Vacuum...	19	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	K	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Ithaca
November 28, 1929..	I	Vacuum...	21	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	K	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
December 29, 1929..	I	Vacuum...	17	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	K	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Ithaca
February 13, 1930...	I	Vacuum...	13	5.....	Very coarse	No.....	Moist.....	Ithaca
February 13, 1930...	J	Hermetic..	.....	5.....	Very coarse	No.....	Moist.....	Ithaca
February 13, 1930...	K	Friction...	.....	5.....	Very coarse	No.....	Drying....	Ithaca
February 13, 1930...	L	Glass.....	.....	5.....	Very coarse	No.....	Drying....	Ithaca
March 14, 1930.....	I	Vacuum...	14	.....*	Very coarse	No.....	.....*	Chicago
March 14, 1930.....	J	Hermetic..	.....	.....*	Very coarse	No.....	.....*	Chicago
March 14, 1930.....	K	Friction...	.....	.....*	Very coarse	No.....	.....*	Chicago
March 14, 1930.....	L	Glass.....	.....	.....*	Very coarse	No.....	.....*	Chicago
May 23, 1930.....	I	Vacuum...	16	5.....	Very coarse	No.....	Moist.....	Ithaca
May 23, 1930.....	J	Hermetic..	.....	5.....	Very coarse	No.....	Moist.....	Ithaca
May 23, 1930.....	K	Friction...	.....	5.....	Very coarse	No.....	Dry.....	Ithaca
May 23, 1930.....	L	Glass.....	.....	5.....	Very coarse	No.....	Dry.....	Ithaca
June 4, 1930.....	I	Vacuum...	21	10.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	J	Hermetic..	.....	10.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	K	Friction...	.....	10.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	L	Glass.....	.....	10.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	I	Vacuum...	20	15.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	J	Hermetic..	.....	15.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	K	Friction...	.....	15.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	L	Glass.....	.....	15.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	I	Vacuum...	15	30.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	J	Hermetic..	.....	30.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	K	Friction...	.....	30.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	L	Glass.....	.....	30.....	Very coarse	No.....	Moist.....	Guelph
February 20, 1931...	I	Vacuum...	10	20.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	J	Hermetic..	.....	20.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	K	Friction...	.....	20.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	L	Glass.....	.....	20.....	Very coarse	No.....	Moist.....	Ithaca

*Incomplete.

Rapid crystallization with the formation of small crystals occurred in the unheated honey used in series A–D, while slow crystallization with the formation of large crystals developed in the same honey used in series I–L, which was heated. This again indicates that large crystals are formed when crystallization is delayed. It is interesting to note that the unheated honey which formed small crystals in series A–D was extracted from wet combs but was not run through a honey pump. Apparently, sufficient

crystals were obtained from the wet combs to hasten crystallization without the necessity of mechanical action of the pump.

Since it is rather common for buckwheat honeys to form small crystals, the following explanation may have some bearing on this phenomenon. When clover honey is extracted, the wet combs are usually returned to the hives in order that the bees may fill them with buckwheat honey. It is possible that sufficient crystals are obtained from these wet combs from which clover honey has been extracted, to hasten crystallization and to cause small crystals to be formed in buckwheat honey.

Separation was noticed in series A–D in June, 1930, but no fermentation could be detected until February, 1931. It is difficult to detect slight fermentation in buckwheat honey, and even in February, 1931, definite fermentation could not be claimed. It is fairly certain, however, that no fermentation was present in June, 1930, and yet a 5-per-cent separation was present then. It would thus appear that separation may precede fermentation, but it usually occurs in honeys which have a low specific gravity and in which fermentation is present.

Shortly after the honey was sealed, the vacuum was either lost or greatly reduced in the unheated honeys used in series A while several inches of vacuum were retained in series L. Here again there is further indication that the air bubbles drawn out of the cold unheated honey by the vacuum above may reduce the vacuum or cause its complete loss. In February, 1931, slight fermentation was detected in series A, and it is possible that the gases evolving from the ferment may have caused the loss of vacuum; but, since the vacuum was greatly reduced long before fermentation was evident, fermentation should not be considered the major reason for the reduction of vacuum.

Experiment 4

Series A–D of experiment 4, made from White Dutch and alsike clover, sp. gr. 1.419, was produced in the apiary of the Ontario Agricultural College, in Wellington County, Ontario. It was taken from the cappings of the honey used in experiment 1, series A–D, on August 17, 1929. The cappings and the adhering honey from the extracting combs were allowed to fall on a capping melter, where liquefaction took place. The liquid honey and wax was drained from the capping melter into a separation tank. The honey, having a higher specific gravity than the wax, settled to the bottom of the tank, while the wax rose to the top. On passing over the capping melter, the honey was heated to about 110° F. and was found to contain considerable pollen and other particles. The honey was taken from wet combs, was not pumped, and was totally liquid at the time of canning, August 19, 1929.

Discussion

As in the preceding experiments, the absorption and evaporation of moisture in glass and in friction-top tins caused the honey in these containers to be inferior. Owing to the slight heat applied to the honey as it ran over the capping melter, crystallization was delayed and coarse crystals were subsequently formed. The results of the experiment are shown in table 4.

TABLE 4. CONDITION OF HONEYS UNDER VARIOUS METHODS OF PACKING AFTER VARIOUS TIME INTERVALS, EXPERIMENT 4

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				Series A–D				
October 26, 1929....	A	Vacuum...	12	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	B	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	C	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	D	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
November 26, 1929..	A	Vacuum...	9	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	B	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	C	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	D	Glass.....	.....	0.....	.....	No.....	Moist.....	Ithaca
November 28, 1929..	A	Vacuum...	14	10.....	Coarse....	No.....	Moist.....	Guelph
November 28, 1929..	B	Hermetic..	.....	10.....	Coarse....	No.....	Moist.....	Guelph
November 28, 1929..	C	Friction...	.....	10.....	Coarse....	No.....	Moist.....	Guelph
November 28, 1929..	D	Glass.....	.....	10.....	Coarse....	No.....	Moist.....	Guelph
December 29, 1929..	A	Vacuum...	7	20.....	Coarse....	No.....	Moist.....	Ithaca
December 29, 1929..	B	Hermetic..	.....	20.....	Coarse....	No.....	Moist.....	Ithaca
December 29, 1929..	C	Friction...	.....	20.....	Coarse....	No.....	Drying....	Ithaca
December 29, 1929..	D	Glass.....	.....	20.....	Coarse....	No.....	Drying....	Ithaca
February 14, 1930...	A	Vacuum...	12	40.....	Coarse....	No.....	Moist.....	Ithaca
February 14, 1930...	B	Hermetic..	.....	40.....	Coarse....	No.....	Moist.....	Ithaca
February 14, 1930...	C	Friction...	.....	40.....	Coarse....	No.....	Dry.....	Ithaca
February 14, 1930...	D	Glass.....	.....	40.....	Coarse....	No.....	Dry.....	Ithaca
May 23, 1930.....	A	Vacuum...	10	80.....	Coarse....	No.....	Moist.....	Ithaca
May 23, 1930.....	B	Hermetic..	.....	80.....	Coarse....	No.....	Moist.....	Ithaca
May 23, 1930.....	C	Friction...	.....	90.....	Coarse....	No.....	Dry.....	Ithaca
May 23, 1930.....	D	Glass.....	.....	80.....	Coarse....	No.....	Dry.....	Ithaca
June 4, 1930.....	A	Vacuum...	6	100.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	B	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	C	Friction...	.....	100.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	D	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	A	Vacuum...	2	100.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	B	Hermetic..	.....	100.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	C	Friction...	.....	100.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	D	Glass.....	.....	100.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	A	Vacuum...	0	5% sep.*..	Coarse....	Yes.....	Moist.....	Guelph
February 9, 1931....	B	Hermetic..	.....	5% sep....	Coarse....	Yes.....	Moist.....	Guelph
February 9, 1931....	C	Friction...	.....	5% sep....	Coarse....	Yes.....	Moist.....	Guelph
February 9, 1931....	D	Glass.....	.....	5% sep....	Coarse....	Yes.....	Moist.....	Guelph
February 20, 1931...	A	Vacuum...	0	10% sep...	Coarse....	Yes.....	Moist.....	Ithaca
February 20, 1931...	B	Hermetic..	.....	10% sep...	Coarse....	Yes.....	Moist.....	Ithaca
February 20, 1931...	C	Friction...	.....	10% sep...	Coarse....	Yes.....	Moist.....	Ithaca
February 20, 1931...	D	Glass.....	.....	10% sep...	Coarse....	Yes.....	Moist.....	Ithaca

* Separation: a term applied to crystallized honey which shows a liquid layer on the surface.

Fermentation appeared in February, 1931, but this may be attributed to low specific gravity and to the abundance of pollen grains in the honey. Experiments conducted at Guelph, Ontario, in 1925 indicated that when an excessive amount of pollen is present in a honey, fermentation is accelerated. Lochhead and Heron (1929) have shown also that the presence of nitrogenous compounds in honey promotes the growth of sugar-tolerant yeasts. Most pollen grains are high in protein, and when large numbers of these grains are present in honey the chances of fermentative action are increased. It is interesting to note that separation was detected simultaneously with fermentation, in February of 1931.

Experiment 5

In experiment 5 each container was inoculated with a pure culture of sugar-tolerant yeasts. Seven cultures of yeasts were used. Four were obtained from Dr. A. G. Lochhead, Dominion Bacteriologist, of Ottawa, Ontario, and three were cultured from fermented honey by Professor D. F. Jones, of the Ontario Agricultural College, Guelph, Ontario. Inoculations and care of the cultures were in charge of E. H. Garrard, of the Department of Bacteriology at the Ontario Agricultural College. The author is indebted to these three men for their assistance.

The yeasts used in these inoculations are described in the following tabulation:

Yeast identification no.	Obtained from	Species	Cultured from
D1	Lochhead	*Zygosaccharomyces mellis*	
E6	Lochhead	*Zygosaccharomyces barkeri*	
J7	Lochhead	*Zygosaccharomyces nusshaumi*	
M1	Lochhead	*Zygosaccharomyces richteri*	
E2	Jones	(Not identified)	Amber honey fermented, sp. gr. 1.413, from Middlesex County, Ontario
E3	Jones	(Not identified)	Light honey fermented, sp. gr. 1.402, from Middlesex County, Ontario
E4	Jones	(Not identified)	White-clover honey fermented, sp. gr. 1.420, from Lincoln County, Ontario

Inoculations were made by inserting into the honey, to a depth of about one-half inch, a previously sterilized needle carrying an abundance of sugar-tolerant yeast. The needle was then drawn horizontally about one inch, being turned at the same time to release the yeast before the needle was withdrawn from the honey.

Series A–D of experiment 5 was the same honey as was used in experiment 3, series A–D — buckwheat honey, sp. gr. 1.414, produced in Norfolk County, Ontario. The honey was extracted from wet combs on September 20, 1929, and was not run through a honey pump. Prior to the date of canning, the honey was about 80 per cent crystallized but had a soft, fine texture with the ability to flow. When the various containers were filled, they were divided into approximately seven groups and one culture of yeasts was used to inoculate each group. To insure later identification, the number of the yeast culture used was marked on each container. The honey was unheated and was about 80 per cent crystallized when it was canned on October 21, 1929.

Series E–H was the same honey as was used in series A–D of this experiment. The honey was poured into the various containers, and each was inoculated individually. All the samples were then heated to 120° F.

for thirty minutes, and were canned on October 21, 1929, while they were still warm.

Series I–L was the same honey as was used in series A–D. It was poured into the various containers, and each was inoculated individually. All the samples were then heated to 140° F. for thirty minutes, and were canned on October 21, 1929, while they were still warm.

Series M–P was the same honey as was used in series A–D. It was poured into the various containers, and each was inoculated individually, canned or sealed, and then heated to 120° F. for thirty minutes, on October 21, 1929.

Series Q–T was the same honey as was used in series A–D. It was poured into the various containers, and each was inoculated individually, canned or sealed, and then heated to 140° F. for thirty minutes, on October 21, 1929.

Discussion

The object of experiment 5 was to make sure that yeasts were present to cause fermentation if other conditions were favorable. This condition was insured by the introduction of sugar-tolerant yeasts into the honey. The inoculated honey used in series A–D of this experiment was unheated, and early fermentation was anticipated. The remaining series also were inoculated with yeasts and the honey was subsequently heated to different temperatures in order to determine which treatment of heating would generally be effective in destroying the yeasts. The results are shown in table 5.

In the series of experiment 5 which were heated, no fermentation was present. Series E–H and M–P were heated to 120° F. for thirty minutes, but, while slight fermentation occurred in the unheated samples of series A–D, it would not be safe to claim that this amount of heating is always effective in destroying the yeasts present in the honey.

Further evidence of the significance of separation may be obtained by comparing the honey used in series A–D of experiment 1, with that used in series A–D of experiment 5. Both honeys had a similar specific gravity and appeared to be alike in crystallization. Fermentation occurred in the former many months earlier than in the latter. Separation occurred in series A–D of experiment 5 eight months prior to the detection of fermentation, though in cases of slight fermentation it is often difficult to be sure whether fermentation has occurred.

Crystallization was rapid, with the formation of small crystals, in the unheated honeys in series A–D of experiment 5, but was retarded, with the consequent formation of large crystals, in the heated samples. The honeys in series E–H and M–P, which were heated to 120° F. for thirty minutes, showed more advanced crystallization than did the honeys in series I–L and Q–T, which were heated to 140° F. for thirty minutes, but the crystals formed in the two last-named series were of greater size. Heating apparently destroys the crystals which induce further crystal growth in honey, and the reduction of these crystals lowers the rate of crystallization, with the formation of larger crystals.

TABLE 5. CONDITION OF HONEYS UNDER VARIOUS METHODS OF PACKING AFTER VARIOUS TIME INTERVALS, EXPERIMENT 5

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
I. Series A–D								
October 26, 1929....	A	Vacuum...	2	100.....	Fine.....	No.....	Moist.....	Guelph
October 26, 1929....	B	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Guelph
October 26, 1929....	C	Friction...	.....	100.....	Fine.....	No.....	Moist.....	Guelph
October 26, 1929....	D	Glass.....	.....	100.....	Fine.....	No.....	Moist.....	Guelph
November 26, 1929..	A	Vacuum...	3	100.....	Fine.....	No.....	Moist.....	Ithaca
November 26, 1929..	B	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
November 26, 1929..	C	Friction...	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
November 26, 1929..	D	Glass.....	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
November 28, 1929..	A	Vacuum...	0	100.....	Fine.....	No.....	Moist.....	Guelph
November 28, 1929..	B	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Guelph
November 28, 1929..	C	Friction...	.....	100.....	Fine.....	No.....	Moist.....	Guelph
November 28, 1929..	D	Glass.....	.....	100.....	Fine.....	No.....	Moist.....	Guelph
December 29, 1929..	A	Vacuum...	1	100.....	Fine.....	No.....	Moist.....	Ithaca
December 29, 1929..	B	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
December 29, 1929..	C	Friction...	.....	100.....	Fine.....	No.....	Drying....	Ithaca
December 29, 1929..	D	Glass.....	.....	100.....	Fine.....	No.....	Drying....	Ithaca
February 14, 1930...	A	Vacuum...	5	100.....	Fine.....	No.....	Moist.....	Ithaca
February 14, 1930...	B	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
February 14, 1930...	C	Friction...	.....	100.....	Fine.....	No.....	Dry.....	Ithaca
February 14, 1930...	D	Glass.....	.....	100.....	Fine.....	No.....	Dry.....	Ithaca
March 14, 1930.....	A	Vacuum...	5	100.....	Fine.....	No.....	Moist.....	Chicago
March 14, 1930.....	B	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Chicago
March 14, 1930.....	C	Friction...	.....	100.....	Fine.....	No.....	Drying....	Chicago
March 14, 1930.....	D	Glass.....	.....	100.....	Fine.....	No.....	Moist.....	Chicago
May 23, 1930.....	A	Vacuum...	0	100.....	Fine.....	No.....	Moist.....	Ithaca
May 23, 1930.....	B	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
May 23, 1930.....	C	Friction...	.....	100.....	Fine.....	No.....	Dry.....	Ithaca
May 23, 1930.....	D	Glass.....	.....	100.....	Fine.....	No.....	Dry.....	Ithaca
June 4, 1930.....	A	Vacuum...	2	5% sep.*..	Fine.....	No.....	Moist.....	Guelph
June 4, 1930.....	B	Hermetic..	.....	5% sep....	Fine.....	No.....	Moist.....	Guelph
June 4, 1930.....	C	Friction...	.....	5% sep....	Fine.....	No.....	Moist.....	Guelph
June 4, 1930.....	D	Glass.....	.....	5% sep....	Fine.....	No.....	Moist.....	Guelph
September 2, 1930...	A	Vacuum...	0	5% sep....	Fine.....	No.....	Moist.....	Guelph
September 2, 1930...	B	Hermetic..	.....	5% sep....	Fine.....	No.....	Moist.....	Guelph
September 2, 1930...	C	Friction...	.....	5% sep....	Fine.....	No.....	Moist.....	Guelph
September 2, 1930...	D	Glass.....	.....	5% sep....	Fine.....	No.....	Moist.....	Guelph
February 9, 1931....	A	Vacuum...	0	5% sep....	Fine.....	Slightly...	Moist.....	Guelph
February 9, 1931....	B	Hermetic..	.....	5% sep....	Fine.....	Slightly...	Moist.....	Guelph
February 9, 1931....	C	Friction...	.....	5% sep....	Fine.....	Slightly...	Moist.....	Guelph
February 9, 1931....	D	Glass.....	.....	5% sep....	Fine.....	Slightly...	Moist.....	Guelph
February 20, 1931...	A	Vacuum...	0	10% sep...	Fine.....	Slightly...	Moist.....	Ithaca
February 20, 1931...	B	Hermetic..	.....	10% sep...	Fine.....	Slightly...	Moist.....	Ithaca
February 20, 1931...	C	Friction...	.....	10% sep...	Fine.....	Slightly...	Moist.....	Ithaca
February 20, 1931...	D	Glass.....	.....	10% sep...	Fine.....	Slightly...	Moist.....	Ithaca

* Separation: a term applied to crystallized honey which shows a liquid layer on the surface.

