The Secretion of Milk and the Milking Process

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The inside of the cow's udder is an obscure and inaccessible place. As a consequence the process of milk secretion has not been well understood. During recent years, however, intensive studies of the structure of the udder and the mode of milk secretion have turned the spotlight on the processes involved in converting feeds into milk.

Many questions have been asked by dairymen and others as to the process by which the blood is transformed into milk fat, milk protein, milk sugar, and other minor constituents which are combined with water to form milk. In the first place the question may be asked, "Where is the milk formed?" Is it formed in the blood and merely stored in the udder until milking time, or is it formed within the udder?

Another question commonly asked about this process is the time of milk secretion. Is milk secreted continuously during the interval between milking and stored in the udder, or is most of the milk secreted during the milking process? If the milk is stored in the udder between milkings, how then is the cow able to "hold up" her milk at milking time?

The object of this bulletin is to report the results of research in all parts of the world which have been undertaken to answer these and similar questions. While many problems concerned with the process of milk secretion are yet unsolved, a great deal of information which is believed to be of interest and practical value has been discovered.

The Blood in Relation to Milk Secretion

The blood is conveyed to and from all parts of the body, including the udder, through a system of branching tubes—the vascular system (see Missouri Agricultural Experiment Station Bulletin 344 for a description). From the fine ducts—the capillaries—the blood plasma passes out into the tissue spaces, bathing the individual epithelial secreting cells of the udder. Much of the tissue fluid again returns to the capillaries and passes back to the heart by way of the veins. Part of the tissue fluid passes into the lymph capillaries and returns to the heart by way of the lymphatic system.

Blood is composed of red and white corpuscles floating in the plasma or the liquid portion. In normal cow's blood slightly less than 40 per cent consists of corpuscles and 60 per cent of plasma. It should be remembered that it is in the plasma that the constituents are found which contribute to the secretion of milk.
In recent studies at this Station it has been found that in non-lactating cows the amount of blood present averaged 6.38 per cent of the body weight, of which 3.78 per cent was plasma. In comparison, lactating cows were observed to have a higher blood volume, averaging 8.11 per cent of the total body weight and 4.92 per cent of plasma.

From studies of the speed of circulation of blood through the udder of milking cows, it has been observed that it required 52 seconds for the blood to make a complete circuit from the udder to the heart and return through the udder in cows with an average pulse rate of 63 per minute.

The proportion of the total blood which passes through the udder of the dry and milking cow has not been determined. In the goat it has been found that 3.7 per cent of the total blood passes through the udder when lactating and about 1 per cent in the dry animal. If approximately similar conditions hold for the cow, a 1000 pound cow would have about 81 pounds of blood in her circulatory system. Of this amount about three pounds would pass through the udder each 52 seconds or about 200 pounds per hour. If the cow were producing 24 pounds of milk per day or about 1 pound per hour, 0.5 per cent of the blood passing through the udder would be converted into milk.

The Formation of Milk

In a previous publication (Missouri Agricultural Experiment Station Bulletin 344) describing the structure of the cow’s udder, it was shown that the udder consisted of four large mammary glands, each of which was designed to secrete and store large quantities of milk. Microscopic study of the tissue of the gland shows the presence of large numbers of little hollow spherical structures called alveoli lined by single layers of cells. It is within these cells that the marvelous transformation of certain constituents of blood into the various constituents of milk which we call “milk secretion” takes place.

It is of interest to examine the blood to determine if possible the constituents present which play a part in the manufacture or synthesis of milk. There are three well recognized proteins in milk—casein, albumin, and globulin. Casein, the principal protein, is unique in that it is found only in milk, not being present in the blood. It would appear that this protein is synthesized by the gland epithelium. There are present in blood the various amino acids formed from the breaking down of protein in the digestive tract. These building stones of the proteins are believed to be rearranged and united into casein in the epithelial cells. Albumin and globulin, however, are found in blood. The question arises in connection with these milk proteins as to their source, whether coming as preformed proteins from the blood or formed by the epithelial cells
from the amino acids as in the case of casein. A number of investigators have come to the conclusion that albumin in colostrum and milk is not identical with the albumin in blood serum and therefore is manufactured from the amino acids. On the contrary, all agree that the globulin of colostrum and milk is identical with serum globulin.

