SOME FACTORS AFFECTING THE SPEED AND EFFICIENCY OF MACHINE MILKING

by

DONALD B. ROARK

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INTRODUCTION

The cow's udder is the most important economic unit in American agriculture. Approximately one-fifth of the total farm income comes from the sale of the products of this gland. The labor required to secure the milk from this gland constitutes about 10 percent of the total labor needed yearly to grow and harvest all crops, to care for all livestock, and to perform maintenance, repair, and miscellaneous farm work. Demands for increased milk production from a relatively smaller labor force have resulted in extensive and widespread use of milking machines. Around 25 per cent of the dairy cows, now numbering about 27 million head in about 4 million herds, are milked by machine. The milking machine is used an average of approximately 200 hours more per year than any other piece of farm machinery in common use. It is estimated that the labor saved by the use of milking machines is equivalent to 70,000 workers each working 3,000 hours yearly. Approximately 90 per cent of the estimated 325,000 milking machines (number of installations) are used in herds of 10 cows or more (41).

Worldwide attention has been directed to employing a system of "fast" milking that is based on a theory advanced as a result of recent research in the physiology of milk secretion. Representatives of milking machine companies and extension agencies of agricultural colleges agree on and advocate the "fast" milking principle, but they are not in agreement on the methods that should be used in preparing the cow for best utilization of this principle.

A survey of the recommendations of 12 leading milking machine companies showed the divergence of recommendations (47).

Also, practical dairymen are confronted with variations between cows, such as fast and slow milkers, varying response to different methods of preparation, etc., which tend to disrupt the routines of fast milking. The difficulty of exact measurement of these variables has resulted in lack of experimental data; hence, the relationship of the organisation of labor to efficient milking by machine is not well established.

In view of the differences in recommended practices and the lack of experimental data, it seemed desirable to study three aspects of mechanical milking: (a) the variations in cows from day to day and between cows, (b) the methods of preparing cows, and (c) the organization of labor in an effort to determine its role in the speed and efficiency of machine milking.

REVIEW OF LITERATURE

The older idea that milk secretion takes place in two phases, one in the interim between milking and the other at milking time due to the milking stimulus, was supported by the report of Maxwell and Rothera (33) in 1915, who concluded that at least 40 percent of the milk produced by rats was secreted during the nursing act. In a later report in 1923 by Isaachsen (26), it was found that cows producing 5 to 6 kilos per day secreted 2 to 2½ kilos during milking.

Some doubt was cast on the above theory and four groups of investigators working independently furnished convincing evidence that all the milk was present in the udder at milking time. In 1927, Gaines and Sanmann (14) attacked the problem by removing the udder before the usual milking time, grinding it up, and extracting the lactose from the macerated tissue. They were able to recover nearly 20 percent more lactose than could be normally accounted for in the milk. The research of Gowen and Tobey (18), also reported in 1927, was quite similar to that of Gaines and Sanmann, except that it was more extensive. In 1931 Swett (58) attacked the problem in a somewhat different manner. He had the cow to be studied milked at regular intervals and the amount of milk obtained carefully recorded. Then the cow was killed at the exact time she was usually milked and the udder removed as quickly as possible without unnecessary handling. The udder was then suspended in as nearly normal position as possible in a box held at body temperature and the gland milked. Only about 57 percent of the normal amount of milk was secured at the first post-mortem milking. On the other hand, as much as 101 percent was secured by repeated milkings, which indicated that as much milk as was normally secreted was actually stored in the udder at the time she was killed. Petersen et al. (44) using a somewhat similar technique confirmed Swett's results. They milked some of the udders as late as 24 hours after removal and in some instances obtained even more milk than had been produced at the regular milking period.

Since it seems well established that all of the milk is present in the udder at milking time, it is apparent that some physiological process occurs within the udder which releases or "ejects" the milk. Several theories have been advanced in an attempt to explain how milk is "ejected". One of the earliest theories advanced by Hammond (21), was that the milk was forced out of the alveoli by erection. He claimed that the milking stimulus reflexly causes the teat and gland to become engorged with blood. Petersen (38) reasoned that the regression in the size of the udder during the process of milking was evidence against the validity of this theory. In 1942, Espe and Cannon (10) showed by an anatomical study of the teat that erection of the teat walls was not associated with the "ejection" of milk.

That the nervous system is involved in milking has been supported by a number of experiments. As early as 1898, Ribbert (46) transplanted the mammary gland of a rabbit into its ear and found that the transplanted gland, which was free of nervous connections, secreted milk. With this evidence, he concluded that the udder was independent of an extrinsic nerve supply. In 1931, Cannon and Bright (2) sympathectomized cats and reported that the amount of milk secreted greatly diminished. Simeone and Ross (52), also working with sympathectomized cats, confirmed the report of Cannon and Bright. Working with rats in 1935, Ingelbrecht (25) claimed that the "letting-down" of the milk in the mammary gland was dependent upon an intact nerve supply. When he destroyed the nerves to the posterior mammary glands and covered the anterior glands the rats failed to lactate normally and the young soon died.

But when he permitted the young rats to nurse the anterior glands with an intact nerve supply, both the anterior and posterior glands secreted milk and the nursing young grew normally. Five years later, Ely and Petersen (8) cut the inguinal nerve trunk to the left halves of the udders of three dry cows and noted no effect upon udder development or the rate of milk "ejection" from the denervated glands during the subsequent lactation. All of these experiments indicated the involvement of the nervous system in milk "ejection", but, how it was involved was not established.

For many years it has been known that an extract of the posterior lobe of the pituitary gland affects either milk secretion or milk "ejection". In 1910, Ott and Scott (36) discovered that the intravenous injection of an extract of the posterior lobe of the pituitary into a lactating goat caused the contraction of the glands and the discharge of milk. These results were soon confirmed by Schafer and MacKenzie (50) with lactating cats and dogs, with dairy cattle by Gavin (16), and with women by Schafer (49). In 1913, Hammond (20) found that when an extract of the posterior pituitary was injected intravenously after milking 20 percent more milk was obtained than normally. Later, in 1930, Turner and Slaughter (60) reported that the injection of an extract of the posterior pituitary permitted the removal of milk which was otherwise unavailable.

In 1928, Kamm et al. (28) effected a separation of posterior pituitary lobe extract into two fractions, now sold commercially as pitocin and pitressin. Twelve years later, Ely and Petersen (8) injected both pitocin and pitressin into the blood of lactating dairy cows and found that milk could be removed more quickly. They reported further that a smaller quantity of pitocin was required to induce prompt and rapid milk "ejection" than was the case with pitressin. On the basis of these results and their assumption that smooth muscles were present in the alveoli and smaller ductules of the udder, they advanced the hypothesis that milk "ejection" was due to a nerve-endocrine mechanism. They suggested that the sensory endings on the teat and the afferent nerves are the only ones involved in milking response. They reasoned that a stimulation of these nerve endings conceivably caused afferent impulses to reach the central nervous system which, in turn, stimulated the posterior lobe of the pituitary to secrete pitocin into the blood. They believed that the presence of pitocin in the blood stream was largely responsible for the increase in intra-glandular pressure that presumably resulted in "squeezing" the milk from the alveoli and smaller ductules. It is under such a situation that a cow is said to have "let-down" her milk.

In 1932, Houssay (24) reported that the removal of the posterior pituitary of the dog failed to interfere with parturition or the lactation process. Smith (53) confirmed Houssay's results with rats in 1935. These reports caused Gomez (17) to cast doubt upon the nerve-endocrine mechanism theory of milk "ejection". In an experiment with lactating hypophysectomized rats, Gomez (17) reported that such rats could be maintained in lactation by suitable replacement therapy, but the young seemed to be unable to obtain milk present in the gland. Injections of a posterior pituitary extract along with the daily "lactation maintaining" therapy permitted the young to get the milk from the mammary glands. Withdrawal of the posterior pituitary extract at any time during the course of the experiment was immediately followed by a rapid loss of body weight of the young, terminating in death unless the injections were promptly resumed. This report confirms the theory of Ely and Petersen (8) to the extent that an extract of the posterior pituitary is needed for lactation. Swanson and Turner (57), reporting in 1941, were the first to show that smooth muscles were present in the alveoli and smaller ductules of the udder, thus confirming this assumption of Ely and Petersen (8). Recently (1947) Espe (9) helped to confirm the theory that milk "ejection" is due to a nerve-endocrine mechanism by transplanting the mammary tissue of a calf so as to sever all of the original nerve and vascular supply between the body and mammary glands. He found that the udder developed normally during pregnancy with the exception of the right half, which had no sensory nerve supply due to a second incision which apparently destroyed the regenerated nerves. He reported further that the glands with an intact nerve supply were milked more quickly than the glands without an afferent nerve supply.

The development of mechanical milking has aroused interest in the factors affecting the speed of milking. Early investigations showed from 4 to 8 minutes was required for machine milking.

