

SOME FACTORS ASSOCIATED WITH THE RATE OF MILK FLOW
IN DAIRY CATTLE

By

Eugene Wesley Hupp

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies
of Michigan State University of Agriculture and
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ABSTRACT

EUGENE WESLEY HUPP

This study was undertaken to investigate the effect of several factors involving milk let down and rate of removal of milk from the udder of the dairy cow.

In the first experiment, the effect of addition of water to the concentrate mix during milking was investigated. Water was added at the rate of $1\frac{1}{2}$ pounds of water per pound of concentrate mix. This change reduced the milking time 30 percent for the 16 cows used. The maximum rate of milk flow was not changed significantly, but the average rate of flow decreased 12 percent. However, this statistically significant decrease was due primarily to increased time spent by the machine operator during stripping. This cannot be attributed to the effect of addition of water to the concentrate mix upon the milk flow characteristics of the cow.

In the second experiment, intravenous injections of 20 International Units of Oxytocin were given immediately before milking to assure a complete let down of milk. These injections had no effect on rate of flow in trial 1 involving seven slow milking cows, and only a slight effect on rate of flow in trial 2 in which seven average and fast milking cows were used. This effect on the faster milking cows may have been due to a greater increase in intra-mammary pressure following oxytocin injections. These changes in

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rate of flow were small compared to differences in rate of flow between cows. This indicates that let down failure was not responsible for the slow rate of flow of all but one of the cows studied. One cow did exhibit a faulty let down which was quite different from the normal let down pattern for that cow.

The effect of varying the interval between stimulation of let down by preparation of the udder by a warm water wash and use of the strip cup and attachment of the teat cups was also investigated. The intervals used were 0, 4, 8, 12, 16, and 20 minutes. Ten cows were milked at three milkings following each of these intervals. The maximum rate of flow was significantly faster when the teat cups were attached immediately after preparation. This change in rate of flow was quite small, but could be responsible for some milking to milking variation. Milk production and butterfat percentage decreased slightly but not significantly as the interval between preparation and milking increased. These results indicate that the shorter intervals between stimulation of let down and attachment of the teat cups did result in a more complete emptying of the udder.

Data were presented to establish the precision of the measuring devices employed in these studies to determine the

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rate of milk flow. The Milk-O-Meter had a gross error of 2.2 percent and a net error or bias of minus 0.5 percent in tests in the barn involving 545 actual milkings. The spring scales used had an error of 0.43 percent when weighing weights of known mass and 1.43 percent under milking conditions.

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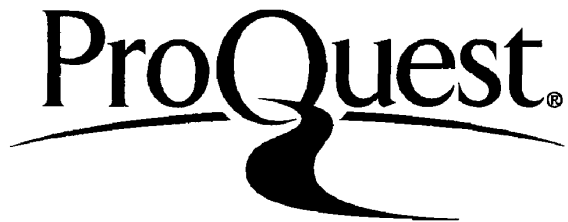
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INTRODUCTION

Modern milking machines have greatly increased the efficiency of milking cows. However, the physiological mechanisms that control the rate of milk removal are still not well understood.

Two groups of conditions may be considered to act in controlling the rate of milk flow from the udder. The first may be referred to as let down and involves the transfer of milk from the alveoli to the teat and gland cisterns and the pressure which it exerts. The second is the tension of the teat sphincter which surrounds the streak canal. This controls the pressure required to open the teat sphincter as well as the degree to which it will open under a given set of conditions.

The object of this investigation has been to ascertain the effect of several factors involving milk let down and rate of removal of milk from the udder.

REVIEW OF LITERATURE

Development of the Milking Machine

The perfection of a machine that would rapidly and efficiently remove the milk from the cow's udder has long been the aim of inventors and investigators. Although the milking machines in operation today are all of the intermittent suction type, the methods of achieving the desired amount of intermittent suction and transporting the milk from the teat cups to the storage receptacle are as varied as American inventive ingenuity can make them. In spite of these developments, research in machine modifications is still being conducted.

Erf (1906) stated that American inventors attempted to perfect milking machines as early as 1819. He described many types of milking tubes and pressure devices designed to remove milk from the udder. Woll and Humphrey (1909) reported that the first American patent on a continuous suction machine was obtained in 1860.