TABLE 5 (*continued*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
II. Series E–H								
October 26, 1929	E	Vacuum	22	0		No	Moist	Guelph
October 26, 1929	F	Hermetic		0		No	Moist	Guelph
October 26, 1929	G	Friction		0		No	Moist	Guelph
October 26, 1929	H	Glass		0		No	Moist	Guelph
November 26, 1929	E	Vacuum	16	0		No	Moist	Ithaca
November 26, 1929	F	Hermetic		0		No	Moist	Ithaca
November 26, 1929	G	Friction		0		No	Moist	Ithaca
November 26, 1929	H	Glass		0		No	Moist	Ithaca
November 28, 1929	E	Vacuum	13	0		No	Moist	Guelph
November 28, 1929	F	Hermetic		0		No	Moist	Guelph
November 28, 1929	G	Friction		0		No	Moist	Guelph
November 28, 1929	H	Glass		0		No	Moist	Guelph
December 29, 1929	E	Vacuum	12	0		No	Moist	Ithaca
December 29, 1929	F	Hermetic		0		No	Moist	Ithaca
December 29, 1929	G	Friction		0		No	Drying	Ithaca
December 29, 1929	H	Glass		0		No	Drying	Ithaca
February 14, 1930	E	Vacuum	8	5	Very coarse	No	Moist	Ithaca
February 14, 1930	F	Hermetic		5	Very coarse	No	Moist	Ithaca
February 14, 1930	G	Friction		5	Very coarse	No	Dry	Ithaca
February 14, 1930	H	Glass		5	Very coarse	No	Dry	Ithaca
March 14, 1930	E	Vacuum	0	†	Very coarse	No	†	Chicago
March 14, 1930	F	Hermetic		†	Very coarse	No	†	Chicago
March 14, 1930	G	Friction		†	Very coarse	No	†	Chicago
March 14, 1930	H	Glass		†	Very coarse	No	†	Chicago
May 23, 1930	E	Vacuum	12	5	Very coarse	No	Moist	Ithaca
May 23, 1930	F	Hermetic		5	Very coarse	No	Moist	Ithaca
May 23, 1930	G	Friction		5	Very coarse	No	Dry	Ithaca
May 23, 1930	H	Glass		5	Very coarse	No	Dry	Ithaca
June 4, 1930	E	Vacuum	9	10	Very coarse	No	Moist	Guelph
June 4, 1930	F	Hermetic		10	Very coarse	No	Moist	Guelph
June 4, 1930	G	Friction		10	Very coarse	No	Moist	Guelph
June 4, 1930	H	Glass		10	Very coarse	No	Moist	Guelph
September 2, 1930	E	Vacuum	7	10	Very coarse	No	Moist	Guelph
September 2, 1930	F	Hermetic		10	Very coarse	No	Moist	Guelph
September 2, 1930	G	Friction		10	Very coarse	No	Moist	Guelph
September 2, 1930	H	Glass		10	Very coarse	No	Moist	Guelph
February 9, 1931	E	Vacuum	10	20	Very coarse	No	Moist	Guelph
February 9, 1931	F	Hermetic		20	Very coarse	No	Moist	Guelph
February 9, 1931	G	Friction		20	Very coarse	No	Moist	Guelph
February 9, 1931	H	Glass		20	Very coarse	No	Moist	Guelph
February 20, 1931	E	Vacuum	9	10	Very coarse	No	Moist	Ithaca
February 20, 1931	F	Hermetic		10	Very coarse	No	Moist	Ithaca
February 20, 1931	G	Friction		10	Very coarse	No	Moist	Ithaca
February 20, 1931	H	Glass		10	Very coarse	No	Moist	Ithaca

† Incomplete.

TABLE 5 (*continued*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				III. Series I–L				
October 26, 1929....	I	Vacuum...	18	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	K	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
November 26, 1929..	I	Vacuum...	7	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	K	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Ithaca
November 28, 1929..	I	Vacuum...	11	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	K	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
December 29, 1929..	I	Vacuum...	0	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	K	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	L	Glass.....	.....	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	I	Vacuum...	22	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	J	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	K	Friction...	.....	0.....	.....	No.....	Drying....	Ithaca
February 14, 1930...	L	Glass.....	.....	0.....	.....	No.....	Drying....	Ithaca
March 14, 1930.....	I	Vacuum...	0	5.....	Very coarse	No.....	.....†	Chicago
March 14, 1930.....	J	Hermetic..	.....	5.....	Very coarse	No.....	.....†	Chicago
March 14, 1930.....	K	Friction...	.....	15.....	Very coarse	No.....	.....†	Chicago
March 14, 1930.....	L	Glass.....	.....	20.....	Very coarse	No.....	.....†	Chicago
May 23, 1930.....	I	Vacuum...	13	5.....	Very coarse	No.....	Moist.....	Ithaca
May 23, 1930.....	J	Hermetic..	.....	5.....	Very coarse	No.....	Moist.....	Ithaca
May 23, 1930.....	K	Friction...	.....	5.....	Very coarse	No.....	Dry.....	Ithaca
May 23, 1930.....	L	Glass	.....	5.....	Very coarse	No.....	Dry.....	Ithaca
June 4, 1930.....	I	Vacuum...	9	10.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	J	Hermetic..	.....	10.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	K	Friction...	.....	10.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	L	Glass.....	.....	10.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	I	Vacuum...	10	15.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	J	Hermetic..	.....	15.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	K	Friction...	.....	20.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	L	Glass.....	.....	20.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	I	Vacuum...	13	15.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	J	Hermetic..	.....	15.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	K	Friction...	.....	20.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	L	Glass.....	.....	20.....	Very coarse	No.....	Moist.....	Guelph
February 20, 1931...	I	Vacuum...	8	10.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	J	Hermetic..	.....	10.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	K	Friction...	.....	10.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	L	Glass.....	.....	10.....	Very coarse	No.....	Moist.....	Ithaca

TABLE 5 (*continued*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				IV. Series M–P				
October 26, 1929....	M	Vacuum...	16	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	O	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	P	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
November 26, 1929..	M	Vacuum...	11	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	O	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	P	Glass.....	.....	0.....	.....	No.....	Moist.....	Ithaca
November 28, 1929..	M	Vacuum...	9	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	O	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	P	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
December 29, 1929..	M	Vacuum...	14	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	O	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	P	Glass.....	.....	0.....	.....	No.....	Drying....	Ithaca
February 14, 1930...	M	Vacuum...	23	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	O	Friction...	.....	0.....	.....	No.....	Dry.....	Ithaca
February 14, 1930...	P	Glass.....	.....	0.....	.....	No.....	Dry.....	Ithaca
March 14, 1930.....	M	Vacuum...	12	.....†	.....	No.....	.....†	Chicago
March 14, 1930.....	N	Hermetic..	.....	.....†	.....	No.....	.....†	Chicago
March 14, 1930.....	O	Friction...	.....	.....†	.....	No.....	.....†	Chicago
March 14, 1930.....	P	Glass.....	.....	.....†	.....	No.....	.....†	Chicago
May 23, 1930.....	M	Vacuum...	15	0.....	.....	No.....	Moist.....	Ithaca
May 23, 1930.....	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
May 23, 1930.....	O	Friction...	.....	0.....	.....	No.....	Dry.....	Ithaca
May 23, 1930.....	P	Glass.....	.....	0.....	.....	No.....	Dry.....	Ithaca
June 4, 1930.....	M	Vacuum...	20	5.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	N	Hermetic..	.....	5.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	O	Friction...	.....	5.....	Very coarse	No.....	Moist.....	Guelph
June 4, 1930.....	P	Glass.....	.....	5.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	M	Vacuum...	16	10.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	N	Hermetic..	.....	10.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	O	Friction...	.....	10.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	P	Glass.....	.....	10.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	M	Vacuum...	13	20.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	N	Hermetic..	.....	20.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	O	Friction...	.....	20.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	P	Glass.....	.....	20.....	Very coarse	No.....	Moist.....	Guelph
February 20, 1931...	M	Vacuum...	6	15.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	N	Hermetic..	.....	15.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	O	Friction...	.....	15.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	P	Glass.....	.....	15.....	Very coarse	No.....	Moist.....	Ithaca

† Incomplete.

TABLE 5 (*concluded*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				V. Series Q–T				
October 26, 1929....	Q	Vacuum...	14	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	R	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	S	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	T	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
November 26, 1929..	Q	Vacuum...	11	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	R	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	S	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	T	Glass.....	.....	0.....	.....	No.....	Moist.....	Ithaca
November 28, 1929..	Q	Vacuum...	16	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	R	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	S	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	T	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
December 29, 1929..	Q	Vacuum...	9	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	R	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	S	Friction...	.....	0.....	.....	No.....	Drying....	Ithaca
December 29, 1929..	T	Glass.....	.....	0.....	.....	No.....	Drying....	Ithaca
February 14, 1930...	Q	Vacuum...	20	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	R	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	S	Friction...	.....	0.....	.....	No.....	Dry.....	Ithaca
February 14, 1930...	T	Glass.....	.....	0.....	.....	No.....	Dry.....	Ithaca
March 14, 1930.....	Q	Vacuum...	0	.....†	.....	No.....	.....†	Chicago
March 14, 1930.....	R	Hermetic..	.....	.....†	.....	No.....	.....†	Chicago
March 14, 1930.....	S	Friction...	.....	.....†	.....	No.....	.....†	Chicago
March 14, 1930.....	T	Glass.....	.....	.....†	.....	No.....	.....†	Chicago
May 23, 1930.....	Q	Vacuum...	12	0.....	.....	No.....	Moist.....	Ithaca
May 23, 1930.....	R	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
May 23, 1930.....	S	Friction...	.....	0.....	.....	No.....	Dry.....	Ithaca
May 23, 1930.....	T	Glass.....	.....	0.....	.....	No.....	Dry.....	Ithaca
June 4, 1930.....	Q	Vacuum...	3	0.....	.....	No.....	Moist.....	Guelph
June 4, 1930.....	R	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
June 4, 1930.....	S	Friction...	.....	0.....	.....	No.....	Moist.....	Guelpn
June 4, 1930.....	T	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
September 2, 1930...	Q	Vacuum...	19	0.....	.....	No.....	Moist.....	Guelph
September 2, 1930...	R	Hermetic..	.....	5.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	S	Friction...	.....	5.....	Very coarse	No.....	Moist.....	Guelph
September 2, 1930...	T	Glass.....	.....	5.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	Q	Vacuum...	14	10.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	R	Hermetic..	.....	10.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	S	Friction...	.....	10.....	Very coarse	No.....	Moist.....	Guelph
February 9, 1931....	T	Glass.....	.....	10.....	Very coarse	No.....	Moist.....	Guelph
February 20, 1931...	Q	Vacuum...	16	5.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	R	Hermetic..	.....	5.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	S	Friction...	.....	5.....	Very coarse	No.....	Moist.....	Ithaca
February 20, 1931...	T	Glass.....	.....	5.....	Very coarse	No.....	Moist.....	Ithaca

† Incomplete.

The remaining points of interest in the results from experiment 5, such as the reduction of vacuum in the unheated samples, the evaporation and absorption of moisture in the glasses and in the friction-top tins, and the slight separation prior to obvious fermentation, are identical with the results of experiment 3, which have already been discussed.

Experiment 6

In experiment 6 a level tablespoonful of previously fermented honey was placed on the surface of each container, without stirring. A 5-pound pail of fermented honey was procured from Wentworth County, Ontario. It was totally crystallized, and had a specific gravity of 1.419. Professor D. F. Jones, of the Ontario Agricultural College, cultured a yeast from the sample, but it was not identified.

Series A–D of experiment 6 was the same honey as was used in experiment 5, buckwheat honey, sp. gr. 1.414, produced in Norfolk County, Ontario. The honey was extracted from wet combs on September 20, 1929, and was not run through a honey pump. Prior to the date of canning, the honey was about 80 per cent crystallized but was of a soft, fine texture with the ability to flow. When the containers were filled, a level tablespoonful of fermented honey was placed on the surface of the honey in each container. The honey was unheated and was about 80 per cent crystallized when it was canned on October 21, 1929.

Series A1–D1 was the same honey as was used in series A–D. Tap water was added to the honey until a specific-gravity reading of 1.400 was obtained after thorough mixing of the honey and the water. The fermented honey was added, and the containers were then sealed, without being heated, on October 21, 1929.

Series E–H was the same honey as was used in series A–D. After the fermented honey was added, the honey was heated to 130° F. for thirty minutes and was canned or sealed on October 21, 1929, while it was still warm.

Series M–P was the same honey as was used in series A–D. After the fermented honey was added, the containers were sealed and were then heated to 130° F. for thirty minutes, on October 21, 1929.

Discussion

The object of experiment 6, as of experiment 5, was to stimulate fermentation, in this case by the addition of fermented honey to the surface of the honey in each container. The buckwheat honey used in this experiment was the same honey as was used in experiments 3 and 5. The results are shown in table 6.

Fermentation in series A–D of experiment 6 was not stimulated by the addition of fermented honey. Only slight fermentation occurred in February, 1931, this being at the same time that slight fermentation was observed in the non-contaminated honey used in series A–D of experiment 3 (table 3, page 22). It is interesting to note that the yeasts added to the honey used in series A–D of experiment 5, and the fermented honey added to the honey used in series A–D of experiment 6, caused no apparent increase in the rapidity of fermentation beyond that observed in the normal non-contaminated honey used in series A–D of experiment 3.

TABLE 6. CONDITION OF HONEYS UNDER VARIOUS METHODS OF PACKING AFTER VARIOUS TIME INTERVALS, EXPERIMENT 6

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				I. Series A–D				
October 26, 1929	A	Vacuum	6	100	Fine	No	Moist	Guelph
October 26, 1929	B	Hermetic		100	Fine	No	Moist	Guelph
October 26, 1929	C	Friction		100	Fine	No	Moist	Guelph
October 26, 1929	D	Glass		100	Fine	No	Moist	Guelph
November 26, 1929	A	Vacuum	3	100	Fine	No	Moist	Ithaca
November 26, 1929	B	Hermetic		100	Fine	No	Moist	Ithaca
November 26, 1929	C	Friction		100	Fine	No	Moist	Ithaca
November 26, 1929	D	Glass		100	Fine	No	Moist	Ithaca
November 28, 1929	A	Vacuum	4	100	Fine	No	Moist	Guelph
November 28, 1929	B	Hermetic		100	Fine	No	Moist	Guelph
November 28, 1929	C	Friction		100	Fine	No	Moist	Guelph
November 28, 1929	D	Glass		100	Fine	No	Moist	Guelph
December 29, 1929	A	Vacuum	2	100	Fine	No	Moist	Ithaca
December 29, 1929	B	Hermetic		100	Fine	No	Moist	Ithaca
December 29, 1929	C	Friction		100	Fine	No	Drying	Ithaca
December 29, 1929	D	Glass		100	Fine	No	Moist	Ithaca
February 14, 1930	A	Vacuum	0	100	Fine	No	Moist	Ithaca
February 14, 1930	B	Hermetic		100	Fine	No	Moist	Ithaca
February 14, 1930	C	Friction		100	Fine	No	Dry	Ithaca
February 14, 1930	D	Glass		100	Fine	No	Moist	Ithaca
May 23, 1930	A	Vacuum	2	100	Fine	No	Moist	Ithaca
May 23, 1930	B	Hermetic		100	Fine	No	Moist	Ithaca
May 23, 1930	C	Friction		100	Fine	No	Dry	Ithaca
May 23, 1930	D	Glass		100	Fine	No	Moist	Ithaca
June 4, 1930	A	Vacuum	3	5% sep.*	Fine	No	Moist	Guelph
June 4, 1930	B	Hermetic		5% sep.	Fine	No	Moist	Guelph
June 4, 1930	C	Friction		5% sep.	Fine	No	Moist	Guelph
June 4, 1930	D	Glass		5% sep.	Fine	No	Moist	Guelph
September 2, 1930	A	Vacuum	1	5% sep.	Fine	No	Moist	Guelph
September 2, 1930	B	Hermetic		5% sep.	Fine	No	Moist	Guelph
September 2, 1930	C	Friction		5% sep.	Fine	No	Moist	Guelph
September 2, 1930	D	Glass		5% sep.	Fine	No	Moist	Guelph
February 9, 1931	A	Vacuum	0	5% sep.	Fine	Slightly	Moist	Guelph
February 9, 1931	B	Hermetic		5% sep.	Fine	Slightly	Moist	Guelph
February 9, 1931	C	Friction		5% sep.	Fine	Slightly	Moist	Guelph
February 9, 1931	D	Glass		5% sep.	Fine	Slightly	Moist	Guelph
February 20, 1931	A	Vacuum	0	10% sep.	Fine	Slightly	Moist	Ithaca
February 20, 1931	B	Hermetic		10% sep.	Fine	Slightly	Moist	Ithaca
February 20, 1931	C	Friction		10% sep.	Fine	Slightly	Moist	Ithaca
February 20, 1931	D	Glass		10% sep.	Fine	Slightly	Moist	Ithaca

* Separation: a term applied to crystallized honey which shows a liquid layer on the surface.

TABLE 6 (*continued*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				II. Series A1–D1				
October 26, 1929....	A1	Vacuum...	2	Slight sep.*	Fine.....	No.....	Moist.....	Guelph
October 26, 1929....	B1	Hermetic..	.....	Slight sep..	Fine.....	No.....	Moist.....	Guelph
October 26, 1929....	C1	Friction...	.....	Slight sep..	Fine.....	No.....	Moist.....	Guelph
October 26, 1929....	D1	Glass.....	.....	Slight sep..	Fine.....	No.....	Moist.....	Guelph
November 26, 1929..	A1	Vacuum...	1	10% sep...	Fine.....	No.....	Moist.....	Ithaca
November 26, 1929..	B1	Hermetic..	....	10% sep...	Fine.....	No.....	Moist.....	Ithaca
November 26, 1929..	C1	Friction...	.....	10% sep...	Fine.....	No.....	Moist.....	Ithaca
November 26, 1929..	D1	Glass.....	.....	10% sep...	Fine.....	No.....	Moist.....	Ithaca
November 28, 1929..	A1	Vacuum...	0	10% sep...	Fine.....	No.....	Moist.....	Guelph
November 28, 1929..	B1	Hermetic..	.....	10% sep...	Fine.....	No.....	Moist.....	Guelph
November 28, 1929..	C1	Friction...	.....	10% sep...	Fine.....	No.....	Moist.....	Guelph
November 28, 1929..	D1	Glass.....	.....	10% sep...	Fine.....	No.....	Moist.....	Guelph
December 29, 1929..	A1	Vacuum...	0	20% sep...	Fine.....	Slightly...	Moist.....	Ithaca
December 29, 1929..	B1	Hermetic..	.....	20% sep...	Fine.....	Slightly...	Moist.....	Ithaca
December 29, 1929..	C1	Friction...	.....	20% sep...	Fine.....	Slightly...	Moist.....	Ithaca
December 29, 1929..	D1	Glass.....	.....	20% sep...	Fine.....	Slightly...	Moist.....	Ithaca
February 14, 1930...	A1	Vacuum...	0	25% sep...	Fine.....	Yes.....	Moist.....	Ithaca
February 14, 1930...	B1	Hermetic..	.....	25% sep...	Fine.....	Yes.....	Moist.....	Ithaca
February 14, 1930...	C1	Friction...	.....	25% sep...	Fine.....	Yes.....	Drying....	Ithaca
February 14, 1930...	D1	Glass.....	.....	25% sep...	Fine.....	Yes.....	Drying....	Ithaca
May 23, 1930.....	A1	Vacuum...	0	30% sep...	Fine.....	Yes.....	Moist.....	Ithaca
May 23, 1930.....	B1	Hermetic..	.....	30% sep...	Fine.....	Yes.....	Moist.....	Ithaca
May 23, 1930.....	C1	Friction...	.....	30% sep...	Fine.....	Yes.....	Dry.....	Ithaca
May 23, 1930.....	D1	Glass.....	.....	30% sep...	Fine.....	Yes.....	Dry.....	Ithaca
June 4, 1930.....	A1	Vacuum...	0	30% sep...	Fine.....	Yes.....	Moist.....	Guelph
June 4, 1930.....	B1	Hermetic..	.....	30% sep...	Fine.....	Yes.....	Moist.....	Guelph
June 4, 1930.....	C1	Friction...	.....	30% sep...	Fine.....	Yes.....	Moist.....	Guelph
June 4, 1930.....	D1	Glass.....	.....	30% sep...	Fine.....	Yes.....	Moist.....	Guelph
September 2, 1930...	A1	Vacuum...	0	40% sep...	Fine.....	Yes.....	Moist.....	Guelph
September 2, 1930...	B1	Hermetic..	.....	40% sep...	Fine.....	Yes.....	Moist.....	Guelph
September 2, 1930...	C1	Friction...	.....	40% sep...	Fine.....	Yes.....	Moist.....	Guelph
September 2, 1930...	D1	Glass.....	.....	40% sep...	Fine.....	Yes.....	Moist.....	Guelph
February 9, 1931....	A1	Vacuum...	0	50% sep...	Fine.....	Yes.....	Moist.....	Guelph
February 9, 1931....	B1	Hermetic..	.....	50% sep...	Fine.....	Yes.....	Moist.....	Guelph
February 9, 1931....	C1	Friction...	.....	50% sep...	Fine.....	Yes.....	Moist.....	Guelph
February 9, 1931....	D1	Glass.....	.....	50% sep...	Fine.....	Yes.....	Moist.....	Guelph
February 20, 1931...	A1	Vacuum...	0	70% sep...	Fine.....	Yes.....	Moist.....	Ithaca
February 20, 1931...	B1	Hermetic..	.....	70% sep...	Fine.....	Yes.....	Moist.....	Ithaca
February 20, 1931...	C1	Friction...	.....	70% sep...	Fine.....	Yes.....	Moist.....	Ithaca
February 20, 1931...	D1	Glass.....	.....	70% sep...	Fine.....	Yes.....	Moist.....	Ithaca

*Separation: a term applied to crystallized honey which shows a liquid layer on the surface.