Matthews et al. (32) reported that on the average 6 minutes machine milking was satisfactory for cows producing 12 pounds of milk or more, and that 4 minutes were sufficient for cows giving less than 6 pounds. Two years later, in 1930, M'Candlish and Cochrane (34) reported that the average machine time required per cow varied from 4.8 to 5.4 minutes. Petersen (41) recently reported that many cows were milked in 2 minutes and that the majority of cows were milked in 3½ minutes. Parkin (37) confirmed Petersen's report with over 900 cows milked at fast milking demonstrations in which most of these cows were milked in 3 to 3½ minutes.

Some attempts have been made to measure the actual rates of milk flow throughout the entire milking operation. Matthews et al. (32), M'Candlish and Cochrane (34) and Foot (12) measured the rate of milk flow at various intervals throughout the complete milking act. In each case an accurate spring balance was suspended from overhead so that the milking machine unit could be placed in its normal position at the side of the cow and about 2 or 3 inches clear of the floor. Readings on the dial of the balance were recorded at timed intervals. Whittleston (64) developed a milk-flow-recording apparatus in which a sight glass indicated when the milk flow fell to a predetermined level as shown by the graph in a recorder. By the use of these graphed curves, he was able to study the characteristics of the rates of milk "ejection".

M'Candlish and Cochrane (34) stated that the rate of milking increased with yield, but they also noted the influence of the individuality of the cow on the speed of milking. Matthews et al. (32) found that the rate of milking in individual cows showed wide variations which were associated with yield. Foot (12) found that the maximum rate of flow was reached about 2 minutes after milking commenced, despite a temporary lag about ½ to 1 minute after milking commenced. He showed that the rate of milk flow decreased toward the end of the milking and that this decrease was more rapid with high yielding cows. He further reported that the rate of flow was more rapid with high yields than with low yields. In addition, he found that each cow had a characteristic "rate of milking" curve, which, under normal conditions, did not vary greatly from day to day. Whittleston (66) studied the characteristics of milk "ejection" curves and was the first to show that the rate of flow tended to decrease toward the end of the lactation. He found also that there was a tendency for a greater delay in the starting time and that the starting time became erratic towards the end of the lactation.

Dairymen have long been aware of the fact that cows respond more completely to the milking act when milked in a quiet environment. Almost a century ago, Guenon (19) suggested that dairymen abstain from gossiping during milking. It is an observation of dairymen that disturbances, such as the presence of strangers at milking time, interfere with the rate of milk flow from cows. Although the effect of fright could have been discussed in connection with the role of the nervous system in milk "ejection", it was considered more appropriate to reserve its discussion until the factors affecting the rate of milk flow were reviewed. Ely and Petersen (8) showed that fright inhibited the response of cows to the milking stimulus. Strong excitation caused by sticking the cow with needles, placing a cat on her back, exploding inflated paper bags, or placing a cage of rats before her resulted in complete inhibition of milk "let-down". They explained this inhibition on the basis that in times of emotional stress adrenalin is ejected into the blood and that it causes a special response of the musculature served by the sympathetic nerves. To verify these results, they injected intrajugularly as much as 4 cc. of adrenalin, several times, and demonstrated that inhibition of milk "let-down" caused by fright was due to the presence of adrenalin in the blood.

Only a few investigators have studied the effects of the mechanical features of milking machines on the rate of milk flow. Smith and Petersen (54) studied the rates of milk withdrawal at 10, 12, 14 and 16 inches Hg negative pressures and for 1:1, 2:1, and 3:1 pulsation ratios. With every increase in negative pressure they noted an increased rate of milk withdrawal, but the rates of increase varied with different levels of negative pressure and with the individuality of cows. They explained these variations on the basis that negative force affected the speed of milk withdrawal in two ways. One was upon the size of the opening of the teat meatus, and the other was upon the rate of flow through the meatus. In addition, they found that widening the pulsation ratio increased the rate of milk withdrawal but not in proportion to the increased time of vacuum application. Whittleston (65), in a study of pulsator action as a stimulus to machine milking, found that the presence of enough pulsator action to avoid discomfort to the cow would ensure the "let-down" of milk. On the other hand, he reported that the absence of pulsator action caused severe discomfort to the cow which interfered with milk "let-down". He reported further that once the milk flow had started with the pulsator operating that cows would continue to milk if the pulsator was stopped. Upon these results, he regarded the pulsator as a relatively unimportant factor in milking machine efficiency.

There appears to be universal agreement among both manufacturers of milking machines and dairymen that fast milking is desirable. Dahlberg (5), working at the New York State Station, was the first to advocate fast mechanical milking. In general, the proponents (13), (70), (37) of fast mechanical milking agree with the system outlined by Petersen (39). The essential features of this system are: (a) massaging the teats and udder vigorously for several seconds with a cloth wrung out of warm water, (b) attaching the machine about one minute later, (c) machine stripping as soon as there is evidence of the teat cups crawling upward, and (d) removal of the machine when the milk apparently ceases to flow freely.

A number of advantages have been cited in favor of fast milking. Petersen (43) has demonstrated that the effectiveness of the pituitary factor causing milk "ejection" decreases rapidly after stimulation. He reported experimental evidence which showed that the pituitary factor causing milk "ejection" began to be destroyed as soon as it was secreted into the blood. Petersen (41) milked out each quarter completely in succession and found a progressive drop in the amount of milk obtained because the time increased with each successive quarter following preparation for milking. When the milking was finished, the "let-down" hormone was injected and the milk left in each quarter removed. The second quarter milked had 7 per cent of the milk left, the third quarter had 15 per cent of the milk left, and the last quarter milked still had about 30 per cent of the milk left. On this type of experiments, he concluded that not more than seven minutes could be taken from the time the cow was prepared for milking until the milking was completed if all the milk was to be gotten. Dahlberg (5) reported that operation of milking machines on a definite schedule of 4 to 4½ minutes per cow for five years resulted in the maintenance of monthly butterfat production throughout the lactation better than when milking by machine for longer periods. A number of writers on this subject are of the opinion that fast milking maintains milk production at a higher level than does slow milking (13), (37), (22), and (70).

Some investigators have claimed that fast milking is less harmful to the udder. Little (31) and Johnston (27) found that a slight vacuum developed at the external opening of the teat when the pressure of milking was released. On the other hand, Espe and Cannon (10) obtained no indication that a vacuum developed at the external orifice of the teat when the pressure of milking was released. They cautioned that the milking machines should not be left on cows too long as an eroded orifice offered greater opportunity for mastitic infections. Petersen (42) studied the forces exerted in both hand and machine milking. In machine milking, he found that when the milk ceased flowing, a force extended into the teat producing a vacuum identical to that in the milk line. Then, and only then, was the machine milking process harmful to the delicate tissues lining the teat. He further reported that good hand milkers applied a greater force to the teat with each squeeze than did the milking machine at ordinary recommended vacuums.

Besides reducing the labor required in milking, Fountaine (13) reasoned that fast milking makes possible the production of cleaner milk. His explanation was that washing the udder reduced the dirt that fell into the milk, that the use of the strip cup aided in reducing the bacteria count, and that the reduction of hand stripping helped to keep sediment out of the milk.

Much emphasis has been placed on training cows to fast milking. Petersen (39) and Hopson and Lovelace (23) have stated that cows must like to be milked. Petersen (39) cautioned that when a first-calf heifer is first milked that care should be exercised to see that she does not associate milking with something unpleasant. He pointed out that it was a good practice to gently massage the udder and teats of heifers prior to calving so they might become accustomed to the milking act. He continued that before milking actually begins the udder should be massaged to effect a "let-down" of milk; that milking should be rapid and hand stripping avoided, even if all the milk is not obtained. Finally, he warned that if the first-calf heifer is to be machine milked she should be started out by machine milking. Smith and Werner (55) have suggested essentially the same procedures as Petersen for training first-calf heifers to fast milking. They further advised that the best time to train cows already in milk was at the beginning of the next lactation, providing such cows did not readily adapt themselves to fast milking practices. These investigators, (39) and (55), associated "stripper" cows with slow milking and prolonged stripping, and concluded that all normal cows can be trained to respond quickly and completely to fast milking.

Several problems have arisen in training cows to respond to fast mechanical milking which have not been adequately answered experimentally. No experimental work has been reported showing the effects of various methods of massaging a cow's udder to stimulate milk "ejection". Petersen (41) has recommended a warm water wash (110° F. or warmer) or wiping the teats and lower part of the udder with a wet warm cloth as the method next best to the stimulation caused by the nursing action of the calf. Others (13), (37), (55), and (70) suggested the same procedure of udder massage but advise that the temperature of the water out of which the cloth is wrung should range from 120 to 130° F.

Most of these writers advocating fast milking (13), (37), (40), and (70) recommend a massage of several seconds but only Smith and Werner (55) give a definite length of the massage period. They considered 15 to 20 seconds sufficient. All writers (13), (37), (40), (55) and (70) recommend milking out several streams of milk from each teat with a full-hand squeeze as the final step in preparation of a cow for machine milking.

Another problem which has received some experimental attention but is still controversial is the time that should elapse between preparation of the cow for machine milking and attachment of the teat cups. Petersen (43) found that when cows were prepared 20 minutes prior to milking, total milk production decreased rapidly. In cows that milked 40 pounds or more daily, the drop was 16 per cent in two weeks. On the other hand, Knodt et al. (30) found that time intervals up to 20 minutes between preparation and attachment of the teat cups had no significant effect upon total milk production. Smith and Worner (55), Fountaine (13), Zehner (70) and Parkin (37) were of the opinion that one to two minutes interval between preparation and attachment of the teat cups was the most satisfactory.