Matthews et al. (1928) credited Scottish inventors with the development, in 1902, of a milking machine which successfully used intermittent suction. William Lawrence and Robert Kennedy patented the machine which included a pulsator on the cover of the milk receptacle and a vacuum

regulating device. D. H. Burrell of Little Falls, New York, made some improvements on this machine and in 1905 marketed the first modern American milking machine as the Burrell-Lawrence-Kennedy cow milker. The machines in operation today are all improvements of this intermittent suction type milker.

Recently, several types of adjustments in operation of the milking machine have been investigated. Several groups of workers, Smith and Petersen (1946), Baxter et al. (1950), Gregoire et al. (1954), Caroulo et al. (1955), and Stewart and Schultz (1956 & 1958) have all reported increased milking rate with increased level of vacuum.

Smith and Petersen (1944) and Baxter et al. (1950) reported that the increase in rate of flow was greater than might be expected due to change in vacuum level alone, and postulated that increased vacuum levels also cause the sphincter to open wider.

However, there are limits beyond which the vacuum level should not be increased, since such increases may cause udder injury. (For a discussion see Mochrie et al. (1955). Petersen (1944a) also reported that increased vacuum levels increase the time required for stripping due to a greater tendency for the teat cups to crawl upward as the rate of flow decreases near the end of milking.

Although it is generally agreed that increased vacuum increases the rate of flow of milk from the udder, there are reports in opposition to this view. Whittlestone and Verrall (1947) found no significant difference in milking rate when cows were milked at a vacuum of 10 and 19 inches of mercury. Only in the case of an extremely hard milker was there a noticeable change, and the difference here was not significant. Dahlberg (1943) noted that the amount of suction, within reason, did not materially vary the rate of milking.

Smith and Petersen (1946) also reported changing the pulsator ratio so that vacuum was applied in the ratio of 2:1 or 3:1 of vacuum to release, rather than the 1:1 of conventional milkers. This resulted in an increase in rate of flow comparable to that obtained with a two inch increase in vacuum level. There was a lesser increase in rate of flow with the wider pulsator ratio's as higher levels of vacuum were used. It was postulated that at the higher vacuum levels, maximum drainage rates from the udder had been reached. Clough and Dodd (1956) also reported increased rates of flow with 2:1, 3:1, and 4:1 ratio's of vacuum to release, when compared to the normal 1:1.

The effect of varying the pulsator rate has also been investigated. Using a standard milking machine which

normally operated at 20 pulsations per minute, Clough et al. (1953) found that decreasing the pulsator rate to 20 pulsations per minute decreased the peak rate of flow 18.9 percent. Increasing the rate to 80 pulsations per minute increased the peak flow 9.7 percent. They point out that the milking machine must allow a complete evacuation of the pulsation system during each cycle if the higher pulsation rate is to be effective. In a later publication, Clough and Dodd (1956) reported increased rate of flow with pulsator rates of 110, 140, and 170 pulsations per minute.

Stewart and Schultz (1956, 1958) reported the effect of variations in pulsation rate on the rate of milking in slow milking cows. Decreasing the pulsation rate from 50 to 20 pulsations per minute resulted in a 0.5 pound per minute decrease in maximum rate of flow. Increasing the pulsation rate from 50 to 80 pulsations per minute resulted in only a very slight increase in maximum rate of flow.

However, Foot (1951a) reported very little difference and Whittlestone and Verall (1947) found no difference in milking rate which could be attributed to pulsation rate. As pointed out by Clough et al. (1953) these conflicting reports may have been due to the failure to completely evacuate the pulsation system during each cycle.

Methods of Measuring Rate of Milk Flow

The evaluation of the effect of machine modifications on the rate of milk flow and the recognition of the differences in rate of flow between cows has created the need for methods of measuring rate of flow. Early investigators such as Woll and Humphrey (1909) and Smith and Harding (1912) determined the rate of milking by the time required to milk the entire herd by machine. Dahlberg (1935) and Elting and La Master (1936) used the average milking time required per cow to test different milking procedures. Dalton et al. (1953) also reported the total milking time per individual cow.