TABLE 6 (*continued*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
III. Series E–H								
October 26, 1929....	E	Vacuum...	20	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	F	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	G	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	H	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
November 26, 1929..	E	Vacuum...	13	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	F	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	G	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	H	Glass.....	.....	0.....	.....	No.....	Moist.....	Ithaca
November 28, 1929..	E	Vacuum...	9	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	F	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	G	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	H	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
December 29, 1929..	E	Vacuum...	12	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	F	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	G	Friction...	.....	0.....	.....	No.....	Drying....	Ithaca
December 29, 1929..	H	Glass.....	.....	0.....	.....	No.....	Drying....	Ithaca
February 14, 1930...	E	Vacuum	10	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	F	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	G	Friction...	.....	0.....	.....	No.....	Dry.....	Ithaca
February 14, 1930...	H	Glass.....	.....	0.....	.....	No.....	Dry.....	Ithaca
May 23, 1930.....	E	Vacuum...	14	5.....	Coarse....	No.....	Moist.....	Ithaca
May 23, 1930.....	F	Hermetic..	.....	5.....	Coarse....	No.....	Moist.....	Ithaca
May 23, 1930.....	G	Friction...	.....	5.....	Coarse....	No.....	Dry.....	Ithaca
May 23, 1930.....	H	Glass.....	.....	5.....	Coarse....	No.....	Dry.....	Ithaca
June 4, 1930.....	E	Vacuum...	18	10.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	F	Hermetic..	.....	10.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	G	Friction...	.....	10.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	H	Glass.....	.....	10.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	E	Vacuum...	11	15.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	F	Hermetic..	.....	15.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	G	Friction...	.....	15.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	H	Glass.....	.....	15.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	E	Vacuum...	13	15.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	F	Hermetic..	.....	15.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	G	Friction...	.....	15.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	H	Glass.....	.....	15.....	Coarse....	No.....	Moist.....	Guelph
February 20, 1931...	E	Vacuum...	9..	10.....	Coarse....	No.....	Moist.....	Ithaca
February 20, 1931...	F	Hermetic..	.....	10.....	Coarse....	No.....	Moist.....	Ithaca
February 20, 1931...	G	Friction...	.....	10.....	Coarse....	No.....	Moist.....	Ithaca
February 20, 1931...	H	Glass.....	.....	10.....	Coarse....	No.....	Moist.....	Ithaca

TABLE 6 (*concluded*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				IV. Series M–P				
October 26, 1929....	M	Vacuum...	18	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	O	Friction...	.....	0.....	.....	No.....	Moist.....	Guelph
October 26, 1929....	P	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
November 26, 1929..	M	Vacuum...	13	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	O	Friction...	.....	0.....	.....	No.....	Moist.....	Ithaca
November 26, 1929..	P	Glass.....	.....	0.....	.....	No.....	Moist.....	Ithaca
November 28, 1929..	M	Vacuum...	8	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	O	Friction....	.....	0.....	.....	No.....	Moist.....	Guelph
November 28, 1929..	P	Glass.....	.....	0.....	.....	No.....	Moist.....	Guelph
December 29, 1929..	M	Vacuum...	11	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
December 29, 1929..	O	Friction...	.....	0.....	.....	No.....	Drying....	Ithaca
December 29, 1929..	P	Glass.....	.....	0.....	.....	No.....	Drying....	Ithaca
February 14, 1930...	M	Vacuum...	21	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
February 14, 1930...	O	Friction...	.....	0.....	.....	No.....	Dry.....	Ithaca
February 14, 1930...	P	Glass.....	.....	0.....	.....	No.....	Dry.....	Ithaca
May 23, 1930.....	M	Vacuum...	9	0.....	.....	No.....	Moist.....	Ithaca
May 23, 1930.....	N	Hermetic..	.....	0.....	.....	No.....	Moist.....	Ithaca
May 23, 1930.....	O	Friction...	.....	0.....	.....	No.....	Dry.....	Ithaca
May 23, 1930.....	P	Glass.....	.....	0.....	.....	No.....	Dry.....	Ithaca
June 4, 1930.....	M	Vacuum...	10	5.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	N	Hermetic..	.....	5.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	O	Friction...	.....	10.....	Coarse....	No.....	Moist.....	Guelph
June 4, 1930.....	P	Glass.....	.....	5.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	M	Vacuum...	14	10.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	N	Hermetic..	.....	10.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	O	Friction...	.....	15.....	Coarse....	No.....	Moist.....	Guelph
September 2, 1930...	P	Glass.....	.....	10.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	M	Vacuum...	18	15.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	N	Hermetic..	.....	15.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	O	Friction...	....	20.....	Coarse....	No.....	Moist.....	Guelph
February 9, 1931....	P	Glass.....	.....	15.....	Coarse....	No.....	Moist.....	Guelph
February 20, 1931...	M	Vacuum...	12	10.....	Coarse....	No.....	Moist.....	Ithaca
February 20, 1931...	N	Hermetic..	.....	10.....	Coarse....	No.....	Moist.....	Ithaca
February 20, 1931...	O	Friction...	.....	10.....	Coarse....	No.....	Moist.....	Ithaca
February 20, 1931...	P	Glass.....	.....	10.....	Coarse....	No.....	Moist.....	Ithaca

Series A1–D1 of experiment 6, to which water and fermented honey were added, showed early fermentation, in December, 1929; while series A–D of this experiment, to which an equal amount of fermented honey was added but which was not diluted with water, showed no fermentation until February, 1931. It would appear that high water content in honey is a greater factor in causing early fermentation than the presence of an excessive amount of yeasts. If it is assumed that all honeys contain yeasts, as shown by Lochhead and McMaster (1931), the degree of earliness of fermentation appears to depend less on the number of yeast cells present than on the ability of the honey to form a favorable medium for yeast growth. High water content, and an abundance of pollen grains

which supply nitrogenous compounds, are two important factors in forming a favorable medium for the growth of yeasts in honey.

Separation in the honey used in series A–D of experiment 6 began several months prior to obvious fermentation. Here again there appears to exist a relationship between separation and fermentation. In general, separation occurs just prior to or shortly after fermentation is detected.

The effect of heat in retarding crystallization, the evaporation and absorption of moisture from glass and from friction-top containers, and other points of interest, are identical with the results observed in experiments 3 and 5 and already discussed.

Experiment 7

Series A–D of experiment 7, made from White Dutch and alsike clover, sp. gr. 1.428, was produced in Wellington County, Ontario. It was extracted from wet combs and was run through a honey pump on August 27, 1929. This honey was viscolized under 1500 pounds pressure. The viscolizer used was one such as is commonly used in the dairy industry. The writer is indebted to H. Smallfield, of the Dairy Department of the Ontario Agricultural College, for viscolizing the honey used in this experiment. Before the honey would run through the viscolizer it was necessary to heat it to 122° F. to lower the viscosity. The honey was canned, after it had cooled to room temperature, on August 28, 1929. Three samples in glass, not heated nor viscolized, were kept as controls.

Series E–H, also made from White Dutch and alsike clover, sp. gr. 1.434, was produced in Wellington County, Ontario. It was extracted from dry combs on September 9, 1929, and was not run through a honey pump. The honey was viscolized as was that in series A–D, but was heated to 120° F. It was canned, after it had cooled to room temperature, on September 14, 1929. Three samples in glass, not heated nor viscolized, were kept as controls.

Discussion

The main object in conducting this experiment was to see what effect the atomizing action of the viscolizer would have on the crystallization of honey. The results are shown in table 7. The viscolized honey in both series of this experiment formed very coarse crystals, while the control samples, which were not viscolized nor heated, granulated more rapidly and formed slightly smaller crystals. As the honey in both series had to be heated before it would run through the viscolizer, it is possible that many of the numerous small crystals already existing in it were dissolved. A reduction in number of these small crystals should cause the honey to granulate less rapidly, with the consequent formation of larger crystals.

Fermentation was encountered in the unheated control samples of both series. The viscolized samples, which showed no fermentation, as already related were heated to about 120° F. and immediately run through the viscolizer. The small amount of heat applied in this case was apparently adequate to retard fermentation. Other points of interest in the results from experiment 7, such as the hygroscopic action of honey in the friction top and the glass containers, and separation, are similar to those with the previous experiments.

TABLE 7. CONDITION OF HONEYS UNDER VARIOUS METHODS OF PACKING AFTER VARIOUS TIME INTERVALS, EXPERIMENT 7

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				I. Series A–D				
October 26, 1929	A	Vacuum	24	0		No	Moist	Guelph
October 26, 1929	B	Hermetic		0		No	Moist	Guelph
October 26, 1929	C	Friction		0		No	Moist	Guelph
October 26, 1929	D	Glass		0		No	Moist	Guelph
October 26, 1929	Control (glass)			100	Fine	No	Moist	Guelph
November 26, 1929	A	Vacuum	15	0		No	Moist	Ithaca
November 26, 1929	B	Hermetic		0		No	Moist	Ithaca
November 26, 1929	C	Friction		0		No	Moist	Ithaca
November 26, 1929	D	Glass		0		No	Moist	Ithaca
November 26, 1929	Control (glass)			100	Fine	No	Moist	Ithaca
November 28, 1929	A	Vacuum	18	0		No	Moist	Guelph
November 28, 1929	B	Hermetic		0		No	Moist	Guelph
November 28, 1929	C	Friction		0		No	Moist	Guelph
November 28, 1929	D	Glass		0		No	Moist	Guelph
November 28, 1929	Control (glass)			100	Fine	No	Moist	Guelph
December 29, 1929	A	Vacuum	9	0		No	Moist	Ithaca
December 29, 1929	B	Hermetic		0		No	Moist	Ithaca
December 29, 1929	C	Friction		0		No	Drying	Ithaca
December 29, 1929	D	Glass		0		No	Drying	Ithaca
December 29, 1929	Control (glass)			100	Fine	No	Drying	Ithaca
February 14, 1930	A	Vacuum	16	5	Very coarse	No	Moist	Ithaca
February 14, 1930	B	Hermetic		5	Very coarse	No	Moist	Ithaca
February 14, 1930	C	Friction		5	Very coarse	No	Dry	Ithaca
February 14, 1930	D	Glass		5	Very coarse	No	Dry	Ithaca
February 14, 1930	Control (glass)			100	Fine	No	Dry	Ithaca
March 14, 1930	A	Vacuum	0	*	Very coarse	No	*	Chicago
March 14, 1930	B	Hermetic		*	Very coarse	No	*	Chicago
March 14, 1930	C	Friction		*	Very coarse	No	*	Chicago
March 14, 1930	D	Glass		*	Very coarse	No	*	Chicago
March 14, 1930	Control (glass)			*	Fine	No	*	Chicago
May 23, 1930	A	Vacuum	21	10	Very coarse	No	Moist	Ithaca
May 23, 1930	B	Hermetic		10	Very coarse	No	Moist	Ithaca
May 23, 1930	C	Friction		10	Very coarse	No	Dry	Ithaca
May 23, 1930	D	Glass		10	Very coarse	No	Dry	Ithaca
May 23, 1930	Control (glass)			100	Fine	No	Dry	Ithaca
June 4, 1930	A	Vacuum	13	20	Very coarse	No	Moist	Guelph
June 4, 1930	B	Hermetic		20	Very coarse	No	Moist	Guelph
June 4, 1930	C	Friction		20	Very coarse	No	Moist	Guelph
June 4, 1930	D	Glass		20	Very coarse	No	Moist	Guelph
June 4, 1930	Control (glass)			100	Fine	No	Moist	Guelph
September 2, 1930	A	Vacuum	12	30	Very coarse	No	Moist	Guelph
September 2, 1930	B	Hermetic		30	Very coarse	No	Moist	Guelph
September 2 1930	C	Friction		30	Very coarse	No	Moist	Guelph
September 2 1930	D	Glass		30	Very coarse	No	Moist	Guelph
September 2, 1930	Control (glass)			100	Fine	No	Moist	Guelph
February 9, 1931	A	Vacuum	17	40	Very coarse	No	Moist	Guelph
February 9, 1931	B	Hermetic		40	Very coarse	No	Moist	Guelph
February 9, 1931	C	Friction		40	Very coarse	No	Moist	Guelph
February 9, 1931	D	Glass		40	Very coarse	No	Moist	Guelph
February 9, 1931	Control (glass)			10% sep.†	Fine	Yes	Moist	Guelph
February 20, 1931	A	Vacuum	18	30	Very coarse	No	Moist	Ithaca
February 20, 1931	B	Hermetic		30	Very coarse	No	Moist	Ithaca
February 20, 1931	C	Friction		30	Very coarse	No	Moist	Ithaca
February 20, 1931	D	Glass		30	Very coarse	No	Moist	Ithaca
February 20, 1931	Control (glass)			10% sep.	Fine	Yes	Moist	Ithaca

* Incomplete.

† Separation: a term applied to crystallized honey which shows a liquid layer on the surface.

TABLE 7 (*concluded*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
II. Series E–H								
October 26, 1929	E	Vacuum	16	0		No	Moist	Guelph
October 26, 1929	F	Hermetic		0		No	Moist	Guelph
October 26, 1929	G	Friction		0		No	Moist	Guelph
October 26, 1929	H	Glass		0		No	Moist	Guelph
October 26, 1929	Control (glass)			50	Coarse	No	Moist	Guelph
November 26, 1929	E	Vacuum	22	0		No	Moist	Ithaca
November 26, 1929	F	Hermetic		0		No	Moist	Ithaca
November 26, 1929	G	Friction		0		No	Moist	Ithaca
November 26, 1929	H	Glass		0		No	Moist	Ithaca
November 26, 1929	Control (glass)			70	Coarse	No	Moist	Ithaca
November 28, 1929	E	Vacuum	6	0		No	Moist	Guelph
November 28, 1929	F	Hermetic		0		No	Moist	Guelph
November 28, 1929	G	Friction		0		No	Moist	Guelph
November 28 1929	H	Glass		0		No	Moist	Guelph
November 28 1929	Control (glass)			75	Coarse	No	Moist	Guelph
December 29, 1929	E	Vacuum	12	10	Very coarse	No	Moist	Ithaca
December 29, 1929	F	Hermetic		10	Very coarse	No	Moist	Ithaca
December 29, 1929	G	Friction		10	Very coarse	No	Drying	Ithaca
December 29, 1929	H	Glass		10	Very coarse	No	Moist	Ithaca
December 29, 1929	Control (glass)			85	Coarse	No	Drying	Ithaca
February 14, 1930	E	Vacuum	4	20	Very coarse	No	Moist	Ithaca
February 14, 1930	F	Hermetic		20	Very coarse	No	Moist	Ithaca
February 14, 1930	G	Friction		20	Very coarse	No	Dry	Ithaca
February 14, 1930	H	Glass		20	Very coarse	No	Drying	Ithaca
February 14, 1930	Control (glass)			100	Coarse	No	Dry	Ithaca
March 14, 1930	E	Vacuum	7	*	Very coarse	No	*	Chicago
March 14, 1930	F	Hermetic		*	Very coarse	No	*	Chicago
March 14, 1930	G	Friction		*	Very coarse	No	*	Chicago
March 14, 1930	H	Glass		*	Very coarse	No	*	Chicago
March 14, 1930	Control (glass)			*	Coarse	No	*	Chicago
May 23, 1930	E	Vacuum	19	30	Very coarse	No	Moist	Ithaca
May 23, 1930	F	Hermetic		30	Very coarse	No	Moist	Ithaca
May 23, 1930	G	Friction		30	Very coarse	No	Dry	Ithaca
May 23, 1930	H	Glass		30	Very coarse	No	Dry	Ithaca
May 23, 1930	Control (glass)			100	Coarse	No	Dry	Ithaca
June 4, 1930	E	Vacuum	11	40	Very coarse	No	Moist	Guelph
June 4, 1930	F	Hermetic		40	Very coarse	No	Moist	Guelph
June 4, 1930	G	Friction		40	Very coarse	No	Moist	Guelph
June 4, 1930	H	Glass		40	Very coarse	No	Moist	Guelph
June 4, 1930	Control (glass)			100	Coarse	No	Moist	Guelph
September 2, 1930	E	Vacuum	23	50	Very coarse	No	Moist	Guelph
September 2, 1930	F	Hermetic		50	Very coarse	No	Moist	Guelph
September 2, 1930	G	Friction		50	Very coarse	No	Moist	Guelph
September 2, 1930	H	Glass		50	Very coarse	No	Moist	Guelph
September 2, 1930	Control (glass)			100	Coarse	No	Moist	Guelph
February 9, 1931	E	Vacuum	16	60	Very coarse	No	Moist	Guelph
February 9, 1931	F	Hermetic		60	Very coarse	No	Moist	Guelph
February 9, 1931	G	Friction		60	Very coarse	No	Moist	Guelph
February 9, 1931	H	Glass		60	Very coarse	No	Moist	Guelph
February 9, 1931	Control (glass)			10% sep.†	Coarse	Yes	Moist	Guelph
February 20, 1931	E	Vacuum	13	50	Very coarse	No	Moist	Ithaca
February 20, 1931	F	Hermetic		50	Very coarse	No	Moist	Ithaca
February 20, 1931	G	Friction		50	Very coarse	No	Moist	Ithaca
February 20, 1931	H	Glass		50	Very coarse	No	Moist	Ithaca
February 20, 1931	Control (glass)			10% sep.	Coarse	Yes	Moist	Ithaca

*Incomplete.

†Separation: a term applied to crystallized honey which shows a liquid layer on the surface.

Experiment 8

Series A–D of experiment 8, made from White Dutch and alsike clover and buckwheat, sp. gr. 1.411, was produced in the apiary of the Ontario Agricultural College, in Wellington County, Ontario. This honey was extracted from wet combs which were separated from the normal run of light honey as they contained some buckwheat honey. The honey was run through a honey pump, was not heated, and was totally liquid at the time of canning, August 23, 1929.

Series E–H was the same honey as was used in series A–D. The honey was not pumped, was not heated, and was totally liquid at the time of canning, August 23, 1929.

Series I–L, made from White Dutch and alsike clover, sp. gr. 1.425, was produced in Halton County, Ontario. It was extracted from dry combs and run through a honey pump on September 3, 1929. It was not heated, and was totally liquid at the time of canning, September 11, 1929.

Series M–P was the same honey as was used in series I–L except that it was not run through a pump. The honey was not heated, and was totally liquid at the time of canning, September 11, 1929.

Discussion

The object in conducting experiment 8 was to determine what effect the mechanical action of the honey pump may have on crystallization or on fermentation. The results are shown in table 8.

The honey in series A–D, which was pumped, showed a slight advance over that in series E–H in rate of crystallization, but the crystals formed in both series were small and were of approximately the same size. In May, 1930, the honey in series A–D, which was pumped, showed a little more separation than did the honey in series E–H, which was not pumped. Fermentation was present or suspected in the honey of both series in May, 1930.

The honey in series I–L, which was pumped, also crystallized more rapidly than did the honey in series M–P, which was not pumped. The crystals formed in series M–P were considerably larger than those formed in series I–L. As both honeys that were pumped, in this experiment, formed crystals more rapidly than did the honeys that were not pumped, the mechanical action of the pump must be assumed to hasten crystallization, usually with the consequent formation of smaller crystals. This is in accord with the common experience of beekeepers.