It is generally recognized that incomplete removal of the milk from the udder over a period of time causes a decline in lactation. Partial removal of the milk has been used by many as a means of "drying off" cows. Knodt and Petersen (29) believed that while the reason for the effect of incomplete evacuation of the gland was speculative it could best be explained by increased intra-glandular pressures created by the retained milk. Petersen and Rigor (45) and Garrison and Turner (15) showed a decreased rate of milk secretion with increased pressures. Knodt and Petersen (29) found that when the udder was completely evacuated of milk by the use of pitocin, total milk production tended to increase. The effect of leaving small amounts of milk in the udder has been studied by Woodward et al. (69), Wilson and Cannon (68) and others (48), (61), (62), (63). Woodward et al. (69) compared the effects of one or more normal lactations when milking machines were used and the cows stripped after milking, with a lactation when the cows were not stripped after machine milking. They concluded that incomplete milking did not affect the percentage of fat, the normality of the milk, the persistency of lactation, nor the health of the cow.

The effects of incomplete removal of milk from the udder have directed attention to whether or not stripping should be by hand, machine or both. Petersen (41), (39) has emphatically recommended machine stripping only. He (41) stated, "Do not hand strip after removing the machine." Smith and Werner (55) asserted that cows can be milked as completely by machine stripping as by hand stripping. Others, (13), (37), and (70), likewise, concurred. The general method recommended for machine stripping was reviewed by Petersen (42). He stated that when the teat cups begin to crawl upward that a slight pressure should be placed on the claw which pulled the teat cups downward resulting in removal of the milk whose passageway had become blocked. Woodward et al. (69) found that an average of 39 seconds per cow was required for machine stripping and that machine stripping yielded a net return of 59 pounds of milk per hour of time spent. Wilson and Cannon (68) found that machine stripping reduced from 33 to 55 percent the amount of milk secured as hand strippings.

Reference should be made concerning work done in the past with the effects of hand stripping versus no hand stripping in relation to mastitis. Munchen et al. (35) studied the practice of hand stripping versus no hand stripping in cows artificially infected with streptococci. According to them, the clinical symptoms became more intense in animals not hand stripped after machine milking. In every case studied, Schalm and Mead (51) found streptococci infected quarters were aggravated when hand stripping was not practiced. However, Woodward et al. (69) experimenting with 15 cows, 11 of which were infected with streptococcus agalactiae, failed to find that discontinuance of hand stripping aggravated the infection.

In the days of the family cow or herds of 2 to 3 animals the problem of milking was not so great, but today when dairying is a giant industry the question of labor is of extreme economic importance. Although milking machines may not have been used most efficiently, all studies have shown them to be great labor savers by milking more cows in a shorter time with less labor. As early as 1928, Matthews et al. (32) showed that the use of a milking machine reduced the time required for hand milking by 52 percent. According to Brodell and Cooper (1), 2 1/3 hours were saved daily by the average user of machines. Cuffe (4) stated that the labor saving qualities of milking machines alone were ample justification for their use. He reported that one operator handling a two-unit milking machine milked 20 cows per hour, which was 2½ times the rate of an average hand milker. Dawson and Underwood (6) reported that machine milking reduced the time from 1/3 to 1/2 that required for hand milking. The question arises as to the minimum number of cows that will justify the use of a milking machine. In the literature reviewed, only the DeLaval Company (7) suggested that herds of 10 or more cows were usually considered large enough to justify the use of a milking machine.

The problem of how many cows should be milked per hour per unit has received some attention. Stere (56) and Smith and Werner (55) stated that 15 to 17 cows should be milked per hour per unit. Dawson and Underwood (6), however, are convinced that the maximum number per hour per unit is 10 cows. Dahlberg (5), Zehner (70), Carter (3) and Williams (67) have reported significant decreases in the time required for mechanical milking by the adoption of certain management practices. Their reports indicate that the management practices being followed would influence the maximum number of cows milked hourly per unit.

Experimental evidence was not found in the literature dealing with the ideal crew system for the most efficient utilization of labor in machine milking. Several recommendations are made (6), (43), (56) and (70) as to the number of units one man can operate. Carter (3) presented figures showing that the average distance traveled per cow in doing daily dairy barn chores was 2,803 feet.

Recent research in the physiology of milk secretion with particular emphasis upon how milk is "ejected" from the alveoli of the udder has revolutionized the thinking and practice of both milking machine manufacturers and dairymen. Application of the knowledge gained during the last decade has been largely through a program of fast milking. Many problems have arisen as a result of changing to the fast milking program. From the review of literature, it is apparent that the recognition and attack of these problems has scarcely begun. As the result of a survey and field observations, it is also evident that practical application of the fast milking program has been complicated by wide divergence of recommendations with respect to the practices that tend toward maximum utilization of the fast milking principles. Therefore, since research has been scanty and divergence of recommendations is common, it seemed desirable to develop a method of measuring the rate of milk flow from cows which could be used to study the differences in and between cows in their response to different methods of stimulating the "let-down" of milk and to ascertain how labor should be organized for most efficient machine milking.

DEVELOPMENT OF TECHNIQUE TO MEASURE THE RATE OF MILK FLOW

In order to study the differences in and between cows in their response to different methods of stimulating the "let-down" of milk, it was necessary to develop a method of graphically measuring the rate of milk flow continuously during the entire milking operation.

The apparatus adapted for this purpose was a Phipps and Bird continuous feed kymograph. The kymograph was mounted on a cart so that the mounting was on approximately the same level with the cow's back. On extension coil spring (see A in Plate I) with a stretch coefficient of 5.5 pounds per inch of elongation and an elastic limit of 10 inches was especially made by the American Spring and Wire Specialty Company of Chicago, Illinois. This spring had a hook at either end and was suspended from the cart in such a manner that the milker unit would hang freely about six to eight inches clear of the floor and in normal position at the side of the cow. A small copper wire (see C in Plate I), passing over a pulley (see B in Plate I), connected the extension coil spring to a recording assembly (see D in Plate I). The recording assembly consisted of an adjustable, removable capillary pen[1] attached to a movable bar which was horizontally parallel to the kymograph. As the amount of milk drawn from the cow accumulated, increasing force was exerted on the spring causing it to stretch. This stretch was transposed to the kymograph paper by means of the recording assembly.

[1] Capillary pen was obtained from Republic Flow Meter Company of Chicago, Illinois. Pen number 134.

EXPLANATION OF PLATE I

Photograph of the apparatus adapted to measure the rate of milk flow.

A - Extension coil spring.

B - Ball-bearing pulley.

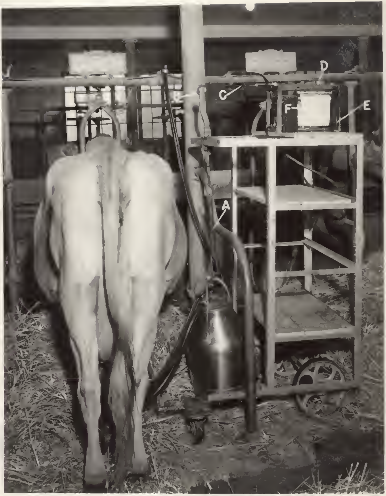
C - Copper wire connecting spring and recording assembly.

D - Recording assembly.

E - Counterweight arrangement.

F - Phipps and Bird continuous feed kymograph.

PLATE I



Simultaneously, the kymograph paper rotated counter-clockwise at the rate of 2.12 centimeters per minute. This produced a graphic record of the amount of milk per unit of time. After the milker unit was detached from the spring, a counter-weight arrangement (see E in Plate I) assured return of the recording assembly to its original position, hence, giving a definite base line for each measurement.

Since the graphic record was made on paper devoid of a scale, it was necessary to devise a transparent scale that could be placed over the graphic records, thus, facilitating direct reading of the accumulated milk at any position along the curve. For this purpose, a piece of celluloid was marked with seconds on the horizontal axis and pounds on the vertical axis.

After having developed this method of measuring the rate of milk flow, the next step was to determine the repeatability of measurements and the uniformity of the response of cows that were treated the same from day to day and week to week. A group of eight cows that was representative of the college herd was chosen and graphic records taken of their milk flow. All cows were prepared for milking exactly the same way. Three graphic records of each cow were taken weekly over a four weeks period. A study of these graphic records showed that the apparatus used to measure the rate of milk flow was highly repeatable and that the response of cows to the same treatment from day to day and week to week was sufficiently uniform to permit use of this technique in future studies.

EXPERIMENTAL PROCEDURES

Survey of Recommended Milking Machine Practices

From general field observations and conversations with representatives of milking machine companies, it was believed that wide divergence of recommendations, as to the methods of stimulating cows to effect a "let-down" of milk, as to the method and length of machine milking and as to the advisability of hand stripping, existed. Letter inquiry (see Form 1) was sent to 26 milking machine companies. From the replies received, it was apparent that wide divergence of recommendations existed with respect to methods of stimulating cows to effect milk "let-down".