Matthews et al. (1928) were the first to report measurements taken during the course of milking. The milker pail was placed on a scale during the milking process. The amount of milk accumulated in the pail at one minute intervals was recorded. Many other workers, Foot (1935), Petersen (1943), Smith and Petersen (1944), Korkman (1948), Dodd and Foot (1947), Baxter et al. (1950), Gregoire et al. (1954) and Stewart and Schultz (1956) have measured the accumulated amount of milk as indicated by scale readings at various intervals throughout the milking process. The length of interval used by different workers has varied from 10 to 60 seconds.

Hupp and Plum (1957) reported the use of a system in which the maximum rate of flow was determined by measuring the time required to produce the five pounds of milk in the interval between five and ten pounds of milk produced. This method avoids the difficulty of attempting to read the scale at an exact instant.

Several groups of workers have used continuous flow kymographs to obtain a graphic record of the amount of milk as it accumulated in the milking receptacle. The use of such a device was first reported by Gaines (1927). Beck et al. (1951a & 1951b), Roark et al. (1952), Thoele (1954), and Ace (1957) have also reported the use of a continuous flow kymograph.

Matthews et al. (1941) used a milking machine which transferred the milk from separate quarters to four cylindrical containers fitted with a graduated scale. Hall (1951) reported the use of a similar device designed to give instant transfer of milk to the cylinders.

Smith and Petersen (1946) used two vacuum flasks joined to the milking machine pail by a vacuum hose. With this device they could transfer milk from one teat to the vacuum flask with one hose while the milk from the other three quarters was transferred to the milker bucket by separate hoses. Through the use of a "Y" tube the milk was deflected into one

flask until full flow was obtained, then shunted into the second flask for exactly one minute so that the amount of milk produced by an individual quarter in one minute of maximum flow under various experimental conditions could be measured.

Knoop and Monroe (1950) used a special Surge milker with two latex bags within the milk receptacle. By means of a valve the milk could be deflected into either of the bags or into the milker receptacle proper.

Whittlestone and Phillips (1953) described an automatic apparatus which they designed for study of milk ejection curves of individual animals. An ordinary set of teat cups was used and the milk was transferred from the teat cups to a special receptacle. Through a series of electrical circuits which plotted the curve automatically this apparatus recorded the accumulated milk in relation to elapsed time. It also determined the end point of milking as the time at which rate of flow dropped to a pre-determined level. The apparatus was completely controlled by the milking machine operator, so that an additional observer was not required during the milking procedure.

Repeatability of Observations

Through the use of measuring methods just discussed, various workers have shown that the repeatability of

observations on individual cows, when milked under the same conditions, is high. Beck et al. (1951a) reported that in three successive afternoon milkings of 26 cows, the coefficient of intra-class correlation for maximum rate of flow was 0.96. The coefficient of correlation, based upon 12 cows, for observations taken once weekly from the fifth to the tenth week was 0.89. The correlation coefficient, based upon 25 cows, measured at the same stage of lactation in two successive lactations was 0.94. Thoele (1954) reported the coefficient of intra-class correlation of 1118 milkings of 38 cows to be 0.93. Ace (1957) reported repeatabilities of 0.904 on morning and evening milkings, and 0.933 considering morning and evening milkings separately.

Whittlestone (1946) and Beck et al. (1951b) have shown that each cow has a rather characteristic flow curve that changes little in appearance from day to day.

Differences Between Individual Cows

While the repeatability of rate of flow within individual cows is high, it has long been recognized that individual cows differ greatly in their response to any method of milking that may be employed. Gaines (1927) noted differences between individual cows in the rate at which they milked when milked under the same conditions. Matthews et al. (1928)

reported that individuals producing at the same level differ markedly in the rate at which they can be milked. The highest producing cow observed milked very rapidly while other high producing cows milked very slowly.

Elting and LaMaster (1936) reported that when grouped by level of production the average total milking time of each group of cows was almost equal. For individual cows, large differences were found in total time required per cow. The shortest time required was 3.37 minutes, while the longest time required was 8.28 minutes. Seven percent of the cows milked out in four minutes or less, 81 percent milked out in 4 to 6.5 minutes, and 12 percent required 6.5 minutes or more.