These findings clearly indicate that the major part of the protein found in milk is synthesized by the secretory cells from the amino acids. Only the milk globulin, traces of which are found in normal milk, comes unaltered from the blood.

Milk sugar or lactose \((C_{12}H_{22}O_{11})\) is formed by the union of two simple sugars, glucose \((C_6H_{12}O_6)\) and galactose \((C_6H_{12}O_6)\). These latter sugars are of similar composition but differ in internal arrangement. The only normal sugar found in the blood is glucose or dextrose as it is sometimes called. In the formation of milk sugar in the cells of the mammary gland, half of the glucose coming from the blood is converted to galactose and then is united with the glucose to form lactose. The transformation of blood sugar to milk sugar undoubtedly takes place within the cells of the gland. This has been shown by the fact that when lactose is injected directly into the blood stream it is not utilized by the gland but is all excreted into the urine.

Milk fat is a mixed fat composed of the glycerides of ten or more fatty acids. The lipoids or fat-like substances of blood include neutral fat, fatty acids, phospholipoids (lecithin), and cholesterol. There is still some uncertainty as to the precursor of milk fat. It was first suggested that the neutral fat of blood was used in forming milk fat. More recently it has been suggested that the phospholipoid, lecithin, is transformed by the mammary gland into milk fat. This theory is supported by the fact that lecithin mixes readily with water, forming a dispersion which while not a true solution provides a convenient means of transport of the insoluble fat throughout the body and particularly across cell membranes. There is also some evidence of a reduction of the lecithin content of the blood upon passage through the udder.

The mineral constituents represent a relatively small but important fraction of milk. Part of the mineral matter present is combined with the protein during the process of synthesis, part comes from the blood either in new combinations or as it exists in the blood.

The vitamins of milk are not synthesized by the mammary gland but come from the blood without change.

**I. THE PROCESS OF MILK SECRETION**

The process of milk secretion should be considered in two parts. The first phase is concerned with the manufacture of the various con-
stituents of milk from their precursors in the blood by the epithelial cells of the alveoli. The second phase is concerned with the discharge of the formed milk from the cells into the lumina of the alveoli. Thus from the standpoint of the cell, milk secretion consists of many cycles of the synthesis of milk followed by its discharge, synthesis and discharge, etc. The speed of this process is unknown but from the considerable weight of milk capable of being secreted during the interval between milkings in relation to the weight of the empty gland, there are undoubtedly many such cycles per day.

The next question to be considered is the rate of secretion during the interval between milkings as compared with the amount secreted during the milking process. On the basis of inadequate information, the earlier students of milk secretion were led to believe that about one-half of the milk was secreted during the interval between milkings, and the other half after the teats were stimulated by the act of milking.

One of the most important reasons for believing that the secretion of milk was very rapid during the act of milking was due to the fact that it was thought that the udder could not hold all the milk produced at one milking. In regard to cows giving 12 to 15 pounds of milk at a milking one investigator stated that, "No udder could contain so much".

In reply, the proponents of the theory that the entire yield of milk is present in the udder at milking time report that: 1. The milk removed from the udder can be reinjected back into the udder, in fact twice the amount of milk can sometimes be reinjected. 2. A quantity of water can be injected into a cow's udder by gravity larger than the maximum amount of milk secreted at one milking. 3. In post-mortem milking experiments it has been found possible to remove from 50 up to 100 per cent of the milk normally obtained at corresponding milkings. It is probable that the reason for the frequent failure to obtain 100 per cent of the milk after the udder has been detached is due to the absence of the active aid of the cow in causing the contraction of the udder at milking time (see page 12). 4. When the post-mortem udder is ground up and the milk sugar is extracted, it has been found that the milk equivalent obtained represents up to 120 per cent of the preceding milking. In this experiment one does not determine the milk which could be obtained at milking time but also residual milk which cannot usually be obtained by milking (see page 17). 5. The post-mortem udder can be injected with a quantity of fluid far greater than is ever obtained at a single milking. In such cases it should be noted that there is no possibility of the liquid injected passing back into the blood stream.