It is interesting to notice that a 5-per-cent separation occurred in the honey of series I–L. The honey in this series and in series M–P was the same except that the honey of series I–L was pumped, and formed smaller crystals than did the honey of series M–P, which was not pumped. Fermentation was evident in both series at the same time. These two series thus offer an excellent opportunity to study the relation of separation to fermentation. On thoroughly examining the samples, it would appear that the larger crystals in the honey of series M–P formed a substantial framework of dextrose hydrate crystals, which would not permit the settling of these large crystals. The crystals formed in the honey of series I–L were much smaller, forming a less substantial framework and

TABLE 8. CONDITION OF HONEYS UNDER VARIOUS METHODS OF PACKING AFTER VARIOUS TIME INTERVALS, EXPERIMENT 8

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				I. Series A–D				
October 26, 1929	A	Vacuum	20	100	Fine	No	Moist	Guelph
October 26, 1929	B	Hermetic		100	Fine	No	Moist	Guelph
October 26, 1929	C	Friction		100	Fine	No	Moist	Guelph
October 26, 1929	D	Glass		100	Fine	No	Moist	Guelph
November 26, 1929	A	Vacuum	8	100	Fine	No	Moist	Ithaca
November 26, 1929	B	Hermetic		100	Fine	No	Moist	Ithaca
November 26, 1929	C	Friction		100	Fine	No	Moist	Ithaca
November 26, 1929	D	Glass		100	Fine	No	Moist	Ithaca
November 28, 1929	A	Vacuum	2	100	Fine	No	Moist	Guelph
November 28, 1929	B	Hermetic		100	Fine	No	Moist	Guelph
November 28, 1929	C	Friction		100	Fine	No	Moist	Guelph
November 28, 1929	D	Glass		100	Fine	No	Moist	Guelph
December 29, 1929	A	Vacuum	5	100	Fine	No	Moist	Ithaca
December 29, 1929	B	Hermetic		100	Fine	No	Moist	Ithaca
December 29, 1929	C	Friction		100	Fine	No	Dry	Ithaca
December 29, 1929	D	Glass		100	Fine	No	Moist	Ithaca
February 14, 1930	A	Vacuum	13	100	Fine	No	Moist	Ithaca
February 14, 1930	B	Hermetic		100	Fine	No	Moist	Ithaca
February 14, 1930	C	Friction		100	Fine	No	Dry	Ithaca
February 14, 1930	D	Glass		100	Fine	No	Moist	Ithaca
March 14, 1930	A	Vacuum	8	100	Fine	No	†	Chicago
March 14, 1930	B	Hermetic		100	Fine	No	†	Chicago
March 14, 1930	C	Friction		100	Fine	No	†	Chicago
March 14, 1930	D	Glass		100	Fine	No	†	Chicago
May 23, 1930	A	Vacuum	0	10% sep.*	Fine	Yes	Moist	Ithaca
May 23, 1930	B	Hermetic		10% sep.	Fine	Yes	Moist	Ithaca
May 23, 1930	C	Friction		10% sep.	Fine	Yes	Dry	Ithaca
May 23, 1930	D	Glass		10% sep.	Fine	Yes	Dry	Ithaca
June 4, 1930	A	Vacuum	0	20% sep.	Fine	Yes	Moist	Guelph
June 4, 1930	B	Hermetic		20% sep.	Fine	Yes	Moist	Guelph
June 4, 1930	C	Friction		20% sep.	Fine	Yes	Moist	Guelph
June 4, 1930	D	Glass		20% sep.	Fine	Yes	Moist	Guelph
September 2, 1930	A	Vacuum	0	30% sep.	Fine	Yes	Moist	Guelph
September 2, 1930	B	Hermetic		30% sep.	Fine	Yes	Moist	Guelph
September 2, 1930	C	Friction		30% sep.	Fine	Yes	Moist	Guelph
September 2, 1930	D	Glass		30% sep.	Fine	Yes	Moist	Guelph
February 9, 1931	A	Vacuum	0	40% sep.	Fine	Yes	Moist	Guelph
February 9, 1931	B	Hermetic		40% sep.	Fine	Yes	Moist	Guelph
February 9, 1931	C	Friction		40% sep.	Fine	Yes	Moist	Guelph
February 9, 1931	D	Glass		40% sep.	Fine	Yes	Moist	Guelph
February 20, 1931	A	Vacuum	0	50% sep.	Fine	Yes	Moist	Ithaca
February 20, 1931	B	Hermetic		50% sep.	Fine	Yes	Moist	Ithaca
February 20, 1931	C	Friction		50% sep.	Fine	Yes	Moist	Ithaca
February 20, 1931	D	Glass		50% sep.	Fine	Yes	Moist	Ithaca

* Separation: a term applied to crystallized honey which shows a liquid layer on the surface.
† Incomplete.

TABLE 8 (*continued*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				II. Series E–H				
October 26, 1929....	E	Vacuum...	10	90.....	Fine.....	No.....	Moist.....	Guelph
October 26, 1929....	F	Hermetic..	.....	90.....	Fine.....	No.....	Moist.....	Guelph
October 26, 1929....	G	Friction...	.....	90.....	Fine.....	No.....	Moist.....	Guelph
October 26, 1929....	H	Glass.....	.....	90.....	Fine.....	No.....	Moist.....	Guelph
November 26, 1929..	E	Vacuum...	7	100.....	Fine.....	No.....	Moist.....	Ithaca
November 26, 1929..	F	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
November 26, 1929..	G	Friction...	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
November 26, 1929..	H	Glass.....	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
November 28, 1929..	E	Vacuum...	2	100.....	Fine.....	No.....	Moist.....	Guelph
November 28, 1929..	F	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Guelph
November 28, 1929..	G	Friction...	.....	100.....	Fine.....	No.....	Moist.....	Guelph
November 28, 1929..	H	Glass.....	.....	100.....	Fine.....	No.....	Moist.....	Guelph
December 29, 1929..	E	Vacuum...	0	100.....	Fine.....	No.....	Moist.....	Ithaca
December 29, 1929..	F	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
December 29, 1929..	G	Friction...	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
December 29, 1929..	H	Glass.....	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
February 14, 1930...	E	Vacuum...	5	100.....	Fine.....	No.....	Moist.....	Ithaca
February 14, 1930...	F	Hermetic..	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
February 14, 1930...	G	Friction...	.....	100.....	Fine.....	No.....	Dry.....	Ithaca
February 14, 1930...	H	Glass.....	.....	100.....	Fine.....	No.....	Moist.....	Ithaca
March 14, 1930.....	E	Vacuum...	8	100.....	Fine.....	No.....	.....†	Chicago
March 14, 1930.....	F	Hermetic..	.....	100.....	Fine.....	No.....	.....†	Chicago
March 14, 1930.....	G	Friction...	.....	100.....	Fine.....	No.....	.....†	Chicago
March 14, 1930.....	H	Glass.....	.....	100.....	Fine.....	No.....	.....†	Chicago
May 23, 1930.....	E	Vacuum...	0	5% sep.*..	Fine.....	?.....	Moist.....	Ithaca
May 23, 1930.....	F	Hermetic..	.....	5% sep....	Fine.....	?.....	Moist.....	Ithaca
May 23, 1930.....	G	Friction...	.....	5% sep....	Fine.....	?.....	Dry.....	Ithaca
May 23, 1930.....	H	Glass.....	.....	5% sep....	Fine.....	?.....	Moist.....	Ithaca
June 4, 1930.....	E	Vacuum...	0	15% sep...	Fine.....	Yes.....	Moist.....	Guelph
June 4, 1930.....	F	Hermetic..	.....	15% sep...	Fine.....	Yes.....	Moist.....	Guelph
June 4, 1930.....	G	Friction...	.....	15% sep...	Fine.....	Yes.....	Moist.....	Guelph
June 4, 1930.....	H	Glass.....	.....	15% sep...	Fine.....	Yes.....	Moist.....	Guelph
September 2, 1930...	E	Vacuum...	0	30% sep...	Fine.....	Yes.....	Moist.....	Guelph
September 2, 1930...	F	Hermetic..	.....	30% sep...	Fine.....	Yes.....	Moist.....	Guelph
September 2, 1930...	G	Friction...	.....	30% sep...	Fine.....	Yes.....	Moist.....	Guelph
September 2, 1930...	H	Glass.....	.....	30% sep...	Fine.....	Yes.....	Moist.....	Guelph
February 9, 1931....	E	Vacuum...	0	40% sep...	Fine.....	Yes.....	Moist.....	Guelph
February 9, 1931....	F	Hermetic..	.....	40% sep...	Fine.....	Yes.....	Moist.....	Guelph
February 9, 1931....	G	Friction...	.....	40% sep...	Fine.....	Yes.....	Moist.....	Guelph
February 9, 1931....	H	Glass.....	.....	40% sep...	Fine.....	Yes.....	Moist.....	Guelph
February 20, 1931...	E	Vacuum...	0	50% sep...	Fine.....	Yes.....	Moist.....	Ithaca
February 20, 1931...	F	Hermetic..	.....	50% sep...	Fine.....	Yes.....	Moist.....	Ithaca
February 20, 1931...	G	Friction...	.....	50% sep...	Fine.....	Yes.....	Moist.....	Ithaca
February 20, 1931...	H	Glass.....	.....	50% sep...	Fine.....	Yes.....	Moist.....	Ithaca

* Separation: a term applied to crystallized honey which shows a liquid layer on the surface.
† Incomplete.

TABLE 8 (*continued*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
III. Series I–L								
October 26, 1929....	I	Vacuum...	7	80.....	Medium coarse	No.....	Moist.....	Guelph
October 26, 1929....	J	Hermetic..	.....	80.....	Medium coarse	No.....	Moist.....	Guelph
October 26, 1929....	K	Friction...	.....	80.....	Medium coarse	No.....	Moist.....	Guelph
October 26, 1929....	L	Glass.....	.....	80.....	Medium coarse	No.....	Moist.....	Guelph
November 26, 1929..	I	Vacuum...	4	90.....	Medium coarse	No.....	Moist.....	Ithaca
November 26, 1929..	J	Hermetic..	.....	90.....	Medium coarse	No.....	Moist.....	Ithaca
November 26, 1929..	K	Friction...	.....	90.....	Medium coarse	No.....	Moist.....	Ithaca
November 26, 1929..	L	Glass.....	.....	90.....	Medium coarse	No.....	Moist.....	Ithaca
November 28, 1929..	I	Vacuum...	16	90.....	Medium coarse	No.....	Moist.....	Guelph
November 28, 1929..	J	Hermetic..	.....	90.....	Medium coarse	No.....	Moist.....	Guelph
November 28, 1929..	K	Friction...	.....	90.....	Medium coarse	No.....	Moist.....	Guelph
November 28, 1929..	L	Glass.....	.....	90.....	Medium coarse	No.....	Moist.....	Guelph
December 29, 1929..	I	Vacuum...	2	100.....	Medium coarse	No.....	Moist.....	Ithaca
December 29, 1929..	J	Hermetic..	.....	100.....	Medium coarse	No.....	Moist.....	Ithaca
December 29, 1929..	K	Friction...	.....	100.....	Medium coarse	No.....	Drying....	Ithaca
December 29, 1929..	L	Glass.....	.....	100.....	Medium coarse	No.....	Moist.....	Ithaca
February 14, 1930...	I	Vacuum...	2	100.....	Medium coarse	No.....	Moist.....	Ithaca
February 14, 1930...	J	Hermetic..	.....	100.....	Medium coarse	No.....	Moist.....	Ithaca
February 14, 1930...	K	Friction...	.....	100.....	Medium coarse	No.....	Dry.....	Ithaca
February 14, 1930...	L	Glass.....	.....	100.....	Medium coarse	No.....	Moist.....	Ithaca
May 23, 1930.....	I	Vacuum...	8	100.....	Medium coarse	No.....	Moist.....	Ithaca
May 23, 1930.....	J	Hermetic..	.....	100.....	Medium coarse	No.....	Moist.....	Ithaca
May 23, 1930.....	K	Friction...	.....	100.....	Medium coarse	No.....	Dry.....	Ithaca
May 23, 1930.....	L	Glass.....	.....	100.....	Medium coarse	No.....	Moist.....	Ithaca
June 4, 1930.....	I	Vacuum...	5	100.....	Medium coarse	No.....	Moist.....	Guelph
June 4, 1930.....	J	Hermetic..	.....	100.....	Medium coarse	No.....	Moist.....	Guelph
June 4, 1930.....	K	Friction...	.....	100.....	Medium coarse	No.....	Moist.....	Guelph
June 4, 1930.....	L	Glass.....	.....	100.....	Medium coarse	No.....	Moist.....	Guelph
September 2, 1930...	I	Vacuum...	0	100.....	Medium coarse	No.....	Moist.....	Guelph
September 2, 1930...	J	Hermetic..	.....	100.....	Medium coarse	No.....	Moist.....	Guelph
September 2, 1930...	K	Friction...	.....	100.....	Medium coarse	No.....	Moist.....	Guelph
September 2, 1930...	L	Glass.....	.....	100.....	Medium coarse	No.....	Moist.....	Guelph
February 9, 1931....	I	Vacuum...	0	Slight sep.*	Medium coarse	Slightly...	Moist.....	Guelph
February 9, 1931....	J	Hermetic..	.....	Slight sep..	Medium coarse	Slightly...	Moist.....	Guelph
February 9, 1931....	K	Friction...	.....	Slight sep..	Medium coarse	Slightly...	Moist.....	Guelph
February 9, 1931....	L	Glass.....	.....	Slight sep..	Medium coarse	Slightly...	Moist.....	Guelph
February 20, 1931...	I	Vacuum...	0	5% sep....	Medium coarse	Yes.....	Moist.....	Ithaca
February 20, 1931...	J	Hermetic..	.....	5% sep....	Medium coarse	Yes.....	Moist.....	Ithaca
February 20, 1931...	K	Friction...	.....	5% sep....	Medium coarse	Yes.....	Moist.....	Ithaca
February 20, 1931...	L	Glass.....	.....	5% sep....	Medium coarse	Yes.....	Moist.....	Ithaca

* Separation: a term applied to crystallized honey which shows a liquid layer on the surface

TABLE 8 (*concluded*)

Date	Series	Type of closure	Vacuum inches	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Condition of honey surface	Stored and opened at
				IV. Series M–P				
October 26, 1929....	M	Vacuum...	5	70.....	Very coarse...	No.....	Moist.....	Guelph
October 26, 1929....	N	Hermetic..	.....	70.....	Very coarse...	No.....	Moist.....	Guelph
October 26, 1929....	O	Friction...	.....	70.....	Very coarse...	No.....	Moist.....	Guelph
October 26, 1929....	P	Glass.....	.....	70.....	Very coarse...	No.....	Moist.....	Guelph
November 26, 1929..	M	Vacuum...	11	80.....	Very coarse...	No.....	Moist.....	Ithaca
November 26, 1929..	N	Hermetic..	.....	80.....	Very coarse...	No.....	Moist.....	Ithaca
November 26, 1929..	O	Friction...	.....	80.....	Very coarse...	No.....	Moist.....	Ithaca
November 26, 1929..	P	Glass.....	.....	80.....	Very coarse...	No.....	Moist.....	Ithaca
November 28, 1929..	M	Vacuum...	8	85.....	Very coarse...	No.....	Moist.....	Guelph
November 28, 1929..	N	Hermetic..	.....	85.....	Very coarse...	No.....	Moist.....	Guelph
November 28, 1929..	O	Friction...	.....	85.....	Very coarse...	No.....	Moist.....	Guelph
November 28, 1929..	P	Glass.....	.....	85.....	Very coarse...	No.....	Moist.....	Guelph
December 29, 1929..	M	Vacuum...	4	95.....	Very coarse...	No.....	Moist.....	Ithaca
December 29, 1929..	N	Hermetic..	.....	95.....	Very coarse...	No	Moist.....	Ithaca
December 29, 1929..	O	Friction...	.....	95.....	Very coarse...	No.....	Moist.....	Ithaca
December 29, 1929..	P	Glass.....	.....	95.....	Very coarse...	No.....	Moist.....	Ithaca
February 14, 1930...	M	Vacuum...	0	100.....	Very coarse...	No.....	Moist.....	Ithaca
February 14, 1930...	N	Hermetic..	.....	100.....	Very coarse...	No.....	Moist.....	Ithaca
February 14, 1930...	O	Friction...	.....	100.....	Very coarse...	No.....	Dry.....	Ithaca
February 14, 1930...	P	Glass.....	.....	100.....	Very coarse...	No.....	Moist.....	Ithaca
May 23, 1930.....	M	Vacuum...	1	100.....	Very coarse...	No.....	Moist.....	Ithaca
May 23, 1930.....	N	Hermetic..	.....	100.....	Very coarse...	No.....	Moist.....	Ithaca
May 23, 1930.....	O	Friction...	.....	100.....	Very coarse...	No.....	Dry.....	Ithaca
May 23, 1930.....	P	Glass.....	.....	100.....	Very coarse...	No.....	Drying....	Ithaca
June 4, 1930.....	M	Vacuum...	3	100.....	Very coarse...	No.....	Moist.....	Guelph
June 4, 1930.....	N	Hermetic..	.....	100.....	Very coarse...	No.....	Moist.....	Guelph
June 4, 1930.....	O	Friction...	.....	100.....	Very coarse...	No.....	Moist.....	Guelph
June 4, 1930.....	P	Glass.....	.....	100.....	Very coarse...	No.....	Moist.....	Guelph
September 2, 1930...	M	Vacuum...	0	100.....	Very coarse...	No.....	Moist.....	Guelph
September 2, 1930...	N	Hermetic..	.....	100.....	Very coarse...	No.....	Moist.....	Guelph
September 2, 1930...	O	Friction...	.....	100.....	Very coarse...	No.....	Moist.....	Guelph
September 2, 1930...	P	Glass.....	.....	100.....	Very coarse...	No.....	Moist.....	Guelph
February 9, 1931....	M	Vacuum...	0	100.....	Very coarse...	Slightly...	Moist.....	Guelph
February 9, 1931....	N	Hermetic..	.....	100.....	Very coarse...	Slightly...	Moist.....	Guelph
February 9, 1931....	O	Friction...	.....	100.....	Very coarse...	Slightly...	Moist.....	Guelph
February 9, 1931....	P	Glass.....	.....	100.....	Very coarse...	Slightly...	Moist.....	Guelph
February 20, 1931...	M	Vacuum...	0	100.....	Very coarse...	Yes.....	Moist.....	Ithaca
February 20, 1931...	N	Hermetic..	.....	100.....	Very coarse...	Yes.....	Moist.....	Ithaca
February 20, 1931...	O	Friction...	.....	100.....	Very coarse...	Yes.....	Moist.....	Ithaca
February 20, 1931...	P	Glass.....	.....	100.....	Very coarse...	Yes.....	Moist.....	Ithaca

permitting the settling of the smaller crystals. The crystals of the latter series, being smaller, would then settle into a more compact mass, leaving a liquid layer at the surface. In series I–L, fermentation appeared to be progressing more in the liquid layer in the surface of the honey; while in series M–P, it appeared to be progressing between the larger crystals throughout the entire honey. Fermentation may therefore be present in coarsely granulated honeys without apparent separation.

It appears that separation is characteristic of honeys which are high in water content and in which the dextrose hydrate crystals are of insufficient size and number to form a substantial framework of crystals throughout the liquid phase which would prohibit the settling of crystals. Since

honeys of high water content are susceptible to fermentation, separation when present is usually, but not necessarily, accompanied by fermentation. Therefore, when separation has been present for some time, fermentation also may be expected to be present; but should these separated samples be observed immediately after separation has become evident, it is doubtful in many cases whether fermentation would be present.

Experiment 9

Series E, E1, H, and H1 were the same honey as was used in series E–H of experiment 2, made from white sweet clover, sp. gr. 1.431, and produced in Simcoe County, Ontario. It was extracted from dry combs on September 2, 1929, and was not run through a honey pump.

About 5 per cent of fine-crystallized honey was added to half of the containers used. To the remaining containers about 5 per cent of coarse-crystallized honey was added. As indicated in table 9, only the vacuum-seal and the glass containers were used in this experiment. The crystallized honey which was added was only slightly stirred into the liquid honey and was by no means thoroughly incorporated. The honey was unheated and was totally liquid at the time of canning, September 7, 1929.