Whittlestone (1946) discussed in detail the milk flow curves of 12 cows which were recorded over the entire lactation. He showed, graphically, individual differences between cows and variations in response during the lactation.

Beck et al. (1951b) studied the response of individual cows to a standard method of machine milking. The studies were conducted on 102 animals of various ages and representing four breeds. The average milking time was 3.5 minutes per cow, with 79 percent of the cows milking out in four minutes or less, but only 39 percent of the cows milked out in three minutes or less.

Dodd (1953) also reported large differences in milking rate within the herd studied. The total time required varied from 4.42 minutes to 21.50 minutes. Only 2.8 percent milked out in five minutes or less, while 8.3 percent of the cows observed required over 14 minutes to be milked out. The peak rate of flow ranged from one pound to 10.4 pounds per minute. Only 3.4 percent of the cows had a peak flow of less than two pounds per minute while only 1.5 percent had a peak flow greater than nine pounds per minute. Sixty percent of those observed had a peak flow of from 2 to 4.9 pounds per minute. The coefficient of variation between cows for the various measures of rate of milking were in the range of 30 to 40 percent while the within cow variations were on the order of 8 to 11 percent.

Petersen (1943) also found great variation in the rate of milking between cows, while Thoele (1954) reported differences in the rate of milking between cows to be significant at the one percent level of probability.

Whittlestone (1954) presents four types of milk flow curves which he describes as representing most of the cows which will be encountered. The first and most desirable is the cow that starts immediately and milks out rapidly with little machine stripping. The second starts immediately, but milks out slowly due to the tightness of the teat

sphincter. In the third a large amount of machine stripping is required to remove the last milk from the udder. In the fourth type, the cow is described as having a faulty let-down response. The milk is not rapidly transferred to the gland cistern; then a second letdown or release of more letdown hormone occurs upon stimulation of machine stripping. Whittlestone attributes much of the difficulty in slow milking to this type of response.

Several workers have investigated the contribution of the individual quarters to the individuality of the milking response of each cow. Matthews et al. (1941) found that in most cows there were wide differences in the performance of the separate quarters of the udder. There were wide variations between individuals in milking rate and in the extent of the differences between quarters. Of the 94 cows observed, 48.9 percent showed a difference of 20 percent or more between the quarter with the lowest percentage of its total yield milked out following the first 2.5 minutes of milking. A difference of 0.6 pounds per minute or more between the quarter with the highest peak flow and the quarter with the lowest peak flow was encountered in 40.4 percent of the cows.

Smith and Petersen (1956) also presented data showing considerable variation in rates of the individual quarters within the same cow. The reaction of the individual

quarters to increased levels of vacuum also varied. In one cow an increase of five inches of mercury in the vacuum level resulted in a 111.4 percent increase in mean rate of flow in the quarter showing the greatest response and only 60.8 percent in the quarter showing the least response.

The Role of Let Down in Controlling Rate of Flow

The term let down will be used in this thesis even though a considerable degree of controversy exists as to the proper term to be used to describe the phenomena generally known to the dairyman as let down. This word itself has been written "let down," "letdown," let-down," and "letting down," and all have been written both with and without quotes. A group of British workers (Cowie et al., 1951) proposed that milk ejection, a term used as early as 1915 by Gaines, be adopted for uniform use. However, Turner (1954), Whittlestone et al. (1952) and others have continued to use let down. Other terms have also been used; "draught" is a term which has been frequently used in human medicine; Espe and Smith (1952) prefer to use the term expulsion, while Kay (1955) and others have used pertrusion to describe this phenomena. Thus there seems to be no common agreement on the proper term to describe this phenomena.

The various aspects of milk let down have been the subject of a great deal of investigation. Although the effect

of one of the hormones of the posterior pituitary was described as early as 1895 by Oliver and Schafer, and the structure of both oxytocin and vasopressin have been elucidated, as reported by du Vigneaud et al. (1953 and 1954) there is much to be learned concerning the mechanism of release and the action of these hormones.