The above evidence is believed to prove definitely that the udder of the dairy cow is large enough to hold all the milk produced at a single milking.
The second reason for the belief of earlier investigators that considerable milk was secreted at milking time was the observation that if milking tubes were carefully inserted into the teats and the milk allowed to flow out without stimulation, only about one-half of the milk could be obtained. If the teats of the cow were massaged, a much larger amount of milk was discharged. The milk thus obtained was thought to have been secreted as a result of stimulating the udder. It is true that the stimulation of the udder and teats causes changes in the udder which aid in the removal of milk. It is believed, however, to be due to the contraction of the muscular elements of the udder rather than secretory activity. The details of this phenomenon will be discussed in a later section (see page 15).

A number of recent experiments and observations, while not individually offering conclusive proof of a lack of secretory activity at milking time, together make a rather strong case.

1. The presence of milk sugar in the cow's udder at milking time in excess of that contained in the milk usually obtained.
2. The observation that more milk can be obtained by rapid milking than by slow milking.
3. The pulse rate is not increased during the act of milking indicating that the blood flow to the udder is not increased.
4. The removal of blood by the udder in sufficient amount to manufacture half of the milk produced at the milking would require a very rapid readjustment of the constituents of the blood and the withdrawal of a large amount of water from the tissue.
5. The increased pressure in the udder at milking time would decrease the flow of blood in the capillaries and thus limit if not suppress the transfer of the precursors of milk to the secretory cells.
6. The intricate chemical transformations involved in secreting one-half of the normal yield could not be completed in the few minutes required for milking.
7. The increased pressure produced in the udder upon stimulating the teats during the interval between milkings recedes again in a short time, indicating that the increase was not due to the rapid formation of milk (see fig. 3).

**The Rate of Milk Secretion**

The evidence just presented is believed to indicate that the larger part, if not all of the milk, is secreted during the interval between milkings. The question arises as to the rate of secretion during this period. Is milk secreted at a more or less uniform rate or are there differences as milk accumulates in the udder? Those who believed that milk secretion was very rapid during the act of milking thought that the secretion of milk was very slight for a period following. The lack of change in the
size of the udder for some time while the storage system was filling was interpreted as indicating a very slow secretion for a time.

One of the first methods employed in attempting to study the rate of milk secretion was the determination of the increase in the pressure in the udder at intervals during the period between milkings. In the more recent work an air pressure gauge was connected with a milking tube (Fig. 1). The tube was inserted into the teats at intervals and the pressure determined. After the previous milking the pressure remained at 0 mm. for some time, then gradually rose until the time of the next

![Fig. 1.—Milk pressure gauge. By inserting the milk tube into the teat, the pressure of the milk contained in the udder may be determined. (From Tgetgel).](image)

![Fig. 2.—The rise in milk pressure during the interval between milkings. The curve shows that the pressure increases very slowly at first as the storage system fills. Toward the end of the period the pressure increases more rapidly as the udder is stretched out to accommodate the milk. (From Tgetgel).](image)
milking (Fig. 2). To obtain such a curve it was necessary to allow the
cow to rest without the application of any sort of stimulation to the
udder or teats. If at any time the cow is stimulated to "let down" her
milk, there is an immediate rise in the curve. The increased pressure
is not lasting but disappears again in from 10 to 60 minutes. The curve
does not again descend to the former height but to a point that would
have been reached in the time interval elapsing had no stimuli been
applied (Fig. 3).