Series M, M1, P, and P1 were the same honey as was used in series E, E1, H, and H1. Prior to the time of canning, the honey was about 80 per cent crystallized. It was liquefied by heating to 130° F. for thirty minutes. After it had cooled to room temperature, about 5 per cent of fine- or of coarse-crystallized honey was added, as in the first series of the experiment. The honey was canned or sealed on October 22, 1929.

Discussion

The object in conducting this experiment was to see what effect the addition of crystallized honey would have on the rate and the type of crystallization of the honey. The results are shown in table 9.

It will be noted that the unheated honey used in series E–H1 to which 5 per cent of granulated honey was added, was not influenced as to the type of crystallization as compared with the same unheated honey used in series E–H of experiment 2 (table 2, page 19), to which no crystals were added. The fineness or coarseness of the crystals added to the honey of series E–H1 also showed little or no effect on the rapidity and the type of crystallization.

On comparing the results of series M–P1 of experiment 9 with series M–P of experiment 2 (page 20), it will be noted that the former series, to which crystallized honey was added, granulated more rapidly than did the latter, with the formation of slightly smaller crystals. No difference could be detected in the rapidity or the type of crystallization as influenced by the fineness or coarseness of the crystals added to the honey.

The results of experiment 9 would indicate that the addition of crystals to liquid honey has little or no effect on the rapidity or the type of crystallization. Theoretically, the addition of crystals to liquid honey should influence the type of crystallization; but the crystals added were not thoroughly incorporated through the honey, and this lack of their thorough dispersion is one of the reasons why crystallization was only slightly influenced.

TABLE 9. CONDITION OF HONEYS UNDER VARIOUS METHODS OF PACKING AFTER VARIOUS TIME INTERVALS, EXPERIMENT 9

Date	Series	Type of closure	Vacuum inches	Type of crystallized honey added	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Stored and opened at
I. Series E, E1, H, and H1								
October 26, 1929....	E	Vacuum...	16	Fine.....	90.....	Coarse....	No.....	Guelph
October 26, 1929....	E1	Vacuum...	11	Coarse....	90.....	Coarse....	No.....	Guelph
October 26, 1929....	H	Glass.....	.....	Fine.....	90.....	Coarse....	No.....	Guelph
October 26, 1929....	H1	Glass.....	.....	Coarse....	90.....	Coarse....	No.....	Guelph
November 26, 1929..	E	Vacuum...	9	Fine.....	100.....	Coarse....	No.....	Ithaca
November 26, 1929..	E1	Vacuum...	2	Coarse....	100.....	Coarse....	No.....	Ithaca
November 26, 1929..	H	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Ithaca
November 26, 1929..	H1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Ithaca
November 28, 1929..	E	Vacuum...	13	Fine.....	100.....	Coarse....	No.....	Guelph
November 28, 1929..	E1	Vacuum...	5	Coarse....	100.....	Coarse....	No.....	Guelph
November 28, 1929..	H	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Guelph
November 28, 1929..	H1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Guelph
December 29, 1929..	E	Vacuum...	7	Fine.....	100.....	Coarse....	No.....	Ithaca
December 29, 1929..	E1	Vacuum...	5	Coarse....	100.....	Coarse....	No.....	Ithaca
December 29, 1929..	H	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Ithaca
December 29, 1929..	H1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Ithaca
February 14, 1930...	E	Vacuum...	0	Fine.....	100.....	Coarse....	No.....	Ithaca
February 14, 1930...	E1	Vacuum...	14	Coarse....	100.....	Coarse....	No.....	Ithaca
February 14, 1930...	H	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Ithaca
February 14, 1930...	H1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Ithaca
March 14, 1930.....	E	Vacuum...	7	Fine.....	.....*	.....*	No.....	Chicago
March 14, 1930.....	E1	Vacuum...	0	Coarse....	.....*	.....*	No.....	Chicago
March 14, 1930.....	H	Glass.....	.....	Fine.....	.....*	.....*	No.....	Chicago
March 14, 1930.....	H1	Glass.....	.....	Coarse....	.....*	.....*	No.....	Chicago
May 23, 1930.....	E	Vacuum...	4	Fine.....	100.....	Coarse....	No.....	Ithaca
May 23, 1930.....	E1	Vacuum...	2	Coarse....	100.....	Coarse....	No.....	Ithaca
May 23, 1930.....	H	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Ithaca
May 23, 1930.....	H1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Ithaca
June 4, 1930.....	E	Vacuum...	0	Fine.....	100.....	Coarse....	No.....	Guelph
June 4, 1930.....	E1	Vacuum...	6	Coarse....	100.....	Coarse....	No.....	Guelph
June 4, 1930.....	H	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Guelph
June 4, 1930.....	H1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Guelph
September 2, 1930...	E	Vacuum...	1	Fine.....	100.....	Coarse....	No.....	Guelph
September 2, 1930...	E1	Vacuum...	3	Coarse....	100.....	Coarse....	No.....	Guelph
September 2, 1930...	H	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Guelph
September 2, 1930...	H1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Guelph
February 9, 1931....	E	Vacuum...	2	Fine.....	100.....	Coarse....	No.....	Guelph
February 9, 1931....	E1	Vacuum...	5	Coarse....	100.....	Coarse....	No.....	Guelph
February 9, 1931....	H	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Guelph
February 9, 1931....	H1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Guelph
February 20, 1931...	E	Vacuum...	3	Fine.....	100.....	Coarse....	No.....	Ithaca
February 20, 1931...	E1	Vacuum...	0	Coarse....	100.....	Coarse....	No.....	Ithaca
February 20, 1931...	H	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Ithaca
February 20, 1931...	H1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Ithaca

* Incomplete.

TABLE 9 (*concluded*)

Date	Series	Type of closure	Vacuum inches	Type of crystallized honey added	Approximate per cent of crystallization	Approximate type of crystallization	Fermented or not	Stored and opened at
II. Series M, M1, P, and P1								
October 26, 1929....	M	Vacuum...	23	Fine.....	0.....	.....	No.....	Guelph
October 26, 1929....	M1	Vacuum...	25	Coarse....	0.....	.....	No.....	Guelph
October 26, 1929....	P	Glass.....	.....	Fine.....	0.....	.....	No.....	Guelph
October 26, 1929....	P1	Glass.....	.....	Coarse....	0.....	.....	No.....	Guelph
November 26, 1929..	M	Vacuum...	21	Fine.....	25.....	Coarse....	No.....	Ithaca
November 26, 1929..	M1	Vacuum...	18	Coarse....	20.....	Coarse....	No.....	Ithaca
November 26, 1929..	P	Glass.....	.....	Fine.....	25.....	Coarse....	No.....	Ithaca
November 26, 1929..	P1	Glass.....	.....	Coarse....	20.....	Coarse....	No.....	Ithaca
November 28, 1929..	M	Vacuum...	14	Fine.....	30.....	Coarse....	No.....	Guelph
November 28, 1929..	M1	Vacuum...	20	Coarse....	30.....	Coarse....	No.....	Guelph
November 28, 1929..	P	Glass.....	.....	Fine.....	30.....	Coarse....	No.....	Guelph
November 28, 1929..	P1	Glass.....	.....	Coarse....	30.....	Coarse....	No.....	Guelph
December 29, 1929..	M	Vacuum...	17	Fine.....	75.....	Coarse....	No.....	Ithaca
December 29, 1929..	M1	Vacuum...	21	Coarse....	75.....	Coarse....	No.....	Ithaca
December 29, 1929..	P	Glass.....	.....	Fine.....	75.....	Coarse....	No.....	Ithaca
December 29, 1929..	P1	Glass.....	.....	Coarse....	75.....	Coarse....	No.....	Ithaca
February 14, 1930...	M	Vacuum...	9	Fine.....	100.....	Coarse....	No.....	Ithaca
February 14, 1930...	M1	Vacuum...	18	Coarse....	100.....	Coarse....	No.....	Ithaca
February 14, 1930...	P	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Ithaca
February 14, 1930...	P1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Ithaca
March 14, 1930.....	M	Vacuum...	.....*	Fine.....	.....*	.....*	No.....	Chicago
March 14, 1930.....	M1	Vacuum...	.....*	Coarse....	.....*	.....*	No.....	Chicago
March 14, 1930.....	P	Glass.....	.....	Fine.....	.....*	.....*	No.....	Chicago
March 14, 1930.....	P1	Glass.....	.....	Coarse....	.....*	.....*	No.....	Chicago
May 23, 1930.....	M	Vacuum...	15	Fine.....	100.....	Coarse....	No.....	Ithaca
May 23, 1930.....	M1	Vacuum...	10	Coarse....	100.....	Coarse....	No.....	Ithaca
May 23, 1930.....	P	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Ithaca
May 23, 1930.....	P1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Ithaca
June 4, 1930.....	M	Vacuum...	7	Fine.....	100.....	Coarse....	No.....	Guelph
June 4, 1930.....	M1	Vacuum...	12	Coarse....	100.....	Coarse....	No.....	Guelph
June 4, 1930.....	P	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Guelph
June 4, 1930.....	P1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Guelph
September 2, 1930...	M	Vacuum...	21	Fine.....	100.....	Coarse....	No.....	Guelph
September 2, 1930...	M1	Vacuum...	11	Coarse....	100.....	Coarse....	No.....	Guelph
September 2, 1930...	P	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Guelph
September 2, 1930...	P1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Guelph
February 9, 1931....	M	Vacuum...	13	Fine.....	100.....	Coarse....	No.....	Guelph
February 9, 1931....	M1	Vacuum...	10	Coarse....	100.....	Coarse....	No.....	Guelph
February 9, 1931....	P	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Guelph
February 9, 1931....	P1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Guelph
February 20, 1931...	M	Vacuum...	10	Fine.....	100.....	Coarse....	No.....	Ithaca
February 20, 1931...	M1	Vacuum...	16	Coarse....	100.....	Coarse....	No.....	Ithaca
February 20, 1931...	P	Glass.....	.....	Fine.....	100.....	Coarse....	No.....	Ithaca
February 20, 1931...	P1	Glass.....	.....	Coarse....	100.....	Coarse....	No.....	Ithaca

*Incomplete.

Experiment 10

Fourteen samples of honeys used in experiments 1 to 9 were chosen. These samples represent different floral sources or honeys that had been treated differently physically. Portions of each sample were placed in eight small glass bottles, 4 inches in height by 1 inch in diameter, with metal screw caps lined with cork. Each group of eight bottles was then treated as follows:

Bottle A. Containing normal honey, cap screwed on, used as check.
Bottle B. Hermetically sealed by immersing the bottle, after applying the cap, in a mixture of liquid wax and paraffin.
Bottle C. Hermetically sealed by pouring a mixture of liquid beeswax and paraffin on top of the honey inside the bottle, the screw cap then being applied.
Bottle D. About 5 per cent of finely granulated honey added, without stirring.
Bottle E. About 5 per cent of coarsely crystallized honey added, without stirring.
Bottle F. Contents stirred with a small wooden paddle for one minute, with about 125 complete circular strokes. No granulated honey added.
Bottle G. Contents stirred with a small wooden paddle for three minutes, with about 375 complete circular strokes. No granulated honey added.
Bottle H. Contents stirred with a wooden paddle for five minutes, with about 625 circular strokes. No granulated honey added.

Discussion

The samples were observed over a period of six months, the bottles not being opened during that time. The addition of granulated honey without stirring caused most of the samples to crystallize more rapidly than did the check, with the formation of smaller crystals. The addition of honey hastened crystallization, roughly in proportion to the amount of coarsely granulated honey, but caused more rapid granulation in a few cases.

Stirring the natural unheated honeys without the addition of granulated honey hastened crystallization, roughly in proportion to the amount of agitation. In other words, the samples that were stirred for five minutes crystallized more quickly, with the formation of smaller crystals, than did the samples that were stirred for only one minute. Where the natural honeys showed slight indications of granulation before agitation, the effect of agitation was increased and the samples became lighter in color as crystallization proceeded, with the formation of smaller crystals.

No influence could be detected on crystallization by the two methods of hermetically sealing the honey.

Fermentation, when present, was found to be equally advanced in the eight bottles of each sample.

Experiment 11

Sixty-eight samples of honey were obtained from various beekeepers in different sections of Ontario. To assist in evaluating certain conditions that might arise in the honeys, each beekeeper was asked to fill out the following questionnaire:

Date of extraction.....
Producer's name.....
P. O. address.....
Township .....
County .....

1. Number of colonies in the apiary.
2. Estimated pounds of honey per colony.
3. Have you experienced trouble with fermentation of honey? Give particulars.
4. From what part of the storage tank is the sample taken: top, bottom, or center?
5. How many and what sized storage cans have you?
6. Is your extracting room heated?
7. Do you use a honey pump?
8. Do you strain your honey?
9. Are your combs put away for winter dry or wet?
10. If combs are stored dry, how are they cleaned out?

Each sample of honey received was graded as to color, floral source, and specific gravity. A portion of the unheated honey of each sample was poured into a tin and sealed under vacuum, as in the preceding experiments. On November 28, 1929, each sample was examined as to percentage and type of crystallization. On February 9, 1931, the honeys were again examined for the presence of fermentation, and at this time all the samples closed under vacuum were opened. From the data on the sixty-eight samples, the following information was obtained.

Coarse crystals were found in all but twenty of the samples. Of the twenty samples that formed fine crystals, nine were extracted from combs stored over winter wet, six were pumped, and three were from combs stored wet and also were pumped. Of twelve samples that were extracted from combs stored wet, nine formed fine crystals. Of seven samples that were pumped, six formed fine crystals. Of four samples that were extracted from combs stored wet and also were pumped, three formed fine crystals. Two samples which were neither from combs stored wet, nor pumped, formed fine crystals. These data indicate that honeys which have been extracted from combs stored wet and honeys which have been pumped will more probably form small crystals. In each case of the formation of fine crystals, the honeys were solid shortly after extraction. The rapidity at which crystals form may therefore be directly correlated with the size of crystals. In other words, honeys that form fine crystals solidify with great rapidity.

Fourteen samples out of the sixty-eight showed advanced fermentation. The average specific gravity of all the samples was 1.433. Of the honeys that fermented, the average specific gravity was 1.428, while the average of the unfermented honeys was 1.435. These data confirm Pugh's work (1927) showing that little or no correlation is apparent

between fermentation and specific gravity. It is true that the samples which fermented had a slightly lower average specific gravity, but fermentation was encountered over a range of specific gravities from 1.414 to 1.441. When fermentation was present in the glass jars, it was present also, and apparently as far advanced, in the vacuum tins. Since this experiment confirms the results of the preceding experiment, it may safely be concluded that vacuum sealing is of no value in controlling fermentation. No correlation can be detected between fermentation and the color or the floral source of the honeys or the type of crystallization.

EXPERIMENTS CONDUCTED AT CHICAGO

Experiments were conducted at Chicago, Illinois, by members of the Research Division of the American Can Company, beginning in September, 1929, to ascertain the value of carbon dioxide and nitrogen sealed hermetically above honey in containers. The writer took no part in these experiments except to supply 120 pounds of White-Dutch-and-alsike-clover honey, sp. gr. 1.428. Since this work was part of the original plan of investigation, the author refers here to the results. The last examination was made in February, 1931.

Unfortunately, none of the honey, including the control samples, developed fermentation, so that no data are available on the effect of carbon dioxide or nitrogen on this phenomenon. Since the sugar-tolerant yeasts which cause fermentation in honey are anaerobic and may grow at any depth in the honey, it may be assumed that carbon dioxide or nitrogen placed on the surface of the honey would not be an effective measure in controlling the growth of these yeasts.

The men of the Research Division of the American Can Company also incorporated varying amounts of gelatin, from 0.25 to 2 per cent, into both cold and heated honey. The results in both cases were unsatisfactory. With the cold honey the gelatin failed to mix with the honey, and small globules of gelatin were prominent among the crystals. With the heated honey the gelatin mixed much better, but, since the honey was heated, crystallization was retarded and large objectionable crystals were formed.

FACTORS CONTROLLING CRYSTAL FORMATION IN HONEY

In the experiments described in the preceding pages, certain evidences were found of the effect of heating on fermentation and granulation of honey. At this stage of the investigation it became clear that the heating of honey is perhaps the most feasible means of preventing fermentation, but the objectionable large size of crystals formed after heating is a serious handicap to the use of this method. A series of experiments was therefore planned with a view to determining those conditions which will facilitate the formation of minute crystals in honey after heating, and the results of this study are presented in the following pages.

It was evident from the foregoing experiments, as well as from a wide experience of beekeepers, that fermentation is vastly increased through the granulation of honey. As the later work progressed, and means were found for causing speedy crystallization, it was found that the

tendency toward fermentation was even greater in the honeys treated by the processes hereinafter discussed, than in honeys normally granulated. It therefore appears that the feasible method for controlling fermentation is first to heat the honey adequately, so as to destroy all sugar-tolerant yeasts present, and then to put it through such a process as to insure a superior type of granulation.

EXPERIMENTS IN THE CONTROL OF CRYSTALLIZATION IN HONEY

Numerous experiments were conducted before the various factors that control crystallization in honey were ascertained. There is no advantage in presenting here all of the experiments that were carried out, and therefore only those experiments which resulted in actual progress toward the control of crystallization are included in this paper.

Experiment 12

The first experiment in this series, experiment 12, was conducted with the object of ascertaining the size of the crystals formed when a small amount of crystallized honey is thoroughly stirred into liquid honey and later reagitated at intervals of twenty-four hours.

White-Dutch-and-alsike-clover honey, the same as was used in series E–H of experiment 1, was liquefied and cooled to room temperature. Twelve small glass jars, such as were used in experiment 10, were filled with this honey, and about 5 per cent of finely crystallized honey, obtained from series A–D of experiment 1, was added. The samples were stirred and restirred as shown in table 10. The honey was left at room temperature (about 75° F.) to crystallize.

TABLE 10. TREATMENT OF HONEYS IN EXPERIMENT 12, AND TYPES OF CRYSTALS FORMED

Sample no.	Minutes stirred for the first time, January 16	Minutes stirred on January 17	Minutes stirred on January 18	Minutes stirred on January 19	Approximate type of crystallization on February 20
1	5	.....	.....	.....	Coarse
2	10	.....	.....	.....	Coarse
3	15	.....	.....	.....	Coarse
4	20	.....	.....	.....	Coarse
5	5	5	.....	.....	Coarse
6	10	5	5	.....	Coarse
7	15	5	5	5	Medium coarse
8	20	5	5	5	Medium coarse
9	20	10	10	10	Medium coarse
10	20	15	15	15	Medium coarse
11	20	20	20	20	Medium coarse
12		Control.	Not stirred		Very coarse

As shown in table 10, stirring apparently stimulates reduction in size of crystals. This was most evident when the samples were agitated on the third and the fourth day following the introduction of crystals and the first agitation of the honey. The length of time that agitation was continued beyond a certain minimum apparently does not induce the forming of smaller crystals.

Further experiments with regard to agitation, not recorded here, indicate that honeys when restirred over a period of ten to twenty days formed small crystals. It may therefore be concluded that reagitating honey to which crystals have been added, over a period of two weeks or more, will usually cause small crystals to be formed if the honey is stirred at room temperature. In commercial practice such a method of producing finely crystallized honey would be of doubtful value, as the time and labor required would be too costly. The author has heard that some such procedure as this is in use in certain European countries.

Experiment 13

Experiment 13 was conducted in order to ascertain the relative importance of the temperature of the honey at the time of introducing the crystals, in causing rapid crystallization.

Light amber honey, sp. gr. 1.414, produced in the apiary of the New York State College of Agriculture, was used in this experiment. The honey was totally crystallized, and was liquefied by heating to 140° F. and holding at this temperature until it was liquid. Fourteen glass jars were filled with this honey and were heated to various temperatures as indicated in table 11. When the desired temperature was reached for each jar, about 5 per cent of crystallized honey was added and was stirred into the honey for about ten minutes. The samples of honey were then left at room temperature to crystallize.