Different Methods of Stimulating Cows to Effect a "Let-Down" of Milk

Preliminary Investigation. The first trial was designed to study the graphic milk flow records of cows stimulated by the method commonly practiced in the college herd as contrasted with the graphic milk flow records of those same cows when they were milked without any stimulation. The existing method of stimulation required 30 seconds per cow, 20 seconds being spent in massaging the floor of the udder and teats with a cloth wrung out of water at 100° F. or warmer and the remaining 10 seconds being used for foremilking. Sixty seconds lapsed between cessation of stimulation and attachment of the teat cups. A group of 16 cows, four each of the Ayrshire, Guernsey, Holstein and Jersey breeds, was chosen which was representative of the college herd (70-80 head) with

Form 1. Letter inquiry sent to milking machine companies dealing with recommended machine milking practices.

Recommendations of ________________ (Company)

For ________________________________
(Type of Unit)

A. Preparation for milking

1. Udder massage

(a) Method ________________________________

____

(b) Temperature of water________________________________

(c) Length of massage (seconds) ________________

2. Foremilking

(a) Type of hand milking (full hand or thumb and index finger or etc. ________________________________

____

(b) Number of streams of milk from each teat ________

B. Machine milking

1. Length of interval (seconds) between preparation (massage and foremilk) and teat cup attachment ________________

2. Length of time (seconds) that teat cups should be left on cow ________________________________

3. Machine stripping

(a) Length of time (seconds) ________________

(b) Method recommended ________________

____

C. Advisability of hand stripping ________________

____

____

respect to health, yield, age, stage of lactation, size and disposition and temperament. For six consecutive evening milkings, three consecutive evening milkings when the cows were stimulated according to existing practice and three consecutive evening milkings when the cows were milked without any stimulation, graphic records of the milk flow were taken on all 16 cows.

Combinations of Water Temperature, Stimulation Periods and Waiting Periods. Next a trial was designed to study the importance of water temperature when massaging a cow's udder, the time spent in massaging the udder and the lapse of time between stimulation of a cow and the attachment of teat cups. For this trial, a group of 18 cows representing four breeds (six Ayrshire, five Guernsey, five Holstein and two Jersey) was chosen. Cows that yielded six pounds or more of milk during the first minute of milking were rated as fast milkers, while cows yielding less than six pounds during the first minute of milking were rated as slow milkers. On this basis the cows were paired into nine groups with a fast and slow milking cow in each group. Also, these cows were classified as being in the first or last halves of their lactation periods.

Nine pre-milking treatments were derived as follows:

A. 60 seconds stimulation (50 seconds udder massage with a cloth wrung from 60° F. water and 10 seconds foremilking) and an eight minute waiting period before attaching the machine.

B. 10 seconds stimulation (five seconds udder massage with a cloth wrung from 135° F. water and five seconds foremilking) and an eight minute waiting period before attaching the machine.

C. 10 seconds stimulation (five seconds udder massage with a cloth wrung from 135° F. water and five seconds foremilking) and immediate application of the machine.

D. 60 seconds stimulation (50 seconds udder massage with a cloth wrung from 135° F. water and 10 seconds foremilking) and an eight minute waiting period before attaching the machine.

E. 60 seconds stimulation (50 seconds udder massage with a cloth wrung from 60° F. water and 10 seconds foremilking) and immediate application of the machine.

F. 10 seconds stimulation (five seconds udder massage with a cloth wrung from 60° F. water and five seconds foremilking) and an eight minute waiting period before attaching the machine.

G. 60 seconds stimulation (50 seconds udder massage with a cloth wrung from 135° F. water and 10 seconds foremilking) and immediate application of the machine.

H. 10 seconds stimulation (five seconds udder massage with a cloth wrung from 60° F. water and five seconds foremilking) and immediate application of the machine.

I. 30 seconds stimulation (20 seconds udder massage with a cloth wrung from 100° F. water and 10 seconds foremilking) and a two minute waiting period before attaching the machine. This treatment will be referred to as the standard treatment.

Preliminary trials had indicated that a two-day test period for each cow-treatment combination would be sufficient. Hence, the rotation of the cow groups from one treatment to another was based on two-day periods. The precise manner of rotating the groups of cows (one fast and one slow milker) was determined by means of a 9 x 9 latin square (11) as follows:

Cow Groups

Treatments

A	B	C	D	E	F	G	H	I
B	C	E	G	D	I	F	A	H
C	D	F	A	H	G	I	E	B
D	H	A	B	F	E	C	I	G
E	G	B	I	C	H	D	F	A
F	I	H	E	B	D	A	G	C
G	F	I	C	A	B	H	D	E
H	E	G	F	I	A	B	C	D
I	A	D	H	G	C	E	B	F

The time spent both in stimulation and wait was accurately controlled with a stop watch and the temperature of the water was controlled by the use of a floating thermometer.

Massive Doses of Pitocin

Since some investigators (38) and (66) believed that the failure of cows to respond to stimulation was due to a lack of pitocin in the blood, massive doses of pitocin were injected intravenously into small groups of cows over a short period of time. Graphic milk flow records had been made earlier of these same groups of cows when milked one minute after a 30 seconds stimulation period. The purpose of this study was to see if massive doses of pitocin would speed up the rate of milk flow from slow milking cows. Six cows, three rated as fast milkers and three rated as slow milkers, were the subjects of this study; so three groups of cows were formed each with a fast and a slow milker in it. The rotation of these groups of cows from one dosage level to another was based on both the morning and evening milkings. The exact manner of rotating the groups of cows was determined by means of a 3 x 3 latin square (11) as follows:

Cow Groups

Dosages			
	A	B	C
	B	C	A
	C	A	B

The three dosage levels were: 10, 20, and 30 International Units of pitocin. One minute following intravenous injections of pitocin, the machine was attached to the cow's udder and graphic records made of the milk flow.

Organization of Labor

Time in Motion on Untimed Milking Program. The organization of labor is important in any system of milking and interest in labor organization has become renewed in attempts to organize labor in the fast milking system. The second primary phase of this investigation was to study the following: the variations of the time in motion in and between operators practicing untimed milking, the effects on time in motion of eliminating hand stripping as a task of operators practicing untimed milking, the effects upon time in motion of stall cocks at alternate and all stanchions, the chore capacity of an operator operating 1, 2, and 3 units when following timed milking, the chore capacity of a milk carrier on a timed milking system when he disposed of the milk obtained by an operator operating two and three units and the time spent and distances traveled by jobs of a milk carrier working on different crew systems of timed milking.

Representatives of milking machine companies have criticized severely an untimed system of milking. They claim that the variations in the length of time cows are machine milked from day to day are extremely large on untimed milking. Records of two operators were taken for the purpose of determining the extent of variations in and between operators. These records included the following: the time spent in stimulation for effecting a "let-down" of milk, the time that lapsed between stimulation and attachment of the units, the time the units remained on the cows, the time required to transfer the units from one cow to another, the time spent in hand stripping and the amount of hand strippings obtained. During the time these records were taken, a three-man crew did the milking. This crew consisted of two men operating two units each on opposite sides of the 70 cow-stanchion barn and each doing his own hand stripping and of one man carrying, weighing and recording the milk obtained. Stall cocks were at alternate stanchions and additional milker pails were supplied for each operator so that the milker assembly could be transferred directly to an empty pail.

Next, one operator, designated Operator 2, was given a three-day training period. After this training period, records were taken of the time spent in motion by various jobs of both operators when hand stripping was eliminated as one of their jobs on an untimed milking system.

Finally, on an untimed milking system, stall cocks were provided at each stanchion to determine the effects on the time spent in motion in various milking jobs. After two days experience with stall cocks at each stanchion, records were taken on Operator 1 of the time spent in motion in various milking jobs.

<u>Time in Motion of Different Crew Combinations on a Timed Milking Program</u>. The system of milking was changed from untimed to timed milking. Operator 2 was relieved of his duties, thus leaving a two-man crew. One man operated two units and the other man cared for the milk in addition to hand stripping those cows that required it. A representative of the company manufacturing the milking machine units being used was in charge of training the operator to the fast milking program advocated by the company

he represented. The operator was trained during seven consecutive milkings. The temperature of the water from which cloths were wrung for massaging the udder was kept at 100° F. or warmer. The massage period which included foremilking was held at a minimum of 15 seconds and a maximum of 30 seconds per cow. The lapse of time between massage and attachment of the units was approximately one minute. The method of massage of the udder and the method of machine stripping were demonstrated by the representative. Three-minute egg-timers were attached to the milking cart and were turned 180 degrees immediately after application of the machines. About 15 to 30 seconds before all the sand had run through the egg-timer, the operator began machine stripping.

After changing to a timed milking system, deviations were made from time to time in order to study different crew systems. The crew systems studied were: one man operating one unit and doing as many chores as possible, a two-man crew with one man operating two units and one man caring for the milk, and a two-man crew with one man operating three units and one man disposing of the milk. Records were taken of the time spent in the milking chores by both the operator and milk carrier when working on the above crew systems.

EXPERIMENTAL RESULTS

Repeatability of Graphic Milk Flow Records

Before making comparisons in and between cows, it was necessary to determine the reliability of the graphic milk flow records.