The change in the size of the udder during the interval between
milking has been studied also. Ten cows were measured prior to the
last milking as follows: (1) length of udder from front to rear, (2)
width of the rear quarters. The measurements were repeated after
milking and at hourly intervals for seven hours. It was found that during
the entire interval the udders increased 34 per cent in size. As will be
noted from Table 1 the extension in the udder during the first three hours
is very slight. Following the third hour the distention of the udder in all
three dimensions became more marked. Assuming a uniform rate of
secretion, it was calculated that in the cows used about 40 per cent of the
milk secreted at a milking could be accommodated in the hollow, empty
udder and the remaining part was accommodated by stretching the
udder.

The fact that the udder has a large storage capacity for milk pre-
vents either the change in milk pressure or in size from giving an ac-
curate picture of the rate of secretion.

Data on the rate of milk secretion might be obtained also by milking
at various intervals. Extensive observations on the influence of milking
two, three, and four times per day on the yield of milk indicates clearly
that there is an advantage in the more frequent removal of milk. Usually
the greatest benefit of frequent milking comes during the period of
maximum production. This would be expected assuming that it is
increasing milk pressure which slows down the rate of secretion.

The storage capacity of the udder of cows at their maximum will
be filled sooner after milking than those of cows further advanced in
lactation.

In studies with cows milked at increasing time intervals after the
regular milking period, it was observed that as the interval between
milking was lengthened the yield of milk in unit time was decreased.
The fat content of the milk after the short intervals was high, then
gradually decreased as the interval increased.

Milking cows at equal intervals (one hour) has been studied also.
The yields of milk so obtained are quite variable. In most cases rather
small amounts of milk are obtained for the first two or three hours, then a
larger amount may be obtained, followed by smaller amounts in addition­
val hourly milkings. The summation of these rather irregular yields
showed a tendency to form a normal frequency curve with a maximum
at about five hours. From these data, the theory was advanced that
the rate of milk is at first rather slow, increases gradually until a maxi­
num is reached about the middle of the interval, and then gradually
declines again.

The writer does not believe this theory is in line with the facts
concerning the changes in the udder at the normal milking period (see
page 12). Before the milk present in a cow's udder can all (except
residual milk) be removed, it is necessary for the cow to respond to the
stimulus of milking and cause an increased pressure in the udder.
Usually this reaction cannot be stimulated at short intervals after the
last regular milking. However, as the interval lengthens, the individual
cows respond and let down all the accumulated milk. Then having once
responded, they will not again respond to the stimulus for a time.
Two further observations have been made concerning the relation of udder pressure to the rate of milk secretion. If air is injected into the udder so that various levels of pressure are maintained for considerable periods of time, the amount of milk obtained at the close of the period decreases as the pressure level increases. When from 30 to 40 mm. of mercury pressure was used, milk secretion was almost completely inhibited.

When milk is allowed to collect in the udder for long periods, the pressure increases for a time but finally stops indicating that the pressure resulting from the accumulation of milk not only reduces the rate of secretion, but eventually causes the total cessation of secretion.

Summary

The mass of direct and indirect evidence available at the present time is believed to warrant the following conclusions as to the mode of milk secretion:

Milk is largely manufactured from certain constituents obtained from the blood by the epithelial cells lining the alveoli of the udder. Certain minor constituents may pass from the blood into the milk unchanged.

Within these cells the cycle of milk secretion includes, first a period of synthesis during which time milk is formed within the cells, followed by the discharge of the milk into the cavity of the alveolus.

Following the removal of the milk at milking time, the cycles of milk secretion and discharge are rapid, filling the lumina of the alveoli, the ducts and storage spaces of the duct system, and the gland cistern. During this period there is little change in the size of the udder or milk pressure and the rate of secretion proceeds at a rapid rate. With the continued secretion and discharge of milk there is a gradual rise in udder pressure. The cycles of secretion and discharge begin to slow down. This is due to the unfavorable effect of the increasing milk pressure on the blood capillaries, reducing the flow of blood, and to the greater and greater difficulty encountered in discharging the cell's content of milk into the lumen.