TABLE 11. RESULTS OF ADDING CRYSTALLIZED HONEY AT VARIOUS TEMPERATURES, AS DETERMINED BY SIZE OF CRYSTALS FORMED LATER

Sample no.	Temperature of honey when crystals were added and stirred	Approximate type of crystallization 35 days later
1	35° F.	Fine
2	40° F.	Fine
3	45° F.	Medium coarse
4	50° F.	Medium coarse
5	55° F.	Medium coarse
6	60° F.	Medium coarse
7	65° F.	Coarse
8	70° F.	Coarse
9	75° F.	Very coarse
10	80° F.	Very coarse
11	85° F.	Very coarse
12	90° F.	Very coarse
13	95° F.	Very coarse
14	100° F.	Very coarse

As shown in table 11, there appears to be a correlation between the temperature at which crystallized honey is added and the formation of small crystals. Since the honey at low temperatures was extremely viscous, considerable air was incorporated on stirring and it was difficult to determine whether it was the lowering of the temperature before seeding or the incorporation of air which stimulated the formation of small crystals.

The results of further experiments not here recorded, in which the incorporation of air was reduced to a minimum, indicate that temperature

at the time of stirring is a greater factor than incorporation of air, but temperature is not regular in its effect as some of the treated honeys stirred at low temperatures failed to form fine crystals. It is shown later in the bulletin that the results of these experiments are somewhat misleading because they failed to include certain other factors; but they are of importance in that they illustrate the fact that temperature at the time of seeding is an important factor to be considered in the control of crystallization of honey.

Experiment 14

Since temperature appears to be a factor in rapid crystallization of honey, experiment 14 was conducted to determine the most favorable temperature at which to store honey for the rapid formation of small crystals.

Sixty pounds of liquid honey, such as was used in experiment 13, was cooled to 40° F., and about 8 per cent of medium coarse crystallized honey was thoroughly stirred into it. The seeded honey was then poured into twelve 5-pound pails and these were placed at different temperatures as shown in table 12. The constant-temperature rooms used did not maintain an entirely satisfactory constant temperature, but the variations were never more than 5° F.

TABLE 12. EFFECT OF STORAGE TEMPERATURE ON TYPE AND AMOUNT OF CRYSTAL FORMATION, EXPERIMENT 14

Sample no.	Temperature at which honey was stored	Approximate per cent of crystallization 10 days later	Approximate type of crystallization 30 days later
1	100° F.	20	Very coarse
2	95° F.	40	Very coarse
3	80° F.	60	Coarse
4	75° F.	85	Coarse
5	70° F.	95	Medium coarse
6	65° F.	100	Medium coarse
7	60° F.	100	Fine
8	55° F.	100	Very fine
9	50° F.	100	Fine
10	45° F.	50	.....*
11	35° F.	5	.....*
12	30° F.	0	.....*

*Owing to the high viscosity of the samples of honey held at 45° F. and below, there appeared to be only slight progress in crystallization, which made it impossible to judge accurately the resulting type of crystallization.

As indicated in table 12, there is a definite correlation between storage temperature and the type of crystallization. Sample 8, which was kept at about 55° F., appeared to crystallize with greatest rapidity, but there was only a slight difference in the size of the crystals formed in the samples stored at temperatures between 50° and 60° F. As the temperature was increased to and above 75° F., larger crystals were formed. Below 50° F. crystallization was greatly retarded, owing apparently to the increased viscosity of the honey. Sample 12 was left at 30° F. for a period of several months, and no progress in crystallization could be detected, as the honey when warmed to room temperature assumed its original liquid condition except for the added starter.

This experiment was duplicated with buckwheat honey, sp. gr. 1.428, and it was found that the sample stored at 60° F. crystallized the most rapidly, but only a slight difference was noted in the size of crystals formed in the samples kept between 55° and 65° F. The results of these two experiments indicate that honeys crystallize more rapidly, and form smaller crystals, when kept at temperatures between 50° and 65° F.

Experiment 15

Since comparatively small amounts of honey under physical control formed fine crystals, it was desirable to determine whether a larger quantity would also respond to the treatment and form small crystals.

In order to ascertain this, a glass-lined tank with a capacity of about 50 gallons was used. This tank is surrounded by a metal jacket and has a three-way pipe-connection for the admission of steam, hot water, or cold water, as desired. The bowl of the tank is about 24 inches in diameter, with a depth of about 28 inches. The propeller, or agitator, which has four 4-inch blades, enters the side of the tank about 8 inches above the bottom. It is driven by an electric motor and is so geared as to give a high and a low speed. The low gear has a speed of 54 r.p.m., while the high gear has a speed of 108 r.p.m.

Four hundred and twenty pounds of light amber honey, sp. gr. 1.414, the same as was used in experiment 13, was heated to 140° F. in the pasteurizer by permitting steam to pass slowly through the jacket. The honey was then cooled as quickly as possible to 60° F. by allowing cold water at a temperature of 48° F. to fill the outer jacket of the tank and then run slowly through it. It required a little more than half an hour to raise the temperature of the honey to 140° F., but cooling it to 60° F. required more than two and one-half hours. It was found that honey on being rapidly reduced in temperature forms a thick insulating layer on the cold sides of the tank. This makes it difficult to reduce the temperature of honey with the heating and cooling devices commonly used in the dairy industry. The crystallized honey which was used as a starter, or seed, was very coarse. An effort was made to reduce the size of the crystals by stirring the starter vigorously with a wooden paddle, but the resulting crystals differed but slightly from their original size. As shown in table 13, 1 per cent of this coarse-crystallized honey was added and a sample was taken after each ten minutes of agitation until the honey contained a total of 5 per cent of starter.

After 5 per cent of crystallized honey was added, the agitation completed, and the samples taken, sixty pounds of the honey was removed from the pasteurizer and placed in a small tank which was connected by means of sanitary pipe to a centrifugal honey pump. From the pump the honey passed through a sanitary pipe and hose to the receiving containers. As shown in table 13, the honey was run through the pump six times, a sample being taken each time it passed through.

Sixteen hours later, the honey that remained in the tank was again stirred for three ten-minute periods, a sample being taken at the end of each period. The temperature of the honey was two Fahrenheit degrees lower than it was on the preceding day, when the honey was agitated for the first time, but this light reduction in temperature should not materially affect the results.

All the samples, as well as the remaining honey in the pasteurizer, were stored in a constant-temperature room in which a temperature of about 60° F. was maintained.

TABLE 13. EFFECT OF ADDING CRYSTALLIZED HONEY, AND AGITATION, ON CRYSTALLIZATION OF HONEY

Sample no.	Per cent of starter added	Minutes agitated in pasteurizer	Minutes reagitated in pasteurizer 16 hours later	Number of times pumped	Approximate per cent of crystallization 3 days later	Approximate type of crystallization 20 days later
1	1	10	.....	0	10	Coarse
2	2	20	.....	0	20	Coarse
3	3	30	.....	0	30	Medium coarse
4	4	40	.....	0	40	Medium coarse
5	5	50	.....	0	50	Fine
6	5	50	.....	1	90	Fine
7	5	50	.....	2	100	Very fine
8	5	50	.....	3	100	Very fine
9	5	50	.....	4	100	Very fine
10	5	50	.....	5	100	Very fine
11	5	50	.....	6	100	Very fine
12	5	50	10	0	60	Fine
13	5	50	20	0	70	Fine
14	5	50	30	0	80	Fine
15	(Control)*				0	(Liquid)

* Original heated honey, taken before starter was added.

As shown in table 13, samples 7 to 11, which were pumped from two to six times, became totally crystallized in about three days. Heretofore such early crystallization has not been observed and the speed of granulation was a matter of some surprise. The honey that was run through the pump had considerable air incorporated into it. The question again arose as to whether it was the incorporation of air or the increased agitation of the honey pump which caused such rapid crystallization. The results with samples 12 to 14 indicate that increased agitation hastens the rapidity of crystallization. It would therefore appear that agitation is a greater factor than the incorporation of minute air bubbles, in causing fine crystals to be formed. As shown by samples 1 to 5, there appears to be a direct correlation between the amount of starter added and the rapidity and size of the crystals formed. Since all of the samples to which 5 per cent of crystallized honey was introduced formed fine or very fine crystals, it would appear that 5 per cent of starter is sufficient for all practical purposes.

The honey when removed from the pasteurizer was placed in 60-, 5-, and 1-pound containers, and some of it in small glass vials. All the honey was placed in a room in which a temperature of about 60° F. was maintained. The honey in all the containers crystallized at about the same speed and formed small crystals of approximately the same size.

Experiment 16

Experiment 16 was conducted with the object of ascertaining the importance of minute air bubbles incorporated into the honey, as a factor in stimulating crystal formation.

Sixty pounds of light amber honey, sp. gr. 1.414, the same as was used in experiment 13, was divided into two lots of thirty pounds each. The honey in the two containers was then placed in a constant-temperature room, and when cooled to 60° F. it was removed for treatment. As shown in table 14, sample 1 was run through a honey pump five times and a large number of small air bubbles were incorporated into it. Five per cent of fine-crystallized honey was then added to both the pumped and the unpumped honey. The crystallized honey added was thoroughly incorporated into both honeys by stirring with a wooden paddle for a period of ten minutes. It was found in previous tests, as well as in this experiment, that little or no air is incorporated when the honey is carefully stirred with a paddle. The honeys in the two containers were therefore alike, except that one had a large number of minute air bubbles, owing to the pumping. The honey was then placed in a constant-temperature room at 60° F., to crystallize.

TABLE 14. EFFECT OF MINUTE AIR BUBBLES ON RATE OF CRYSTALLIZATION

Sample no.	Run through honey pump five times	5 per cent of starter stirred into honey for ten minutes	Amount of air present in honey	Approximate per cent of crystallization 3 days later	Approximate type of crystallization 20 days later
1	Yes	Yes	Great	100	Very fine
2	No	Yes	Small	90	Very fine

The honey which was pumped and which contained a large number of small air bubbles crystallized with a little more rapidity than did the honey which was not pumped and which contained few air bubbles. It would therefore appear that the presence of air bubbles in honey is not an essential factor in causing fine crystals to be formed, but that crystallization may be hastened to a small extent by their presence.

Preliminary experiments not reported in detail in this paper indicate that honeys which have become partly crystallized on being stirred will usually form fine crystals if placed at a temperature of about 55° F., but that if the same honey is totally liquefied, stirred for the same length of time, and placed at the same temperature, fine crystals will seldom be formed. This indicates that before rapid crystallization can proceed, dextrose hydrate crystals must be present, and agitation, which may accidentally introduce air bubbles, is of importance primarily in breaking crystals into smaller fragments and in bringing about their uniform distribution throughout the honey to act as nuclei of future crystal growth.

Different methods of agitation commonly in use usually incorporate air in varying amounts into honey. Since the presence of air bubbles is of only slight value in hastening crystallization, and since it usually happens that a large number of these bubbles later rise to the surface of the honey, giving it an objectionable foamy appearance, it appears desirable that methods of agitation be used which will not incorporate air.

Experiment 17

Most of the experiments thus far reported indicate that fine-crystallized honey used as a starter is to be preferred. However, in order to ascer-

tain definitely the relative merit of fine, medium, and coarse crystals in hastening crystallization, experiment 17 was conducted.

Thirty pounds of liquefied honey, light amber in color, sp. gr. 1.414, the same as was used in experiment 13, was carefully poured into six 5-pound pails, and 5 per cent of fine-, medium-, and coarse-crystallized honey was introduced in each of the pails. The crystals were incorporated by stirring the honey of each pail in identically the same manner. The treated honey was then placed in a constant-temperature room at about 60° F.

As shown in table 15, there is a correlation between the type of crystallized honey added to the liquid honey, and the resulting type of granulation. It is therefore desirable that fine-crystallized honey be used as a

TABLE 15. RELATION OF SIZE OF CRYSTALS ADDED TO HONEY, TO TYPE OF CRYSTALLIZATION PRODUCED

Sample no.	Type of crystallized honey added	Approximate per cent of crystallization 5 days later	Approximate type of crystallization 10 days later
1	Fine	100	Very fine
2	Fine	100	Very fine
3	Medium	90	Fine
4	Medium	90	Fine
5	Coarse	75	Medium coarse
6	Coarse	75	Medium coarse

starter if fine granulation is desired. Unless a type of agitation is used which actually grinds originally coarse crystals into fine fragments, not only will the coarse crystals added retain their original size but they will actually become larger in the honey. The presence of coarse crystals gives an objectionable gritty texture to the honey.

It may be well at this point to discuss briefly the growth of dextrose hydrate crystals in honey. If a slide prepared with a drop of honey containing a few small crystals is observed under the microscope from time to time, the increase in crystals may readily be seen. At first the small crystal fragments form fine needles. These gradually change to flat plates with an area at the blunt end from which other crystals grow or to which they become attached. From this place more crystals are formed in all directions. The final crystal masses are star-shaped and are of considerable size, with numerous layers of plates radiating from the central crystallization focus. When rapid crystallization occurs, the crystals seldom attain a size beyond the stage of flat plates. Such plates are characteristic of fine granulation. The crystals become objectionably large only when the plates are in tiers or when they have commenced to form stars.

Experiment 18

It was indicated in experiment 17 that the addition of 5 per cent of starter to liquid honey hastens crystallization sufficiently to permit only fine crystals to be formed. However, in order to determine the exact quantity of crystallized honey that should be used to give the best results, experiment 18 was conducted.

Twenty-five pounds of liquefied honey such as was used in experiment 13 was cooled to 60° F. and poured into ten 2½-pound pails. As shown in table 16, varying amounts of fine-crystallized honey were added to each of the containers. Each sample of honey was then stirred for ten minutes in exactly the same manner, and then all were placed in a constant-temperature room at 60° F.

TABLE 16. EFFECT OF THE AMOUNT OF FINE CRYSTALS ADDED TO HONEY, ON THE RESULTING TYPE OF GRANULATION

Sample no.	Per cent of crystallized honey added	Approximate per cent of crystallization 2 days later	Approximate type of crystallization 10 days later
1	2	15	Coarse
2	5	70	Fine
3	8	85	Very fine
4	10	90	Very fine
5	12	95	Very fine
6	15	100	Very fine
7	18	100	Very fine
8	20	100	Very fine
9	25	100	Very fine
10	30	100	Very fine

The results of this experiment indicate that crystallization is hastened approximately in proportion to the amount of starter added, but that there is little or no advantage from adding more than 10 per cent of crystallized honey and for all practical purposes 5 per cent is sufficient.

Experiment 19

Experiment 19 was conducted to ascertain the length of time that seeded honey should be agitated to give the most rapid crystallization.

Ten pounds of liquefied light amber honey, the same as was used in experiment 13, was placed in a small 1-gallon glass churn fitted with an agitator about 4 inches square which was turned by a geared crank fixed to the lid. After the honey was cooled to 60° F., 5 per cent of fine-crystallized starter was added and samples were taken at the end of each five-minute period of agitation. During the agitation the churn containing the honey was kept in a water bath at 60° F. so as to keep the temperature of the honey constant. After agitation the samples were kept at 60° F.

The results of this test indicate that a correlation exists between the rapidity of crystallization and the amount of agitation, but, as shown in table 17, there is no advantage in stirring the honey for more than fifteen minutes.

Several devices have been used to agitate seeded honey, and, as would be expected, they vary considerably in efficiency. With the pasteurizer described on page 55, it was found that twenty minutes of agitation is usually sufficient. The necessary time during which agitation should be continued must therefore be determined for the equipment used. It has been found that after the starter has become thoroughly incorporated into

TABLE 17. EFFECT OF TIME OF AGITATION ON THE RESULTING GRANULATION

Sample no.	Number of minutes agitated	Approximate per cent of crystallization 3 days later	Approximate type of crystallization 10 days later
1	5	60	Medium coarse
2	10	85	Fine
3	15	90	Very fine
4	20	95	Very fine
5	25	95	Very fine
6	30	95	Very fine
7	35	95	Very fine
8	40	95	Very fine
9	45	95	Very fine
10	50	95	Very fine

the honey, there is no need of further agitation. In fact, prolonged agitation may cause the honey to increase sufficiently in temperature to dissolve the crystals present, because of the friction. Naturally, if this happens, the rate of crystallization may be reduced and coarse crystals may be formed.

Experiment 20

Experiment 20 was conducted for the purpose of learning whether honey that had been heated to excess would also respond to the crystallization process. One pound of light amber honey such as was used in experiment 13 was heated to 200° F. and held at this temperature for a period of twenty-four hours. The honey was then cooled to 60° F., and 5 per cent of crystallized honey was thoroughly incorporated in it. It was then placed in a constant-temperature room at 60° F.

It was found that crystallization was slightly retarded in the overheated honey, but the crystals formed were as fine as the crystals of the same honey used in the preceding experiments. It therefore appears that heating honey to destroy yeast in no way retards crystallization in processed honeys.

Experiment 21

Experiment 21 was conducted to ascertain the relation of specific gravity of honey to the rate and the type of crystallization. Three pounds of light White-Dutch-and-alsike-clover honey, sp. gr. 1.434, the same as was used in series E–H of experiment 1, was heated to 180° F. and then diluted gradually by stirring hot water into it. Samples were taken from time to time so that a range of specific gravities from 1.434 to 1.390 was obtained. After all the samples were cooled to 60° F., 5 per cent of crystallized honey was thoroughly incorporated into each sample. The samples were then kept at 60° F.

The results of this experiment, given in table 18, indicate that honeys having unusually high water content may fail to crystallize solidly and may show a separated layer at the top. This liquid layer occurred in the samples that had a specific gravity of 1.413 and lower, and showed a steady increase of separation with the lowering of the specific gravity. The results show also a definite correlation between specific gravity and fermentation. After a period of ten months all the samples that had a

specific gravity of 1.413 and lower not only were separated but also had fermented, while the samples that had a specific gravity of 1.417 and above had not fermented. Although this honey had been heated to 180° F. before dilution with hot water, no precautions were taken to prevent the entrance of yeasts.

TABLE 18. RELATION OF SPECIFIC GRAVITY OF HONEY TO NATURE OF GRANULATION

Sample no.	Specific gravity of honey	Approximate per cent of crystallization 4 days later	Approximate type of crystallization 30 days later	Fermented or not 10 months later	Approximate per cent of separation 10 months later
1	1.434	95	Very fine...	No.....	0
2	1.430	100	Very fine...	No.....	0
3	1.427	100	Very fine...	No.....	0
4	1.422	100	Very fine...	No.....	0
5	1.419	100	Very fine...	No.....	0
6	1.417	100	Very fine	No.....	0
7	1.413	95	Very fine...	Yes.....	5
8	1.409	90	Very fine...	Yes.....	15
9	1.406	75	Fine.....	Yes.....	30
10	1.402	60	Fine.....	Yes.....	45
11	1.396	55	Fine.....	Yes.....	55
12	1.390	40	Fine.....	Yes.....	60

DEVELOPMENT OF A PRACTICAL METHOD OF CONTROLLING CRYSTALLIZATION

The results of the tests thus far reported indicate enough similarity in the physical and chemical characteristics of different honeys to suggest that practically all honeys might respond to attempts to cause fine granulation. Some honeys high in levulose, however, might be supposed to be exceptions. More than 100 samples of honey obtained from different parts of the United States and Canada, and from different floral sources, have been put through the process described later, and, without a single exception, fine crystallization has been produced. It is unnecessary to report these tests in detail, since the variations in results are insignificant.

In most cases these honeys were thoroughly liquefied and then cooled to 50° F., but, as is shown later, lowering the temperature to 50° F. is not essential to the process. About 5 per cent of fine-crystallized honey was then thoroughly incorporated into the liquid honey. The samples were then placed in a constant-temperature room at about 55° F.