A total of 96 graphic milk flow records involving eight cows over a period of four weeks showed that the milk flow records of the same cow were essentially the same at different milkings. Each cow had a characteristic milk flow record which did not vary greatly from day to day nor from week to week. The rates of milk flow for the same cow agreed remarkably during the first 1½ to 2 minutes of milking. The slight differences that occurred in the same cow after two minutes of milking can be accounted for in fluctuations of yield. The total milking time (ranged from 2½ to 4 minutes) did not fluctuate more than 12 percent for any of the 8 cows during the 4 weeks period. The maximum rate of milk flow for each cow was reached in approximately the same length of time during each milking. In Figure 1 are presented the graphic milk flow records of 16 milkings from four cows taken at weekly intervals. These cows which are typical of the group were selected in order to show graphic milk flow records of cows in different levels of production.

Methods of Stimulating Cows to Effect a "Let-Down" of Milk

Survey of Recommended Machine Milking Practices. In Table 1 a summary is presented of the replies received from 12 manufacturers of milking machines to a letter inquiry dealing with recommended machine milking practices. All of the companies replying except one recommended massage of the udder and teats prior to machine milking. The Sunshine Milker Company stated that udder massage was a habit never to be developed in a cow since it was

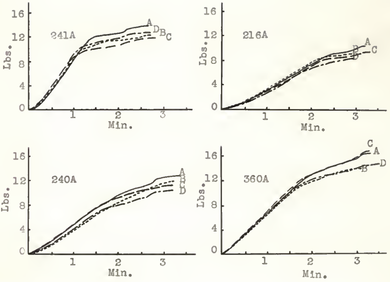


Fig. 1. Graphic milk flow records of 16 milkings from four cows taken at weekly intervals (A is 1st week, B is 2nd week, C is 3rd week and D is 4th week).

time wasted. However, they recommended washing the udder and teats for sanitary reasons. They further advised using water at blood temperature because they claimed that this started up milk secretion. The recommendations for the temperature of the water from which cloths were wrung to massage the udder and teats ranged from 100 to 140° F. The recommendations with respect to the length of the massage period varied from 0 to 60 seconds. The lapse of time recommended between massage of the udder and attachment of the teat cups ranged from 0 to 2 minutes.

Table 1. Summary of replies received from 12 milking machine companies to a letter inquiry dealing with recommended machine milking practices.

Machine or company	Massage water temp. °F.	Seconds of massage	Method of fore-milking	Streams per teat	Seconds of interval	Machine time: Total	Machine time: Strip	Advisability of hand stripping
Marlow	130-140	30	Full hand	2-3	Never over 60	Never over 180	Not over 10	Only during 2 weeks training period
Surge	130	15-30	Full hand	6	Maximum 60-90	180 to 210	Not over 60	Not necessary on normal cows
Chore Boy	130	30	Full hand	1-2	60	180 to 300	30	Not recommended if cows are trained
Universal	120	45	Full hand	4-5	30	180	5	Only to check udder
Ben H. Anderson	125-135	15	Full hand	2	60	Not over 240	10-15	Avoid when possible; never on 1st lactation
Perfection	110 or warmer	20	Full hand	2	60	180 to 210	45	Not recommended
Globe	110-130	--	Full hand	3-4	45-60	180 to 300	15-20	Machine stripping preferred
De Laval	130	30	Full hand	3-4	30-45	180 to 240	15-30	Unnecessary

Table 1 (cont.).

Anderson	100	Varies not over 60	Full hand	2	60-120	Never over 300	Same as hand stripping	Always check udders
International Harvester	130	30-60	Full hand	1 or more	45	180 to 240	10-15	-----
Page	---	---	Depends on operator	3-6	As soon as possible	180-240	30-45	Recommended
Sunshine	Blood temp. only for hygenic reasons	A time wasting habit never to be developed	Thumb and index finger	3	As quickly as possible for 1st 4 months of lactation	Until milk flow ceases in sight glass	30	Not necessary

Preliminary Investigation. A comparison of udder massage prior to milking with no udder massage as measured by the milk flow records and quantity of hand stripping is presented in Table 2. These results show that when cows were milked without udder massage that an average of 1.2 minutes longer per cow were required to obtain an average of 1.4 pounds less milk than when the same cows were milked after the udder had been massaged. Thus, 34 percent more time was required to obtain approximately 10 percent less milk. When cows were milked without udder massage, an average of 0.5 pound more hand strippings was obtained which was 250 percent more than was obtained when the udder was massaged before milking. The rate of milk flow was reduced 33 percent, the average being decreased from 4.0 pounds per minute when the udder was massaged to 2.7 pounds per minute when the udder was not massaged.

A supplementary study was made of selected fast milking and slow milking cows. The fast milking cows (Group A) normally milked in three minutes or less, whereas the slow milking cows (Group B) normally milked in four minutes or more. The average machine yield for Group A when milked without massaging the udder was 5 percent less than when milked after the udder had been massaged, whereas the average machine yield of Group B milked without udder massage was only about 3 percent less than that obtained when milked after the udder had been massaged. Hence, the machine yield of Group A was affected more than that of Group B when both groups were milked without massaging the udder.

Table 2. Comparison of udder massage prior to milking with no udder massage prior to milking as measured by milk flow records and quantity of hand strippings.

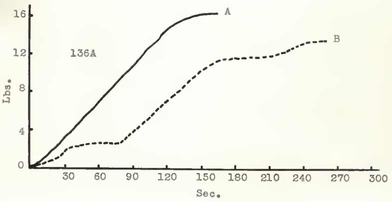
Group	Group identity	No. cows in group	Udder treatment	Av. lbs. machine milk	Av. min. machine milking	Av. lbs. hand stripping	Av. rate milk flow lbs./min.
		16	Massage	14.1	3.5	0.2	4.0
		16	No massage	12.7	4.7	0.7	2.7
Comparison between selected fast milking and slow milking cows							
A	Fast	4	Massage	15.1	2.7	0.3	5.6
		4	No massage	14.2	4.2	0.7	3.4
B	Slow	4	Massage	19.8	4.8	0.3	4.1
		4	No massage	19.2	5.6	1.1	3.4

The average time required to milk Group A when the udder was not massaged was 1.5 minutes greater than when milked after the udder had been massaged. In the case of Group B, the average time for milking without udder massage was only 0.8 minute longer than that required for milking when the udder had been massaged. Thus, Group A required almost 40 percent longer for milking without udder massage than did Group B.

When Group A was milked without massaging the udder, the average quantity of hand strippings obtained was 133 percent greater than that obtained when milked after the udder had been massaged, yet the average quantity of hand strippings obtained from Group B when milked without udder massage was 267 percent more than that obtained when milked after the udders had been massaged. Therefore, the quantity of hand strippings from Group B was twice as great as that of Group A.

The average rate of milk flow per minute for Group A was 5.6 pounds when milked after the udder had been massaged and 3.4 pounds without udder massage, or a decrease of approximately 40 percent. On the other hand, the average rate of milk flow per minute for Group B was 4.1 pounds when milked after the udder had been massaged and 3.4 pounds when the udders were not massaged, or a decrease of 17 percent. Hence, the average rate of milk flow per minute of Group A was roughly 25 percent less than that of Group B when both groups were milked with and without udder massage. The fact that the average rate of milk flow for either Group A or Group B when milked without udder massage was greater than the average rate of milk flow for all 16 cows when milked without udder massage can best be explained by differences in the average yields. These results indicate that the rate of milk flow increases with yield.

The graphic milk flow records of a typical fast milking and of a typical slow milking cow when each was milked with and without udder massage are shown in Fig. 2. Reductions in the rates of milk flow and in the amounts of machine milk are evident when both the fast milking and slow milking cows were milked without massaging the udder. Also, the machine time was greater when both cows were milked without massaging the udder than when the udders were massaged prior to milking.



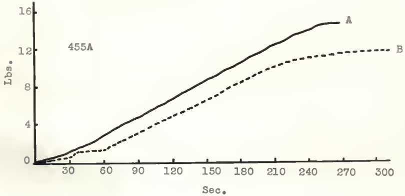


Fig. 2. Graphic milk flow records of a typical fast milking (136A) and a typical slow milking (455A) cow when each was milked with and without udder massage (A is with udder massage and B without udder massage).

Combinations of Water Temperatures, Stimulation Periods and Waiting Periods. The results observed were recorded in terms of rates of milk flow from the udder, total machine milk, length of machine stripping, quantity of machine strippings, total machine time and quantity of hand strippings. In order to have a more detailed picture of the rates of milk flow from the udder, the milking time was broken down into 30 second intervals as follow: 0-30, 30-60, 60-90, 90-120, 120-150, and 150 plus seconds.

The data obtained from each of the above measurements were analyzed by the analysis of variance (11) with particular attention to the following sources of variation: water temperature, stimulation period, waiting period after stimulation, stage of lactation, fast milking cows versus slow milking cows and the several possible interactions involving these factors. Variations due to cows or to two-day periods were removed from the analysis in the usual way (11).