The theory is advanced that the increasing milk pressure causes a gradual change in the mode of milk excretion. Instead of discharging the products of secretion from the cell by the rupture of the cell membrane, the pressure in the lumen of the alveoli becomes sufficient to prevent the rupture of the cells. The constituents of milk are discharged from the cell only as it is possible for them to pass through the semi-permeable cell membrane. The milk fat which is in suspension in the milk serum cannot leave the cell and as a consequence accumulates within the cell as secretion continues. The other constituents of milk are present in various degrees of solution. Their discharge continues at a
reduced rate through the cell wall. As secretion continues a milk is discharged which is low in fat and to a less extent casein, but is normal in sugar and albumin. If the milk is allowed to accumulate in the udder for a long time the pressure practically inhibits both the secretion and excretion of milk.

Thus the milk secreted when the milk pressure is low is high in fat, but as the interval between milkings lengthens this milk is gradually diluted by the discharge of a milk less rich in fat. Therefore, as the interval between milkings lengthens, the fat content of the total yield of milk is reduced.

II. THE MILKING ACT

As soon as the milking act begins, either by hand or by milking machine, a small quantity of milk can be removed from the cistern and larger ducts. There then follows a short period when only a small quantity of milk can be obtained. Soon there is a great inflow of milk into the cistern of the udder. One says that the cow has "let down" her milk, or that the milk has "poured in". This reaction on the part of the cow indicates her response to the stimulus of milking. Without this response the removal of more than about one-half of the milk is made extremely difficult, if not impossible.

In addition to the manipulation of the teats at the beginning of milking, there are other types of stimuli which cause some cows to let down their milk. Animals once becoming accustomed to certain other stimuli react more quickly to that and sometimes will not respond at all to the stimulation of the teats. The sight of the calf, the swinging of the udder in walking into the barn, the noise of milk pails and other dairy equipment such as the milking machine causes some cows to let down their milk. Other cows will respond only to feed and unless fed at milking time will "hold up" their milk. The letting down of milk may also appear spontaneously when the interval between milkings is increased.

The time which passes from the moment of the stimulation to the letting down of milk varies with individuals between one-fourth and two minutes. It is believed that fresh cows react more quickly and clearly. Old cows with large cisterns do not show as much of an increase in pressure as do those with normal udders. The position of the legs in standing may cause a slight alteration in the pressure.

The Milk Pressure at Milking Time

At the time of milking and before the udder or teats have been stimulated, the milk pressure usually varies between 25 and 35 mm. of mercury. In comparison, pressure readings taken as soon as the cow has "let down" her milk reveal milk pressures of 40 to 60 mm. of mercury.
Table 2.—Effect of Massage on Milk Pressure (Tgetgel)

<table>
<thead>
<tr>
<th>Cow No.</th>
<th>Milk Pressure</th>
<th>Increase in Pressure</th>
<th>Milk Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before (mm.)</td>
<td>After (mm.)</td>
<td></td>
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<tr>
<td></td>
<td></td>
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<tr>
<td>1</td>
<td>35.5</td>
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<td>10</td>
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<td>21.9</td>
<td>6.8</td>
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Table 3.—Milk Pressure in Each Quarter Before and After Massage (Tgetgel)

<table>
<thead>
<tr>
<th>Right Front</th>
<th>Right Rear</th>
<th>Left Front</th>
<th>Left Rear</th>
<th>Average Pressure</th>
<th>Yield of Milk</th>
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<tbody>
<tr>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
<td>Before</td>
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<td>29</td>
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</table>

The relation between the change in milk pressure and milk yield is presented in Table 2. It is interesting also to note the differences in the pressure of the four quarters before and after stimulation (Table 3).

When the pressure within the udder has increased, the cow is ready to be milked. As the milking process progresses and more and more milk is removed from the udder, the pressure gradually returns to zero (Fig. 4). If one half of the udder is milked first, the pressure in the other half is reduced slightly. If there is a considerable delay in removing the milk, the pressure may decline considerably as seen in Fig. 5.
Fig. 4.—The change in milk pressure during the milking process. The milk pressure was determined after increasing percentages of the milk had been removed. (Krzywanek and Brueggemann).