Experiment 22

In order to gain more detailed and specific data concerning the effects of various factors on the process of causing rapid crystallization to occur, with resulting minute dextrose hydrate crystals, a series of additional experiments was run. The constant-temperature rooms used in the experiments thus far reported were not adequately constant, and more detailed data concerning the effect of temperature on crystal formation were desired.

Twelve pounds of light clover-and-basswood honey, sp. gr. 1.425, was liquefied by heating to 140° F. for thirty minutes. The honey was then cooled to 75° F. and 5 per cent of fine-crystallized honey was thoroughly incorporated in it. The processed honey was then placed in ten 1-pint

milk bottles which were sealed by pouring a mixture of liquid paraffin and beeswax over the cardboard stopper. Twelve pounds of light amber honey, sp. gr. 1.414, the same as was used in experiment 13, were similarly processed and were sealed in ten 1-pint bottles in identically the same manner.

The samples of both honeys were then suspended in a series of constant-temperature water baths having a range of temperatures above and below 60° F. in short steps. The temperatures remained fairly constant and did not vary more than one degree during the experiment.

After the middle of the second day, thirty-four hours from the beginning of the experiment, the clover-and-basswood samples which were held at 56° and 58° F. were totally crystallized. The remaining samples of clover-and-basswood honey were still liquid, but those at temperatures slightly below 56° appeared to be crystallizing more rapidly than those above 58°. All the samples of light amber honey were still liquid, but those between 50° and 60° appeared to be granulating more quickly than the others.

On the third day, about fifty-eight hours from the beginning of the experiment, it was found that the temperature in most of the compartments had risen about one degree. The samples of clover-and-basswood honey at temperatures between 50° and 58° F. were all solid, but the samples above 60° were still liquid.

In the light amber honeys, only one was found to be crystallized solid after fifty-eight hours, and this was in the water bath which had formerly been at 56° F. but which, owing to the slight rise in temperature, was now at 57°. Since both the honeys under experiment crystallized most rapidly at approximately 57°, it would appear that this temperature is the most desirable for rapid crystal formation.

Daily examinations were made on both series of honeys for fifteen days. As indicated, the most rapid crystallization occurred between 56° and 58° F. The honey at 60° granulated only a little less rapidly. The honeys below 56° granulated progressively down to 40°, while those above 60° did not become solidly granulated in fifteen days.

These results should not be taken as final for all honeys, as further experiments have shown that honeys with an abnormally high specific gravity crystallized more rapidly at a temperature of 60° F. and above. For all usual honeys it has been found that a constant-temperature room maintaining a temperature of about 55° F. has given excellent results, so that it appears unnecessary to insist upon too exact a temperature for this work.

Experiment 23

Since low temperature increases the viscosity of honey, it seems reasonable to suppose that the crystals can be more uniformly distributed with ease if the honey has a slightly higher temperature than 60° F. at the time of the introduction of the starter. Too high a temperature might, however, cause some of the dextrose hydrate crystals to dissolve. It therefore seems important to determine a temperature which will not seriously dissolve the crystals and which will still permit maximum dispersion of crystals throughout the honey with the least effort and with maximum certainty.

A light clover-and-basswood honey, sp. gr. 1.425, such as was used in experiment 22, was placed in 2½-pound pails. As shown in table 19, each sample was brought to a definite temperature at which 5 per cent of fine-crystallized honey was stirred into each one in identically the same manner. All the samples were then placed at a temperature of about 55° F.

TABLE 19. EFFECT OF THE TEMPERATURE OF HONEY AT THE TIME WHEN A STARTER IS ADDED, ON SUBSEQUENT GRANULATION

Sample no.	Temperature of honey when starter was introduced	Approximate per cent of crystallization 3 days later	Approximate type of crystallization 20 days later
1	100° F.	0	Very coarse
2	95° F.	10	Very coarse
3	90° F.	50	Coarse
4	85° F.	75	Medium coarse
5	80° F.	95	Fine
6	75° F.	100	Very fine
7	70° F.	100	Very fine
8	65° F.	100	Very fine
9	60° F.	95	Very fine
10	55° F.	90	Fine
11	50° F.	80	Fine

The results of this experiment indicate that the best temperature at which to introduce the starter is about 70° F. It will be noticed that crystallization was almost as rapid when crystals were introduced at temperatures as low as 60° F. or as high as 80° F. The fact that crystals may safely be introduced at temperatures considerably higher than for later storage is important, since it is difficult to rapidly cool large quantities of honey down to 60° F. Even at ordinary room temperature, the viscosity is greatly increased.

Experiment 24

After processing a large number of samples in the same manner, considerable variation was noticed in the "body" of the crystallized honeys when they were later stored at room temperature. Some remained soft while others remained decidedly hard. Since crystallized honey is suitable for use as a spread, it is important that the honeys should be sufficiently plastic at ordinary temperatures for this purpose. A rough survey of the processed honeys when stored at room temperatures suggested a correlation between specific gravity and later consistency of the honeys, since those having a high specific gravity were considerably harder. Experiment 24 was conducted to obtain more specific information on this phase of the problem.

Fourteen samples of light white honey from different floral sources ranging in specific gravity from 1.414 to 1.463, were all processed in the same manner. Five per cent of starter was added to each sample, and care was taken to incorporate the crystallized honey uniformly. The samples were then placed in a constant-temperature room at 55° F.

At the end of two weeks the samples were placed at a constant temperature of 65° F. After being at this temperature for twenty-four hours,

the honeys were carefully observed and the following terms were used to estimate the consistency of the crystallized samples:

1. Very hard
2. Hard
3. Medium hard*
4. Medium soft*
5. Soft*
6. Very soft
7. Almost liquid
8. Liquid

(*Honeys which are sufficiently plastic to make a satisfactory spread are designated by the terms *medium hard, medium soft,* and *soft.*)

The samples were then placed, as shown in table 20, at successive constant temperatures from 70° to 100° F. At the end of each twenty-four-hour period, the samples were observed and were then placed at a temperature five degrees higher.

It was noticed that the honeys having a high specific gravity crystallized more slowly than did those with a low specific gravity. All honeys were left in the constant-temperature room at 55° F. for two weeks, in order to make sure that all samples had become thoroughly crystallized.

The results as given in table 20 show a correlation between storage temperature and specific gravity. It will be seen that honeys with a low specific gravity are sufficiently plastic to make an ideal spread at 65° F., but those of higher specific gravity may not be entirely satisfactory until a temperature of about 80° to 90° F. is reached. Apparently, honeys either abnormally low or abnormally high in specific gravity have a narrow range of temperatures for satisfactory table use. Sample 1, with a specific gravity of 1.414, became unsuitable at a temperature above 70° F., while sample 14, with a specific gravity of 1.463, did not make an ideal spread until a temperature of 90° F. was reached, but when the temperature was raised to 95° F. the honey liquefied. Fortunately, the average specific gravity for honeys usually lies between 1.419 and 1.435, and, as shown in table 20, the honeys within this range are sufficiently plastic for table use over a fairly wide range of temperatures.

The variations observed at the highest temperatures are not fully explained on the basis of specific gravity alone. Possibly the relative proportion of dextrose to the other sugars present in the honeys is a factor at these temperatures, but no data are available on this subject as chemical analyses were not made. It may be anticipated that honeys relatively low in dextrose will liquefy the most quickly at higher temperatures.

Experiment 25

It is not within the scope of this bulletin to discuss machinery applicable to processing honey. However, honey has certain physical characteristics which must be considered before a satisfactory machine for the purpose can be found.

It is well known that the viscosity of honey increases as the temperature is lowered. When honey is cooled in a large tank, such as was

TABLE 20. EFFECT OF SPECIFIC GRAVITY ON THE CONSISTENCY OF GRANULATED HONEY IN STORAGE

Sample no.	Specific gravity	Storage temperature							
		65° F.	70° F.	75° F.	80° F.	85° F.	90° F.	95° F.	100° F.
1	1.414	Soft*	Soft*	Very soft	Very soft	Almost liquid	Liquid	Liquid	Liquid
2	1.419	Medium hard*	Medium hard*	Medium soft*	Soft*	Soft*	Very soft	Almost liquid	Liquid
3	1.424	Medium hard*	Medium soft*	Soft*	Very soft	Very soft	Almost liquid	Liquid	Liquid
4	1.428	Medium hard*	Medium soft*	Soft*	Soft*	Very soft	Almost liquid	Liquid	Liquid
5	1.430	Medium hard*	Medium soft*	Soft*	Soft*	Very soft	Almost liquid	Liquid	Liquid
6	1.430	Medium hard*	Medium hard*	Medium soft*	Soft*	Soft*	Very soft	Liquid	Liquid
7	1.432	Hard	Medium hard*	Medium soft*	Soft*	Very soft	Almost liquid	Liquid	Liquid
8	1.432	Medium hard*	Medium hard*	Medium soft*	Soft*	Soft*	Very soft	Liquid	Liquid
9	1.435	Hard	Medium hard*	Medium soft*	Soft*	Very soft	Almost liquid	Liquid	Liquid
10	1.435	Hard	Medium hard*	Medium soft*	Soft*	Soft*	Almost liquid	Liquid	Liquid
11	1.437	Very hard	Very hard	Hard	Medium hard*	Soft*	Very soft	Liquid	Liquid
12	1.440	Very hard	Very hard	Hard	Hard	Medium hard*	Almost liquid	Liquid	Liquid
13	1.447	Very hard	Very hard	Hard	Hard	Medium hard*	Soft*	Liquid	Liquid
14	1.463	Very hard	Very hard	Very hard	Hard	Hard	Soft*	Liquid	Liquid

* Sufficiently plastic to make a satisfactory spread.

used in experiment 25, this property becomes most significant. When cold water is circulated through the outer jacket of the tank, the honey next to this jacket cools rapidly and forms a thick insulating layer which retards the cooling of the remainder of the honey. The cooling devices used in the dairy industry are seldom so constructed as to remove such a viscous layer, and the problem of cooling honey with sufficient rapidity becomes important.

The object in conducting experiment 25 was to obtain temperature cooling curves in the jacketed tank used in experiment 15 (described on page 55). The tank was equipped with a motor-driven propeller having a high gear of 108 r. p. m. and a low gear of 54 r. p. m.

Four hundred and twenty pounds of light amber honey, sp. gr. 1.414, was placed in the tank. On three occasions the honey was heated to 140° F. and then cooled to 68° F. It was found that by running the propeller at 54 r. p. m. the honey could be heated from room temperature to 140° F. in about half an hour. Each time the honey was cooled, a different method was used: the first time by running the agitator at 108 r. p. m., the second by running it at 54 r. p. m., and the third without agitation. Temperature readings were taken at the central part of the tank, near the surface. The resulting temperature curves are shown in figure 1. The letter A represents the honey stirred at 108 r. p. m., B

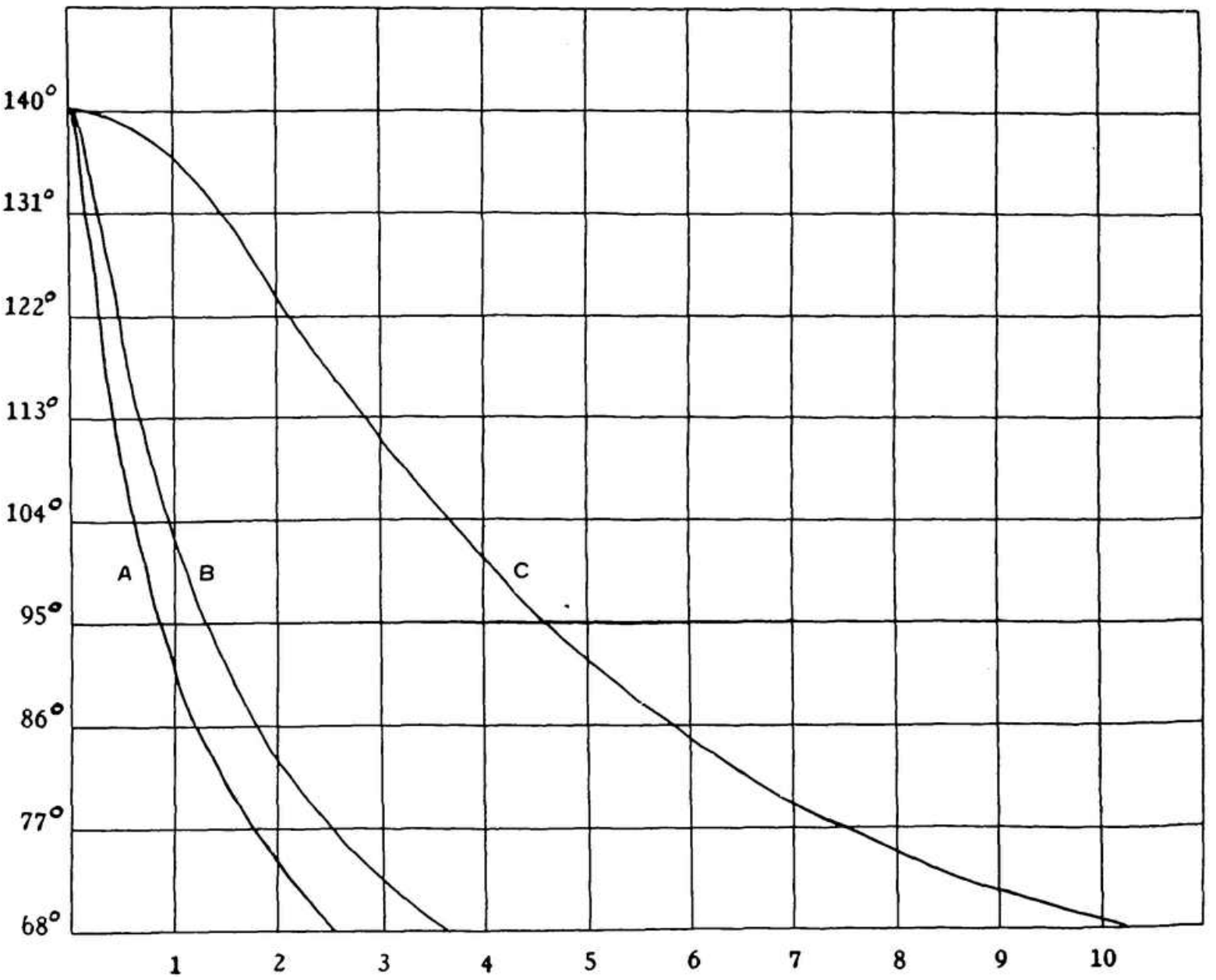

FIGURE 1. COOLING CURVES OF 420 POUNDS OF HONEY COOLED BY COLD WATER RUN THROUGH THE OUTER JACKET OF TANK, PLOTTED AS TIME IN HOURS (ABSCISSA) AGAINST TEMPERATURE IN FAHRENHEIT DEGREES (ORDINATE)

A, Honey stirred with agitator at 108 r.p.m. B, Honey stirred with agitator at 54 r.p.m. C, Honey not agitated

that stirred at 54 r. p. m., and C the honey not agitated. The curves are plotted as time in hours (horizontal) against temperature in Fahrenheit degrees (vertical).

As has already been mentioned, when cold water is run through the outer jacket of the tank the honey lying next to the jacket is rapidly cooled and forms a thick insulating layer. When agitation is applied, as represented by curves A and B, the movement of the mass of honey does not permit the layer to become thick and the rate of cooling is fairly rapid. When the honey is not agitated, as represented by curve C, a thick insulating band is formed almost immediately and this greatly retards the lowering of the temperature. Curves A and B descend rapidly, but it should be noticed that curve C does not follow the course of a normal cooling curve. There is a distinct outward turn in this curve, which represents the effect of the insulating layer of thick honey on the surface of the tank.

Experiment 26

In June, 1930, twelve hundred pounds of White-Dutch-and-alsike-clover honey was processed for the purpose of ascertaining the efficiency of another type of tank as a practicable machine for cooling and processing honey. The pasteurizer employed differed from one used in experiment 15 in that it was much larger and was equipped with a long revolving coil which acted as a heating as well as a cooling unit.

After the liquid honey was poured into the pasteurizer it was heated to 160° F. by passing steam through the revolving coil. A period of eighteen minutes was necessary to raise the honey from 75° to 160° F. This pasteurizer appears to be an efficient machine for heating honey; but, since the revolving coil cannot be entirely submerged in the honey, it incorporates considerable air into the honey as it revolves, and thus is not satisfactory.

When the temperature of the honey reached 160° F., the steam was turned off and cold water was run through the coil. A period of thirteen minutes was required to reduce the temperature from 160° to 140° F. At 140° the cold water was turned off and cold brine was passed through the coil. It took two hours and forty minutes to reduce the temperature of the honey from 140° to 82° F. when cooling with brine.

When the brine was turned on, the honey showed a considerable reduction in rate of cooling. Owing to the low temperature of the brine, the revolving coil accumulated a thick viscous layer of honey which made it difficult for the motor to turn the coil. Since the viscous layer was much thicker when brine was used than when water was run through the coil, it would appear that cold water is more efficient than cold brine for cooling honey in the types of pasteurizers commonly used in the dairy industry.

Experiment 27

It would seem that in a machine so constructed as to have paddles slowly scraping the sides of a jacket tank such as that used in experiment 15, the rate of cooling of honey would be increased. In order to test the value of this theory, twelve pounds of clover honey was placed in a 4-quart ice-cream freezer.

The honey was heated to 150° F., and when this temperature was reached the drum containing the honey was placed in the freezer and cracked ice and salt were packed around it. The freezer was turned at 35 r. p. m. for five minutes, and the temperature of the honey was then taken. It was found that the temperature had dropped from 150° to 70° F.

The honey was again heated to 150° F., and was then cooled in identically the same manner as before except that the scrapers touching the inside of the can containing the honey were removed. The stirring action of the frame and the projecting arms supporting the scrapers was roughly comparable to the ordinary type of agitation. At the end of five minutes the temperature of the honey had dropped from 150° to 100° F.

In the third test, the honey was again heated to 150° F., and was then cooled, with the scrapers still removed, by running cold water at a temperature of 52° F. into the barrel containing the freezer. It was found that after five minutes the temperature was reduced from 150° to 110° F.

In the final test, the honey was cooled with water in the same way except that the scrapers were again installed. It was found that the temperature was reduced from 150° to 72° F. in five minutes.

It is obvious from these tests that scraping the sides of the cooling chamber facilitates the cooling of honey. If a tank were constructed so as to have scrapers constantly removing the viscous layer of honey from the cooling surface of the tank, little difficulty should be experienced in cooling honey with sufficient rapidity for all practical purposes. The scrapers should move slowly, and should be of sufficient depth below the surface of the honey so as not to incorporate air.

FORMATION OF DEXTROSE HYDRATE CRYSTALS IN HONEY

The formation of dextrose hydrate crystals in honey is comparable to crystal formation in other liquids. In view of the phenomena observed in the preceding experiments, it is desirable to interpret the findings in terms of the Noyes-Nernst formula (Gortner, 1929) of crystal formation. This formula is

$$V = \frac{\triangle}{1} S(C-L)$$

in which V = velocity of growth, $\triangle$ = diffusion coefficient, 1 = length of diffusion path, S = surface area of disperse phase, C = concentration of solution, and L = solubility of disperse phase of a given size; (C–L) = absolute supersaturation.

According to this formula, crystal growth in honey is directly influenced by the surface area of the nuclei of crystal formation, by the concentration of the solution, by the solubility of dextrose in relation to the presence of levulose, and by the diffusion coefficient; and inversely by the length of the diffusion path. Diffusion is of course affected by viscosity.

When crystals form in honey, they form about nuclei. These nuclei may be dextrose hydrate crystals which are already existing or are introduced, colloidal particles normal to all honeys, solid particles (as

pollen grains), or minute air bubbles. Such nuclei serve to stimulate crystal formation roughly in proportion to their amount and number.