Following the above analysis, tables of means were used which permitted a detailed study of the important sources of variations among the measurements. The t-test technique (11) was employed to estimate the smallest difference between two means which should be considered significant at the 5 percent level. These "significant differences" do not suffer from the defects of the usual "least significant differences" because they are applied to predetermined comparisons of sample means rather than to ordered selections based upon the outcome of the tests.

Water temperatures (60° or 135° F.) out of which cloths were wrung for massaging the udder and teats were found to be insignificant in the response of cows to milking. These results indicate that water temperatures are not an important factor in the physiological response of cows to the milking act.

Comparison of 10 seconds stimulation to 60 seconds stimulation (Table 3) showed that a significantly greater rate of milk flow was obtained the first minute of milking with 60 seconds stimulation. However, after the first minute of milking the rate of milk flow was significantly greater for a 10 seconds stimulation period than for a 60 seconds stimulation period. Although the amount of milk obtained was essentially the same for either a 10 seconds stimulation period or a 60 seconds stimulation period, the machine time was significantly less for a 60 seconds stimulation period than for a 10 seconds stimulation period. These results indicate, even though the average rate of milk flow was slightly faster with a 60 seconds stimulation period than with a 10 seconds stimulation period, that a 10 seconds stimulation period would be more practical than a 60 seconds stimulation period because the machine milking time was only nine seconds faster when the stimulation period was 50 seconds longer.

Comparison of the effects of a zero waiting period with an eight minute waiting period (Table 3) showed that the rates of milk flow for the first 30 seconds of either wait were not significantly different. During the minute of milking between 30 and 90 seconds, the rate of milk flow was significantly greater for a zero wait than for an eight minute wait, whereas, the rate of

Table 3. Comparison of 10 and 60 seconds stimulation periods, zero and eight minute waiting periods and first and last halves of lactation (18 cows).

	Comparisons								
	10 sec. with 60 sec. stimulation			Zero with 8 min. wait			First with second half lact.		
	10 sec.	60 sec.	Significance	0 wait	8 min.	Significance	First	Last	Significance
Rate of milk flow									
0-30 sec.	1.46	1.99	*	1.78	1.67	N.S.	1.70	1.80	N.S.
30-60 sec.	2.19	2.68	*	2.70	2.17	*	2.68	2.24	N.S.
60-90 sec.	2.51	2.37	*	2.82	2.06	*	2.86	2.01	*
90-120 sec.	2.16	1.92	*	2.10	1.99	N.S.	2.42	1.64	*
120-150 sec.	1.66	1.51	*	1.49	1.68	*	1.97	1.16	*
150 plus sec.	3.32	2.88	*	2.79	3.42	*	3.89	2.26	*
Machine milk	13.30	13.34	N.S.	13.66	12.98	*	15.51	11.12	*
Machine time	246.70	237.74	*	232.32	252.12	*	252.78	230.37	*
Sec. machine stripping	47.99	46.44	N.S.	43.51	50.92	*	45.66	48.52	N.S.
Lbs. machine stripping	1.58	1.42	N.S.	1.42	1.59	*	1.33	1.62	*
Lbs. hand stripping	.65	.74	N.S.	.60	.79	*	.78	.70	N.S.

flow after two minutes of milking was significantly greater for an eight minute wait than for a zero wait. For a zero wait, the machine milk was significantly greater, the machine time significantly less, the machine stripping time significantly less, the amount of machine strippings significantly less and the amount of hand strippings significantly less than for an eight minute wait. These results indicate that a zero waiting period is preferable to an eight minute waiting period because a greater yield is obtained in less time.

Comparison of the two stages of lactation (Table 3) shows that during the first minute of milking there were no significant differences in the rates of milk flow between cows in the first half and cows in the second half of lactation, which contradicts the report by Whittleston (66) that the starting time tended to lag and become erratic towards the end of lactation. Other significant differences noted were expected since cows in the first half of lactation produce more milk than cows in the last half of lactation.

During the course of the above experiment, it was noted that some cows were more sensitive to changes in the stimulation and waiting periods than others. Therefore, a supplementary study was made in which the five fastest milking cows and the five slowest milking cows were selected in order to determine which group of cows (fastest or slowest milking) was most sensitive to changes in the stimulation and waiting periods. The five cows that milked in less than 200 seconds were classed as the fastest milking cows and the five cows which required 265 seconds or more for milking were classed as the slowest milking cows. The normal stimulation period (30 seconds) and the normal waiting period (two minutes) was used as the basis for comparison between the responses of both groups of cows to changes in the stimulation and waiting periods.

Comparison of the changes in stimulation and waiting periods to a normal stimulation and waiting period in the responses of five fast milking and five slow milking cows is presented in Table 4. It is interesting to note that there was not a significant difference in any instance of the response of slow milking cows to changes in the stimulation and waiting periods with respect to the normal stimulation and waiting period. In the case of fast milking cows, the machine time was significantly greater than the normal machine time when milked 8 minutes after either a 10 or 60 seconds stimulation period. However, in case of the fast milking cows the machine time was significantly greater than the normal machine time when these cows were milked 8 minutes after either a 10 or 60 seconds stimulation period. Concurrently, the amount of machine milk with respect to normal amount of machine milk was significantly less for the slow milking cows when milked eight minutes after a 60 seconds stimulation period. These results indicate that fast milking cows are more sensitive than slow milking cows to changes in the stimulation and waiting periods.

Table 4. Comparison of changes in stimulation and waiting periods to a normal stimulation and waiting period as measured by the responses of five fast milking and five slow milking cows.

	Cow group	Normal	10 sec. stimulation 0 wait	60 sec. stimulation 0 wait	10 sec. stimulation 8 min. wait	60 sec. stimulation 8 min. wait
Rate of milk flow						
0-30 sec.	Fast	3.27	2.63*	3.45	2.69	2.61
	Slow	1.12	0.93	1.41	0.88	1.02
30-60 sec.	Fast	3.63	3.76	3.95	2.30*	2.69*
	Slow	1.74	1.91	2.01	1.78	1.86
60-90 sec.	Fast	2.72	3.93*	3.15	2.19	1.92*
	Slow	2.03	2.30	2.29	2.03	2.10
90-120 sec.	Fast	1.61	2.03	1.76	1.91	1.36
	Slow	2.01	2.35	2.30	2.14	2.09
120-150 sec.	Fast	0.91	0.82	0.82	1.31*	1.08
	Slow	2.01	2.24	2.23	2.23	2.10
150 plus sec.	Fast	0.84	1.08	0.64	2.11*	1.94*
	Slow	5.80	5.56	5.12	6.13	5.39
Machine stripping time	Fast	44.50	38.50	37.75	50.50	46.25
	Slow	52.50	44.00	44.25	50.75	50.00
Lbs. machine stripping	Fast	1.31	1.35	1.19	1.92	1.68
	Slow	1.49	1.34	1.30	1.38	1.46
Machine time	Fast	183.00	185.75	175.75	224.75*	213.75*
	Slow	283.00	282.00	281.25	300.00	278.00
Machine milk	Fast	12.98	13.87	13.76	12.50	11.59*
	Slow	14.71	15.28	15.35	15.18	14.55
Lbs. of hand strippings	Fast	0.88	0.58	0.33*	0.99	1.29
	Slow	0.87	0.87	1.08	0.90	0.87

* Significant difference with respect to normal.

Massive Doses of Pitocin

Since some investigators (59) and (60) found that pitocin aided in complete evacuation of milk from the udder, massive doses of pitocin were injected intravenously into small groups of cows to determine if the rate of milk flow from slow milking cows could be speeded up. Comparisons of massive doses of pitocin with no pitocin upon the yield, machine time and amount of hand strippings showed that the differences between 10, 20 and 30 International Units[1] of pitocin and no pitocin were extremely small (Table 5). The greatest yield was obtained with 30 I. U. of pitocin, however, more time was required to obtain this yield. The smallest yield was obtained and the least machine time required when the cows were milked after injections of 20 I. U. of pitocin. With the exception of the quantity of hand strippings which was greater, milking without injections of pitocin (30 seconds stimulation period and one minute waiting period) produced results that were intermediate to the results produced by the injections of 10, 20 and 30 I. U. of pitocin. These results indicate that massive doses of pitocin did not speed up the rate of milk flow from slow milking cows.

[1] See 3rd International Conference on the Standardization of Hormones. Geneva. 1938.

Table 5. Effects of injections of pitocin upon yield, machine time and quantity of hand strippings. (5 cows injected at three levels)[1].

Treatment	Av. lbs. of mach. milk	Av. sec. of mach. time	Av. lbs. of hand strippings
10 I. U.[2] pitocin	13.6	230	0.37
20 I. U. pitocin	13.0	219	0.37
30 I. U. pitocin	14.0	242	0.37
No pitocin (30 sec. stimulation, 1 min. wait)	13.4	229	0.53

[1] One cow dropped from this experiment due to mastitis and impaction of the bowels.

[2] See 3rd International Conference on the Standardization of Hormones. Geneva. 1938.