Fig. 5.—The effect on the milk pressure in the rear quarters when the fore quarters were milked first: —rear quarters,—fore quarters. (From Krzywanek and Brueggemann).
The Cause of the Increase in Pressure After Stimulation

It is seen that with the stimulation of the milking cow in any one of several ways, a rapid reaction occurs which causes an easily apparent tenseness, together with a filling and lengthening of teats, and a measureable increase in the pressure in the cisterns of the udder. The cause of these changes undoubtedly rests upon a nervous reaction by one of two paths—a reflex action through the sympathetic system as the result of a stimulus applied to the udder and teats, or a sensory stimulation from the cranial nerves (sight, hearing, etc.) to the spinal nerves and indirectly to the sympathetic system. Assuming that the stimulus causing the increase in pressure within the cistern system is of a nervous origin, it is interesting to try and determine how it is accomplished.

The older workers were of the opinion that the very rapid secretion of milk was the cause of the phenomenon observed. With the stimulation of the teats about one-half of the total yield of milk was secreted. The reasons for no longer adhering to this theory have been presented in a previous section. It has also been suggested that the increase in milk pressure was due to the dilation of the blood vessels of the udder. While this is possible, no evidence has been obtained that such is the case.

The writer is of the opinion that the pressure developed in the udder upon the stimulation of the teats is due to the contraction of smooth muscles and other contractile elements throughout the udder, causing an internal squeezing action upon all the milk storage spaces such as the alveoli, the ducts, etc. Surrounding the alveoli are cells which are believed to have contractile properties, even though not true muscle cells. The ducts, however, have smooth muscle cells in their walls. These muscles are arranged longitudinally in the larger ducts and upon contraction cause a shortening and widening of these ducts. The tension produced throughout the storage system forces the milk downward into the cistern ready to be removed. The rapid removal of milk as soon as the pressure increases is most effective in securing the maximum yield of milk.

How the Cow “Holds Up” the Milk

One of the most unpleasant experiences of a milker is for the cow to refuse to “let down” her milk after the usual manipulation at the time of milking. There are two closely related phenomena. The first is the case where the cow does not let her milk down. The second is the case where the milk is at first let down, but then before the milk is completely removed holds up the latter part for a time or until the next milking period.

This condition is generally caused by some unusual condition in the barn to which the animal is subjected. Sometimes after the removal
of the calf, the cow is nervous and uneasy and holds up her milk. The barking of dogs, excessive noise or shouting at milking time disturbs the more nervous animals. Sores or injuries to the udder and teats which are painful at milking time may cause trouble. Kicking or hitting the cow is almost sure to cause the cow to hold up her milk. When cows are ordinarily fed at milking time, the withholding of feed usually causes irregularity in milk removal. The dairy cow is a creature of habit and whenever there is any upset in the normal routine of barn management the more nervous cows become upset.

Many theories have been advanced to explain how the cow was able to “hold up” her milk. Some folks have thought that she was able to wilfully withhold her milk and believed a well placed kick or the application of the end of the milking stool would coax her to let it down. However, such treatment always aggravates the condition. From a consideration of the factors involved in “letting down” the milk it was pointed out that this condition is brought about by a nervous response to the normal stimulation of milking. The smooth or involuntary muscles of the udder contract, forcing down the milk. The continuous manipulation of the teats furnishes sufficient nervous stimuli to maintain the contraction of the muscles and the resulting milk pressure. It is at this time that the milk can be removed with the greatest ease and completeness. By milking rapidly during the time of maximum pressure more milk and slightly richer milk will be obtained. Soon the contracted muscles begin to relax and as a consequence the milk pressure declines. Milk not removed at this time from the smaller capillary milk ducts becomes unavailable to the milker.

It is seen then that the cow does not wilfully “hold up” her milk but rather there is required her active aid through her nervous system to “force down” the milk. If cows at milking time become excited for any reason there is great difficulty in obtaining the cow’s cooperation in this important matter. The contraction of the muscles does not occur and the pressure within the udder does not increase. The relaxation of the muscles may occur at any time during the milking period if the cow becomes unduly disturbed. When this occurs there is little use in continuing milking until the cow “calms down” and will respond to the stimulus of milking or feeding.