As indicated in the introduction to this bulletin, it has been shown by Jackson and Silsbee (1924) that practically all honeys are saturated with respect to dextrose, with the accompanying levulose, at 30° C. (86° F.), while at lower temperatures the solution becomes supersaturated as to dextrose so long as the honey remains in liquid form. Under these conditions of supersaturation, crystal formation becomes possible and will normally occur unless it is prevented by some means as by heating and sealing hermetically. It has been shown also by Jackson and Silsbee that levulose in a water solution of levulose and dextrose modifies the saturation point of dextrose at different temperatures; but, since more than one hundred different honeys, including those high in levulose, responded typically to the crystallization process herein described, the retarding action of levulose by lowering the saturation point of dextrose may apparently be ignored in all practical investigations of means of causing fine crystals to form in honey.

The degree of concentration of honey is usually measured by specific gravity, or by the Baumé hydrometer. Honeys giving a specific-gravity reading of 1.407 or lower usually crystallize slowly, and if crystals form there is a tendency toward separation, especially in partly fermented samples, leaving a liquid layer on the top. On the other hand, honeys showing a specific-gravity reading of 1.435 or above also may crystallize slowly. Since in such honeys the diffusion coefficient is low, a higher temperature is required to increase the rate of diffusion, and this facilitates crystal growth.

Temperature has a direct effect on absolute saturation, since it affects the solubility of dextrose in honey. Jackson and Silsbee give (in table 6, page 291 of reference cited) the approximate composition of invert-sugar solutions which are saturated with respect to dextrose at various temperatures. Saturation of dextrose is obtained at 0° C. (32° F.) with 50.8 per cent of invert sugar, while at 50° C. (122° F.) 81.9 per cent of invert sugar is required to obtain saturation of dextrose. The effect of temperature on viscosity also is well recognized. When honey is subjected to low temperatures it becomes highly viscous, while at room temperature its mobility is greater. The effect of temperature on the presence of dextrose crystals in honey is equally well known, and these crystals may by their presence constitute the disperse phase. Honey prepared for the bottle trade is heated so that the crystals become completely dissolved, and, when this is done, the dextrose in honey may remain in solution for a period of months, provided the honey is sealed hermetically.

Since temperature affects absolute saturation as well as the diffusion coefficient of honey, it markedly affects the rate of crystal formation. To maintain maximum supersaturation and adequate diffusion, honeys of low specific gravity should be placed at a lower temperature during the period of crystallization than is best for honeys of high specific gravity. In fact, for the most rapid crystallization of honey a different temperature is perhaps most suitable for each step in specific gravity. Since the relative proportions of dextrose to the other sugars in honey

modify the saturation point of dextrose, and since honeys show considerable variation in percentage of sugars present, the exact temperature for one honey would probably be incorrect for another. However, a knowledge of the approximate temperature is of value. It was found, as previously mentioned, that a temperature of about 55° F., which is slightly below the temperature giving most rapid crystallization in average honeys, has produced excellent results. By keeping the temperature of the constant-temperature room a little lower than optimum, an accidental rise in temperature may occur without seriously affecting the rapidity of crystallization and the resulting size of crystals.

The surface area of the disperse phase of crystals has a direct influence on the type of crystallization. If nuclei are present in abundance, especially if they are minute, the surface area is large and the dextrose in excess of saturation is rapidly drawn to these many points of growth. Each crystal, when once started, grows at approximately the same rate as do the others, and the dextrose in excess of saturation is depleted before the crystals have become of objectionable size, when crystal formation is rapid. If, on the other hand, only a few nuclei are present, the surface area of the disperse phase is small. The length of the diffusion path is then relatively great, and the dextrose in excess of saturation becomes slowly attached to these few points of crystal growth. The resulting crystals will naturally be large. It is therefore important to add sufficient nuclei in the form of finely crystallized honey to obtain the results desired. It was found that a minimum of 5 per cent and a maximum of 15 per cent gives satisfactory results.

The surface area of the disperse phase may be increased by using a type of agitator which breaks the crystals into fragments. The effect of such breakage is most evident when a honey pump is used. Since the pump almost invariably causes many minute air bubbles to be incorporated into the honey, and since many of these bubbles rise to the surface of the honey, giving it an objectionable foamy appearance, such methods of increasing the disperse phase should be discouraged. If fine-crystallized honey is not available for use as a starter, it is advisable to reduce the size of the crystals prior to introducing them into the honey. By first processing a small amount of honey with these ground crystals, sufficient starter is obtained to process a larger amount.

Most honeys at ordinary temperature have a relatively low diffusion coefficient. This is exemplified in a practical manner by placing two honeys, one on top of the other, in a glass jar. Even at room temperature no noticeable diffusion occurs. The honey containing the larger number of crystals will granulate before the other does, and the line of demarcation becomes obvious.

The length of the diffusion path is directly influenced by the number and the size of crystals added and by their degree of dispersion throughout the honey. For rapid crystallization the length of the diffusion path should be reduced to a minimum. In order to accomplish this, a large number of fine crystals should be added and thoroughly distributed through the honey. Temperature materially modifies the rate of diffusion. If the honey is kept at too high a temperature, its viscosity will be reduced and the crystals may settle to the bottom. Should this occur, the length

of the diffusion path will be increased and slow crystallization will result, with the formation of large crystals. Such precipitation of crystals may occur also in honeys abnormally high in water content. If, on the other hand, the honey is kept at too low a temperature, its increased viscosity reduces the coefficient of diffusion, thereby delaying the formation of crystals. As an illustration of this, it may be noted that sample 12 of experiment 14, which was processed and left at 30° F. for a period of months, made no progress toward crystallization.

On briefly summarizing the Noyes-Nernst formula for crystal growth, it is seen that the formula is not set in motion until crystal nuclei are present. It requires, however, a disperse phase with a large surface area. In order to meet this requirement, an abundance of small crystals in the form of finely granulated honey may be introduced. Since the length of the diffusion path should be reduced as much as possible for the maximum rate of crystal growth, the disperse phase must be thoroughly distributed throughout the solution. The diffusion coefficient is usually unmodified except by temperature. It therefore becomes essential to select a temperature that will maintain supersaturation, giving abundance of diffusion without reducing the solubility of the disperse phase.

SUMMARY AND CONCLUSIONS

The inadequate control of fermentation and crystallization of honey has been a serious handicap in the successful marketing of the product. The only suitable method of controlling fermentation now in use is to heat the honey sufficiently to destroy the sugar-tolerant yeasts present. In doing this, beekeepers and packers commonly heat their honey to excess, not only to destroy the yeasts but also to delay later formation of coarse crystals until the honey is consumed. Excessive heating drives off the aroma, breaks down the sugars, especially levulose, and causes the honey to be lowered in quality and darkened in color.

Granulated honeys ferment more readily than do liquid honeys. When dextrose forms crystals in water solution, the composition of the crystals is that of dextrose hydrate, and the water of crystallization amounts to only 9.09 per cent of the material in solid form. Since the average water content of honey is about 18 per cent, this means that, when crystals form, the remaining liquid phase has an increased water content, giving a favorable medium for the growth of yeasts.

The market quality of granulated honey is directly influenced by the size of crystals. Honey which forms fine crystals is more palatable, and more satisfying to the person who eats it, than honey which contains coarse, gritty crystals. All honey, to be marketed successfully, should have fine crystals.

In order to gain some definite information on the keeping qualities of honey packed in the usual ways, certain experiments were conducted. For purposes of comparison, more than 2800 containers, each holding about 1 pound of honey, were packed in the following ways: (1) under vacuum; (2) in hermetically sealed containers; (3) in friction-top tins; and (4) in glass. Selected honeys varying in specific gravity, and from different floral sources, were used. To obtain some much-needed information on the physical properties of honey, portions from some of the

honeys were subjected to different treatments and were packed under the four methods mentioned. Records were kept of the origin, the source, the color, the specific gravity, and the treatment of each sample, as well as of the results obtained. A few of the more important observations are briefly sketched in the following paragraphs.

Fermentation occurred under all four methods of packing. The addition of sugar-tolerant yeasts and of fermented honey to normal honey did not appear to stimulate fermentation; but when the same honey was slightly diluted with water, fermentation progressed with great rapidity. The earliness of fermentation appears to depend less on the number of yeast cells present in the honey, than on the ability of the honey to form a favorable medium for yeast growth. High water content, and abundance of pollen grains which supply nitrogenous compounds, are two important factors in forming a favorable medium for the growth of yeasts in honey.

Under conditions of high humidity the hygroscopic property of honey is evident, and the samples in glass and in friction-top tins showed a slight increase in fermentation over the vacuum-sealed and hermetically sealed honeys. Under conditions of low humidity, the samples in glass and in friction-top tins showed considerable drying on the surface. This drying, although it tends to conceal apparent fermentation, causes the surface of the honey to become plastic and to have an objectionable thick consistency. Not all the friction-top and the glass containers showed absorption or evaporation of moisture, but in most cases the sealing was not sufficiently tight to prevent the effect of changes due to atmospheric humidity.

It appears that separation in crystallized honeys is characteristic of those which are high in water content and in which the dextrose hydrate crystals are of insufficient size and number to form a substantial framework of crystals throughout the liquid phase which would prohibit the settling of crystals. Since honeys of high water content are susceptible to fermentation, separation is usually, but not necessarily, accompanied by fermentation. Therefore, when separation has been present for some time, fermentation also may be expected to be present; but should these separated samples be observed immediately after separation has become evident, it is a matter of doubt in many cases whether fermentation is occurring.

The number of inches of vacuum retained in the samples sealed under vacuum varied considerably. The vacuum was lost or was greatly reduced in unheated samples, but was usually retained in heated samples. Since little or no vacuum was lost in containers which were sealed empty, it would appear that the loss of vacuum is due largely to air bubbles contained in unheated honey, rather than to the inefficiency of the vacuum machine or of the containers.

Since fermentation was controlled in most of the samples by heating to 130° F. for thirty minutes, excessive heating to control fermentation is not essential. No deterioration in quality could be detected in the samples given this treatment. Honeys heated to 200° F. and then rapidly cooled to room temperature were uninjured; but when honeys were heated to about 160° F. and then left to cool slowly, the quality was always injured.

To destroy yeasts and yet to preserve the quality of the honey, equipment should be used which will heat and cool the honey rapidly.

In no case did the samples closed by vacuum excel the hermetically sealed samples in keeping quality, but honey sealed by both these methods excelled the samples placed in glass containers and in friction-top tins. It is therefore desirable to place honey in air-tight containers. Since the vacuum seal is more costly than the hermetic seal, it is desirable to choose the latter method for packing honey.

Honeys that have been extracted from combs stored wet are more likely to form fine crystals than are honeys from dry combs. It is possible that the film of honey adhering to the cell walls of the wet combs crystallizes during the winter. This crystallized honey, which is in the combs while they are being filled again by the bees, may cause large numbers of small crystals to be incorporated in the honey. Should this occur, crystallization will be hastened, with the formation of small crystals.

In heated honeys, crystallization is retarded and larger crystals are formed, roughly in proportion to the temperature and to the length of time during which heat is applied. Heating destroys the crystals which stimulate further crystal growth in honey, the reduction of these crystals lowers the rate of crystallization, and the crystals which again form are larger and coarser.

Honeys that were stirred or pumped usually crystallized more rapidly and formed smaller crystals than did honeys that were not agitated. Since the mechanical action of a honey pump breaks up the small crystals already present, its effect on crystallization is roughly in proportion to the speed at which the pump is run and the number of crystals previously present. Liquid honeys to which crystallized honey was added also showed a slight advance in the rate of crystallization. In these cases, small, fine crystals were rarely formed; yet the samples clearly indicated that the introduction of crystals, and their subsequent distribution in honey by agitation, are two important factors in causing the formation of fine crystals.

As the work progressed, it became evident that fermentation cannot be controlled by methods of packing alone. No fermentation was present in the heated honeys, but the crystals which formed later were so large and coarse that the honey was entirely unsuitable for the market. There appeared to be only one channel left by which the fermentation problem might be attacked, and that was to first kill the yeasts and then control crystallization in honey. The control of crystallization not only would solve the problem of fermentation, but also would standardize the product and cause the honey to be much higher in quality.

Numerous experiments were conducted before the various factors which control crystallization in honey were ascertained. The following is a brief outline of the steps to be taken and the factors to be observed in producing honey with fine crystals. The formation of dextrose hydrate crystals in honey is discussed in detail on pages 68 to 71 of this bulletin.

Since all honeys are assumed to contain sugar-tolerant yeasts which are capable of setting up fermentation under favorable conditions, it is advisable to heat all honeys. This destroys the yeasts and liquefies any coarse crystals that may be present. The honey should then be cooled

as quickly as possible, so as to reduce darkening due to the breakdown of one or more of the sugars.

Different types of equipment may be used to heat and cool honey rapidly. If a tank is used, the part containing the honey should be surrounded by an outer jacket. The heating may be done by injecting live steam into the outer jacket, provided the inner wall of the tank is lined with a heavy enamel or other material which serves partially as an insulator, and provided also that at the time of heating the honey is constantly agitated. Cooling may be accomplished by passing cold water or brine through the outer jacket of the tank. Honey on being cooled becomes highly viscous and forms a thick insulating layer on the inner wall of the tank. Unless a type of agitation is used which removes this layer, the rate of cooling is greatly retarded. If a tank is used which has scrapers constantly removing the viscous layer of honey from the cooled walls, little difficulty should be experienced in cooling the honey with sufficient rapidity for all practical purposes. The scrapers should move slowly, and should be of sufficient depth under the surface of the honey so as not to incorporate air bubbles.

When the honey is cooled to a temperature of about 75° F., the starter, consisting of previously processed, finely crystallized honey, is added. The temperature at which the starter is added need not be exactly 75° F. Good results have been obtained on introducing the starter at temperatures as high as 85° and as low as 50° F. It is necessary only that the temperature be so lowered that when the starter is added the small crystals will not be liquefied. At a temperature of about 75° F. the consistency of the honey is such that a thorough mixing of the starter with the liquid honey is easily accomplished. If the temperature of the liquid honey is too low, such a mixing is more difficult, and it may become almost impossible much below 50° F. If the honey is of high consistency, it is desirable to introduce the portion of finely granulated honey at slightly higher temperatures than are most suitable when honeys of average water content are used, while for thinner honeys a temperature slightly lower than 75° F. is more favorable.

It is not necessary to add a large amount of starter, but it is necessary that the crystals added be fine. Large crystals added to honey continue to grow, and cause the final product to be gritty. Good results have been obtained on using various percentages by weight, of starter and of liquid honey, from as low as 3 per cent to as high as 20 per cent. In general, within reasonable limits, the larger the proportion of starter used, the more speedy is further crystal formation, owing to the larger number of foci of crystal formation incorporated. For practical purposes, from 5 to 10 per cent of the added material seems preferable, and a good working rule is to add a little more than 5 per cent.

When about 5 per cent of starter is added to the liquid honey, it is desirable that there be a thorough mixing of the two portions so that the minute crystals of dextrose hydrate may become thoroughly distributed in all parts of the liquid honey. The length of time that agitation should be continued varies with the type of equipment, but in general about fifteen minutes is sufficient. It is desirable to use a type of agitation which will not incorporate small air bubbles into the honey, since these tend to rise to the top of the honey and form a scum. Besides giving

the surface of the honey an objectionable appearance, air bubbles may harbor yeasts which may later, under favorable conditions, cause fermentation.

After the starter has been thoroughly incorporated into the liquid honey, it is desirable to run the honey immediately into the final containers. If this is done, the formation of crystals takes place in the containers and the possibility of yeast contamination from the air is lessened. It is desirable that all processed honeys be placed in tin or air-tight containers which are capable of being sealed hermetically, so that the honey may not be subjected to any change in atmospheric humidity.

After the honey has been poured into the containers, it should be placed at such a temperature that further crystal formation will progress with the greatest possible rapidity. For honeys of average consistency, a temperature of about 57° F. has given the most rapid crystal formation. For honeys that are below the average specific gravity, a temperature slightly below 57° has given the best results, while for more concentrated honeys a slightly higher temperature may give added speed to the process. For average honeys the best results are obtained when the temperatures are maintained as nearly constant as is practicable.

If the correct temperatures and other factors are observed, the processed honey should reach the solid stage of crystallization in two to four days. Rapid crystallization is desirable, not only from the standpoint of the greatest possible utilization of the equipment, but especially from the standpoint of the size of crystals and the resulting quality of the processed honey.

After the honey has been granulated by the process described, it can be removed from the constant temperature to which it has been subjected and may then be kept at ordinary room temperature without fermentation or liquefying. Honeys abnormally low in specific gravity tend to soften or to liquefy at room temperature, while honeys abnormally high in specific gravity may remain solid even at high temperatures. The relation of sugars present may also affect the consistency of crystallized honey. Honeys high in levulose should soften and tend to liquefy at room temperatures more than do honeys that are high in dextrose; but for all normal honeys, which have a specific gravity ranging from 1.419 to 1.435, the relation of sugars should not materially affect the consistency of crystallization.

REFERENCES CITED

BROWNE, C. A. Chemical analysis and composition of American honeys. *In* U. S. Chem. Bur., Bul. 110: 1–69. 1908.

FABIAN, F. W., AND QUINET, R. I. A study of the cause of honey fermentation. Michigan State Coll. Agr. Exp. Sta. Tech. bul. 92: 1–41. 1928.

GORTNER, ROSS AIKEN. Outlines of biochemistry, p. 1–793. (Reference on p. 14.) 1929.

JACKSON, RICHARD F., AND SILSBEE, CLARA GILLIS. Saturation relations in mixtures of sucrose, dextrose, and levulose. U. S. Commerce Dept., Standards Bur. Technologic papers 259: 277–304. 1924.

LOCHHEAD, A. G., AND FARRELL, LEONE. Soil as a source of infection of honey by sugar-tolerant yeasts. Canad. journ. research **3**: 51–64. 1930 a.

———— The effect of preservatives on fermentation by sugar-tolerant yeasts from honey. Canad. journ. research **3**: 95–103. 1930 b.

LOCHHEAD, A. GRANT, AND HERON, DORIS A. Microbiological studies of honey. Canada Agr. Dept. Bul. 116 n. s.: 1–47. 1929.

LOCHHEAD, A. G., AND MCMASTER, N. B. Yeast infection of normal honey and its relation to fermentation. Sci. agr. **11**: 351–360. 1931.

MARVIN, G. E. A preliminary report on the cause of the fermentation and souring of honey. Wisconsin beekeeping **4**: 109–110. 1927.

———— The occurrence and characteristics of certain yeasts found in fermented honey. Journ. econ. ent. **21**: 363–370. 1928.

———— Further observations on the deterioration and spoilage of honey in storage. Journ. econ. ent. **23**: 431–438. 1930.

NUSSBAUMER, TH. Beitrag zur Kenntnis der Honiggärung nebst Notizen über die chemische Zusammensetzung des Honigs. Ztschr. Untersuch. Nahr. u. Genussmtl. **20**: 272–277. 1910.

PUGH, R. M. A study of the grading and fermentation of honey for the years 1924 and 1925. Thesis for degree of M. S., Cornell University. 1927.

RAHN, OTTO. Incomplete sterilization of food products due to heavy syrups. Canning age **1928**: 705–706. 1928.

WILSON, H. F., AND MARVIN, G. E. On the occurrence of the yeasts which may cause the spoilage of honey. Journ. econ. ent. **22**: 513–517. 1929 a.

———— Preventing fermentation in honey. Gleanings in bee culture **57**: 434–435. 1929 b.

———— The process of fermentation and how it affects the beekeeper. Iowa State Apiarist. Report **1929**: 58–61. 1930 a.

———— The effect of temperature on honey in storage. Wisconsin beekeeping **7**: 116–118, 121. 1930 b.

———— The effect of temperature on the keeping qualities of honey. Amer. bee journ. **71**: 22–23. 1931.

NOTE. For the purpose of safeguarding the quality of the product that may be obtained by use of the process described in this bulletin, the author has applied for patents on the process and product and has assigned these, if and when issued, to Cornell University for the use of the College of Agriculture in promoting similar researches. Persons residing in the United States who are interested in the manufacture of this product should communicate with the Comptroller of Cornell University, Ithaca, New York.