Organization of Labor

Untimed Milking. Analysis of variance of the machine time of 35 cows for five days when milked by the same operator on an untimed system of milking is shown in Table 6. On a total of 175 individual cow milkings, it was found that there were significant variations between cows in the length of time the machine was left on the udder. However, variations between the machine time for days was not significant. It can be said that day to day differences between cows was not consistent as these differences balanced out over the 35 cows. That variations in the machine time existed was evident by the fact that one cow had a range of five minutes between the maximum and minimum lengths of time the machine was left on the udder in a five day period. Another cow which had the least range

Table 6. Analysis of variance of machine time of 35 cows for five days when milked by the same operator without a timing device.

Source of variation	D/F	Sums of squares	Variance	F
Between cows	34	610,086.46	17,943.72	7.24*
Between days	4	10,495.95	2,623.99	1.06 N.S.
Cows by days	136	336,916.45	2,477.33	
Total	174	957,498.86		

of machine time had 30 seconds variation between the maximum and minimum machine times over the same five day period. In general, this indicates that there is wide variation between and in individual cows from day to day with regard to the length of time they are machine milked on an untimed basis.

The time spent in various milking jobs by two operators on untimed milking when hand stripping and not hand stripping is presented in Table 7. The number of cows milked per hour was an average of 7.6 cows greater for Operator 1 than for Operator 2, when both operators hand stripped the cows they milked. When the operators hand stripped, the waiting period (cessation of stimulation to attaching teat cups) was an average of more than three times as long for Operator 2 as for Operator 1. Also, Operator 2 left the machines on the cows an average of almost 1½ minutes longer per cow than did Operator 1. The average time spent in hand stripping by Operator 2 was more than twice that used by Operator 1. The fact that hand stripping required considerably more time by Operator 2 aids in explaining why he milked an average of 7.6 cows less per

Table 7. Time spent in various milking jobs by two operators on untimed milking with and without hand stripping by operator.

	Hand stripping by operator		No hand stripping by operator	
	Operator 1	Operator 2 (before training)	Operator 1	Operator 2 (after training)
	Av. per cow (35 cows)	Av. per cow (36 cows)	Av. per cow (35 cows)	Av. per cow (36 cows)
Milking jobs (sec. per cow)				
Stimulation	13	24	12	34
Waiting	69	236	65	87
Machine time	230	315	238	234
Unit transfer	30	42	31	44
Hand stripping	27	68	--	--
Walking, idle, mach. stripping	60	45	93	61
Hand strippings (lbs.)	0.7	0.6	1.6*	0.9*
Rate of milking				
Sec. per cow	130.0	179.0	136.0	139.0
Cows per hour	27.7	20.1	26.5	26.6

* Hand stripping done by a special employee.

hour than did Operator 1. It is interesting to note that Operator 2 spent an average of 12 seconds per cow longer in transfer of the units from one cow to another than did Operator 1.

Operator 2 was given a special three-day training period before records were taken of the time spent by both operators in various milking jobs when doing no hand stripping. When both operators did no hand stripping, the average time required to transfer the units from one cow to another was slightly more than that required when the operators were hand stripping. The average numbers of cows milked hourly by Operator 1 was not greatly changed from that when he did hand strip. On the other hand, the number of cows milked hourly by Operator 2 was an average of 6.5 cows more when he did not hand strip after being given a special training period than the average number milked before the training period when he hand stripped the cows. The average waiting period and the length of machine time were considerably less for Operator 2 after he was given a special training period and when he did not hand strip than it was before training when he did his own hand stripping. This indicates that either the training or elimination of hand stripping or both resulted in increasing the average number of cows milked hourly by Operator 2, whereas the time spent in the various milking jobs by Operator 1 was not changed to any great extent when he did or did not hand strip the cows he milked.

A study was made to determine the effects upon the time required to transfer the units from one cow to another when stall cocks were at each stanchion rather than at alternate stanchions. It was found that there was no difference in the time required to transfer units from one cow to another when stall cocks were at each stanchion rather than at alternate ones.

Crew Systems on Timed Milking. The results of the job analysis study of an operator when working under different crew systems are shown in Table 8. The basic system was a one-man crew operating one unit when milking 16 cows. In A of this basic system the operator did the following jobs: massaged and foremilked the cows, machine stripped the cows, hand stripped the cows, transferred the units from one cow to another and cared for the milk obtained. B of the basic system was the same as A except the operator fed grain and hosed the cows prior to milking. In the two-man crew system, the operator did the same tasks when using two or three units as in A of the basic system with the exceptions of hand strippings and caring for the milk obtained.

In A and B of the basic system, the machines were left on the cows approximately the same length of time and the rate of milking, which amounted to 16.6 cows per hour, was the same. In A, the operator spent 150.9 seconds per cow in motion and had 64.9 seconds per cow idle time; whereas, in B, 197.6 seconds per cow were spent in motion and only 19.9 seconds per cow was idle time. Concurrent with a decrease of 6.1 seconds per cow spent in machine stripping there was an increase of 0.3 of a pound per cow in hand strippings. In this study, the operator traveled 75 feet per cow in carrying the milk. The time required to carry the milk 35 feet per cow (which approximates average conditions) and dump the milk amounted

Table 8. Job analysis and rate of milking of an operator working under different crew systems.

	One man crew		Two man crew	
	Operates 1 unit A	Operates 1 unit B	One man operates two units	One man operates three units
	Av. per cow	Av. per cow	Av. per cow	Av. per cow
Time in motion (sec. per cow)				
Massage and foremilk	18.3	18.2	17.9	13.0
Machine stripping	25.3	19.2	23.6	12.4
Unit transfer	25.0	25.6	30.0	29.5
Walking	12.0	15.0	15.9	19.2
Hand stripping	33.9	36.4	---	---
Feeding grain	---	15.7	---	---
Hosing cows	---	29.5	---	---
Care of milk[1]	36.4	38.0	---	---
Total time in motion	150.9	197.6	87.4	74.1
Idle (sec.)	64.9	19.9	18.3	3.9
Machine time (sec.)	181.6	180.0	178.0	186.0
Waiting period (sec.)[2]	75.7	52.6	61.3	51.0
Hand strippings (lbs.)	1.1	1.4	2.7	3.2
Rate of milking				
Sec. per cow	206.6	205.6	104.0	71.8
Cows per hour	16.6	16.6	33.7	46.0

1 Care of milk included carrying, weighing, recording, dumping, and returning empty pail to position behind cow.

2 Waiting period was the time between cessation of massage and foremilking and attachment of the teat cups.

to 16.5 seconds per cow as contrasted to 36.4 seconds per cow when the milk was carried 75 feet per cow and weighed before dumping. At no time in either A or B of the basic system was the operator rushed to maintain a timed milking schedule.

In the case of a two-man crew system, the job analysis of the operator is shown in Table 8 and the job analysis of the milk carrier in Table 10. In a two-man crew system with the operator handling two units, the rate of milking was 33.7 cows per hour or approximately double that of the same operator when handling one unit. When this operator handled three units, the rate of milking increased to 46 cows per hour which was approximately three times his milking rate with one unit. The time in motion of this operator with two units averaged 87.4 seconds per cow as compared with 74.1 seconds per cow in motion with three units. The idle time averaged 18.3 seconds per cow with two units, while the same operator was idle only 3.9 seconds per cow when handling three units. When the operator handled two units, the average time spent in massaging and foremilking of the cow was essentially the same as that spent when he handled only one unit. However, when handling three units the average length of time spent in massaging and foremilking and in machine stripping was considerably less than that spent when handling either one or two units. The amounts of hand stripping obtained under a two-man crew when the operator handled either two or three units were not comparable to those obtained under a one man crew because a different man did the hand stripping.

In a two-man crew, with the operator handling three units for three consecutive days, the operator showed signs of physical strain and objected to continuing with three units if he had to follow a timed milking schedule.

To summarize the results of the crew system study, it is evident that many crew systems are possible which were not subjected to test. It was found that the formula

$$\text{Rate of milking in seconds per cow} = \frac{\text{machine time} + \text{transfer time}}{\text{number of units}}$$

could be used to determine the time available for jobs that could be performed by the operator in any crew system. The time that can be spent in various jobs of the milking operation can not exceed the rate of milking expressed in seconds per cow. For example, let the average machine time per cow be 215 seconds, the time of transferring the units be 35 seconds per cow and the number of units handled be two. Substituting in the formula

$$\frac{215 + 35}{2} = \text{rate of milking in seconds per cow}$$

the rate of milking becomes 125 seconds per cow. In other words, every 125 seconds a cow is completely milked. The total time spent in the various jobs of the milking operation can never exceed the milking rate, which was 125 seconds per cow in this example. If the number of cows milked per hour is known, the number of units used and the average time required to transfer the units, it is possible to solve for the rate of milking in seconds per cow and the average machine time in seconds per cow. Slight differences may occur but can be explained by the fact that the

Table 9. Comparison of the milking rates of different operators and of the same operator when handling different numbers of units.[1]

	Operators[2]		No. units handled		
	1	2	1	2	3
Av. mach. time (sec.)	230	315	182	178	186
Av. transfer time (sec.)	30	42	25	30	30
Rate of milking (sec. per cow)	130	180	207	104	72
Rate of milking (cows per hr.)	28	20	17	34	46

[1] Numbers rounded to nearest whole number.
[2] Both operators 1 and 2 handled two units each.

starting of milking and the close of milking are not considered from the same points by some people.