There are great differences in the nervous temperament of dairy cattle. Some cows are more upset by unusual noise or excitement than others. The best results at milking time will be obtained by maintaining quiet, normal conditions. If cows are accustomed to being fed when they are milked, they will do their best only when so managed. Rapid changes in methods of management should be avoided to prevent cows getting
into bad milking habits. Contented cows will not "hold up" their milk but rather upon proper stimulation will "force" it down so that it may be removed easily by the milker or the milking machine.

Residual Milk

Considering the structure of the udder it is not surprising that there should remain a certain quantity of milk even after the most expert milking. This milk may in part still remain within some of the secreting cells, in the lumina of the alveoli, and in the ducts. In cows of average capacity the amount of milk which has been computed to remain in the udder is about two pounds. This has been demonstrated by determining the milk sugar content of the udder and by the injection of pituitrin, a hormone, which produces a powerful contraction of the udder forcing out milk which was previously unattainable.

Relation of the Method of Milking to the Composition

Observations on the variation in the composition of milk under certain conditions related to the methods of milking may be explained in the light of the preceding discussion.

It has been observed that there is a gradual increase in the fat content of milk as the milk is withdrawn from the udder, the last milk being richest in fat. It has been thought that this phenomenon was due to the effect of gravity acting upon the fat causing it to rise to the higher parts of the udder and coming down in larger amount with the last milk. This may be the major cause, but a contributing mechanism is believed to lie in the discharge of the milk from the cells which are laden with fat as the pressure in the udder declines. The last milk is especially rich in fat as it represents the milk coming from the ruptured cells which is less diluted with milk in the storage system.

When milk is removed at unequal intervals, that is 10 and 14 hours apart, it has been observed that the milk obtained after the shorter interval is highest in fat. This is due to the fact that the secretion and discharge of fat is interferred with as the milk pressure increases. Similarly, if for any reason the yield of milk is suddenly reduced, the fat content of the milk will be higher due to the lessened milk pressure developed and the reduced interference with fat secretion. During the gradual decline of milk secretion with the advance of the stage of lactation, the percentage fat content of the milk gradually increases for the same reason.

If the quarters of a cow's udder are milked one at a time, it has been observed that the milk drawn from the quarter milked first was almost invariably richest in fat and that drawn from the last quarter was the
poorest in fat. The milk yields were higher in the quarters milked first, also. That the factor of time was of importance in milking was demonstrated by comparing very quick milking and very slow milking. There was a difference of 10 per cent in milk yield and 40 per cent in fat yield in favor of quick milking. It seems clear that the most milk is obtained by rapidly removing the milk when the milk pressure is at a maximum and the cow is in effect "forcing down" the preformed milk in the udder. By lengthening the period of milking after the teats are stimulated, the gradual relaxation of the muscles sets in and as a consequence the last milk which is also the richest milk is not obtained at that milking. This observation indicates the importance of permitting nothing to interfere with the rapid removal of milk once the cow has "forced down" the milk.

Summary

The part played by the milker during the removal of milk is well understood. Less clear has been the cooperation required of the cow. Evidence has been presented indicating that at the beginning of the milking act the massage of the teats or the operation of the milking machine may stimulate a great increase in the pressure within the cow's udder. It is believed that the increase in pressure is due to the contraction of smooth muscles lining the ducts of the udder. The milk can be removed from the udder with the greatest ease and completeness while the pressure is maintained. Soon the contracted muscles gradually begin to relax and the pressure declines. If the milk is not completely removed by this time it becomes unavailable to the milker until an increase in pressure can be induced again.

When, for any reason, cows become excited at milking time, they do not respond to the stimulation of the teats and the milk pressure does not increase, thereby "forcing down" the milk. As a consequence considerable milk cannot be obtained and one says that the cow is "holding up" her milk. When this occurs the only way to remedy the condition is to remove the cause and let the animal return to normal, when her cooperation may again be obtained.
OTHER BULLETINS ON MILK SECRETION