From Table 9, it is evident that there are differences in the milking rates of operators due partly to the speed with which they transfer units. Also, the rate of milking increases almost proportionately as the number of units handled increases.

Job analysis of time in motion and distances traveled by a milk carrier working on different crew systems is shown in Table 10. The term "cared for the milk" is used herein to mean carrying, weighing, recording, dumping and returning to position behind the cow the empty pail. When the milk carrier "cared for the milk" obtained by one operator using either two or three units, the average distance traveled was 120 feet per cow. When two operators handled two units each on opposite sides of the barn the average distance traveled per cow by the milk carrier was 24.8 feet more than that traveled when caring for the milk of only one operator that handled either two or three units all the way around the barn. The time required by the milk carrier to "care for the milk" obtained by one operator handling two units was 107 seconds per cow, 78 seconds per cow when one operator used three units and 68 seconds per cow when two operators handled two units each on opposite sides of the barn. Also, the average idle time per cow increased as the number of units operated increased.

Table 10. Job analysis of time in motion and distances traveled by the milk carrier under different crew systems (70 cows).

Jobs	Crews: 2 men with 2 units		2 men with 3 units		3 men with 4 units	
	Av. sec. per cow	Av. ft. per cow	Av. sec. per cow	Av. ft. per cow	Av. sec. per cow	Av. ft per co
Carrying milk	30.0	106.0	30.0	106.0	36.0	130.8
Dumping milk	6.0	9.0	6.0	9.0	6.0	9.0
Weigh and record milk	9.0	5.0	9.0	5.0	9.0	5.0
Idle	62.0	--	33.0	--	17.0	--
Total	107.0	120.0	78.0	120.0	68.0	144.8

Hand stripping was attempted by the milk carrier on a two-man crew handling two units but was found to be impractical because some cows requiring excessive time for hand stripping disrupted the milking routines. With a two-man crew handling two units in which the milk carrier had 62 seconds idle time per cow, it was found that he could feed grain in 7 seconds per cow, that he could feed silage in

14 seconds per cow and that he could hose the cows prior to milking in 13 seconds per cow. However, the milk carrier was rushed when performing these jobs in addition to "caring for the milk."

DISCUSSION

Adaptation of a continuous feed kymograph for use with a standard make milking machine made it possible to obtain reliable milk flow records of the response of individual cows to the milking process. By the use of such apparatus, it was possible to study differences in the responses to the milking operation by different cows and to measure the effects of differences in the preparatory period previous to milking as affected by milking response.

The experiments reported in this thesis might be considered under two general groups: first, variations in methods of preparing cows for machine milking and the differences in the responses of cows to the milking process resulting therefrom; and second, adaptation of the first group in an effort to integrate the problem of efficiency factors in milking into an efficient crew combination, in other words, fitting the facts into every day application in the dairy barn.

In the first group were included such factors as massage versus no massage of the udder, the length of the massage period, the temperature of the water from which cloths were wrung for massaging the udder, the waiting period between completion of massage and starting of the milking process and so forth. Results obtained indicate that cows which are properly massaged respond more completely to the milking process by a more immediate and faster release of milk from the udder, more complete milking with smaller quantities of strippings, less time involved in the milking process and more total milk.

Only two different massage times were used in this study, namely, 10 and 60 seconds. Results showed that the rate of milk flow was significantly faster when 60 seconds massage was used but not enough so as to make this of practical importance since the extreme of 10 seconds is so small that it can hardly be considered under practical operations.

Temperature of the water from which cloths were wrung for massaging the udder did not have any measurable effect upon the responses of cows to the milking process which is in contradiction to recommended practices of commercial companies and of many research workers.

The time interval or waiting period between the completion of the massage of the udder and the beginning of the milking process was studied only from a standpoint of two rather extreme times: no wait and eight minutes wait. The results show that an eight minute wait gave much less satisfactory results than no wait, indicating that the hormone responsible for the "let-down" of milk had been dissipated after an eight minute period. Just how long this hormone is effective and measurable by response to the milking process after completion of the massage is yet to be determined, and experiments are underway to study several intervals between the two extremes of no wait and an eight minute wait. Injections of pitocin, which stimulate the "let-down" of milk, were used as a check against these results to determine when complete response from massage was reached. The practical significance of these results is that good dairy practice demands that the udder be washed previous to milking for sanitary reasons. It would seem that these results tend to emphasize that the udder should be washed carefully and completely and that good practice from a sanitary standpoint and a standpoint of proper preparation of the cow for milking would go hand in hand, with one exception; that is, that the system often practiced of currying and washing all cows as organized barn work before any of the milking routines are started is outlawed by the experimental results obtained in this paper. It is quite evident that the udder washing process must be integrated as a part of the milking operation.

The results obtained from fast milking cows and slow milking cows when prepared for milking in the same manner show definitely that this factor of fast or slow milking cows must be considered by a dairyman in organizing his order of milking and general crew arrangement. Thus, the preparation of the cow has an important effect on the efficiency of the milking process but it can not be accepted as a blanket recommendation without some adaptation to individual herds based on the number of fast or slow milking cows, because the fast milking cows are much more sensitive to changes and are more responsive to the stimulating factors affecting rapid and complete milking. It seems that a dairyman will be faced with the problem of arranging his milking order so that the fast cows will be grouped together in the milking order.

All of this preparation of the cow and the variations in the response of cows to different methods and variations in response of individual cows, depending on whether they are fast or slow milking cows, leads to the second phase of the experiment which involved organization of crews in such a manner that the efficiency of the milking operation can be optimum.

Based on "time in motion" studies, it was apparent that the job routines of any milking machine operator are dependent entirely on the length of time the machines are left on the cows. When one man handles one unit the rate of milking in seconds per cow is equivalent to the sums of the machine time and the transfer time per cow; thus, the rate of milking decreases by 1/2 when two units are handled and so on. The formula

$$\text{Rate of milking (Sec. per cow)} = \frac{\text{Mach. time(sec)} + \text{transfer time(sec)}}{\text{number units handled}}$$

can be used to determine the rate of milking for any number of units, and to calculate the time available to the operator for various jobs of milking under any crew system.

Some milking machine practices being recommended appear to be impossible on a fast milking system. It would be impossible for one man to handle three units on a fast milking program and spend the time recommended for preparation of the cow and machine stripping. In this experiment, it was found that one operator handled three units with an average milking rate of 74.1 seconds per cow, however, he was spending only about 1/4 to 1/3 the times recommended for massaging the udder and for machine stripping.

The milking rate would be 71.6 seconds per cow since the transfer time is relatively constant and was found to average 35 seconds. Thus, it is evident that one man can not handle three units, spend the times recommended in preparing and machine stripping and maintain a three minute milking schedule. Many other recommendations are challenged and can be tested as above.

This study has shown that the jobs that can be done by the operator are limited and that the time available for various jobs of milking can be calculated. The problem that arises now is to determine the optimum time that should be spent in various jobs of milking so that these optimum times could be synchronized with the time and labor available during the entire milking operation into efficient crews. Then, and only then, can the question of the most efficient crew be answered.

SUMMARY AND CONCLUSIONS

Studies were made of differences in the response of dairy cows to the milking process as affected by several different factors. Cows in the college herd (70-80 head) involving Jersey, Guernsey, Ayrshire and Holstein breeds were used in varying sized groups and for varying periods of time in the experimental trials. The method of measuring the results was the milk flow from the udder as recorded graphically by a continuous feed kymograph especially adapted for use with milking machines. The following conclusions seem justified.

1. Graphic milk flow records proved reliable for measuring the responses of cows to different practices preparatory to and during machine milking as shown by the fact that each cow had a characteristic "rate of milking" which did not vary greatly from day to day nor from week to week.

2. Optimum machine milking practices are not yet determined as shown by a survey among milking machine companies which showed wide divergence in recommended practices.

3. Massage of the udder is essential to efficient machine milking as shown by the fact that 34 percent longer time was required to obtain 10 percent less milk when cows were milked without udder massage.

4. The chief considerations with respect to the temperature of the water from which cloths are wrung to massage the udder should be comfort and convenience since temperatures of 60°, 100° and 135° F. did not affect the responses of cows to the milking process.

5. Data obtained showed that the rate of milk flow from cows was significantly faster following 60 seconds stimulation rather than 10 seconds stimulation, however, it is doubtful if the saving in machine time justified lengthening the stimulation period.

6. The hormone responsible for milk "ejection" dissipated after an eight minute waiting period following stimulation as shown by decreased yields and increased machine milking time.

7. Fast milking cows are more sensitive to changes and more responsive to stimulating factors than slow milking cows.

8. A formula was developed that can be used to determine the workability of any crew system. The formula is

$$\text{Rate of milking(sec/cow)} = \frac{\text{mach. time(sec/cow)} + \text{unit transfer(sec/cow)}}{\text{number units handled}}$$

9. Many recommendations as to the number of units one man can operate and maintain a fast milking program when following recommended milking practices can be challenged. For example, it was shown that one man could not operate three units when following recommended practices and maintain a three minute milking schedule.

10. Much research is needed to determine the optimum machine milking practices so that they could be synchronized with the time and labor available into more efficient crew systems.

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