In contrast to the other areas covered in this review, the mechanisms involved in milk let down have been considered in several review articles. Various phases of the problem have been covered by Petersen (1944c), Folley (1947), Cross (1955), Kay (1955) Van Dyke et al. (1955), Benson and Cowie (1957), and Hammond (1957). Since these reviews are readily available, only the more significant material necessary for an understanding of the neurohormonal mechanism of milk let down will be considered here.

Elucidation of the let down mechanism.

Gaines (1915) was the first to demonstrate that the suckling stimulus caused milk let down. He reported that suckling of one gland of a goat by its kid caused a copious flow from the other (cannulated) gland about 50 to 60 seconds after suckling commenced. He stated that practically all of the milk obtained was present as such in the gland at the beginning of milking and was "actively ejected by a reflex contracture of the gland musculature under the

stimulus of milking." Gaines also investigated the effect on the mammary gland of injection of posterior pituitary extract. (The effect of these extracts upon the mammary gland had been reported by Ott and Scott in 1911.) Although Gaines concluded that the extract caused a constriction of the milk ducts and alveoli, with a subsequent expression of milk, he did not implicate the pituitary in milk ejection, but considered milk let down to be a purely reflex act.

Turner and Slaughter (1930) suggested that the let down reflex might act through the posterior pituitary. However, they concluded that it was still an open question whether the posterior pituitary played an active part in the normal discharge of milk during milking.

In 1940 and 1941 Ely and Petersen reported the results of experiments which demonstrated the neuro-hormonal nature of milk let down. They stated that various stimuli such as manipulation of the udder, sight of the milker or calf, or sounds associated with milking, stimulate let down. The reflex nature of the stimulation was substantiated by demonstration that an interruption of the normal milking routine or injection of adrenalin inhibited let down. The hormonal nature of the efferent side of the reflex was demonstrated by showing that let down occurred in the half of the udder in which the efferent nerves had been interrupted through

sympathectomy at the inguinal ring. The hormonal nature was further demonstrated by showing that blood which had been collected from cows after stimulation of let down, when perfused through an isolated cow's udder, produced let down in that udder.

Demonstration of the afferent mechanisms.

Although the report of Ely and Petersen (1941) that sight and sound as well as tactile stimuli can initiate let down in the cow has been well substantiated, several investigators have attempted to elucidate the afferent nerve pathways from the mammary glands. The work of Peeters et al. (1952), Denamur and Martinet (1954), Tsakhaev (1954), and Eayrs and Baddeley (1956) offer conclusive evidence that the afferent stimuli from the mammary glands enter the central nervous system via the dorsal roots of nerves supplying the gland or glands stimulated and are conveyed up the spinal cord deep in the lateral funiculus of the same side.

Grosvenor and Turner (1957), through injection of various drugs which inhibit cholinergic or adrenergic responses, concluded that both cholinergic and adrenergic links exist in the neuro-hormonal arc which is responsible for the discharge of oxytocin by the posterior pituitary.

The effect of stimulation of the reproductive tract upon the let down of milk has been reported by several workers.

Hays and Van Demark (1953) cited the review of literature of Nuesch (1904) who reported a publication in 1727 in which the Hottentots brought about milk let down in the absence of the calf by blowing air into the vagina.

Piana (1950) and Andersson (1951) reported milk let down following massage of the cervix and uterus per rectum. Hays and Van DeMark (1953) reported increased intramammary pressure in 89 of 99 trials following artificial insemination techniques. Harris and Pickles (1953) presented evidence of let down in lactating women following coitus. The exact relationship responsible for this phenomena is not clear; however Hays et al. (1953) and other workers have suggested that oxytocin may play a role in sperm transport in the female following copulation. Thus the same hormone may play a role in both the mammary and reproductive systems, and a stimulus in either system which brings about a release of oxytocin evokes a response in both systems.

Establishment of the role of the pituitary.

Although the action of exogenous oxytocin in causing let down has long been known, and Ely and Petersen (1940) have clearly demonstrated the hormonal nature of the efferent portion of the reflex, much additional work has been done in an attempt to demonstrate the role of the pituitary in normal milk let down. Several approaches to the problem have been

made. The Gomori chrome Alum hematoxylin stain appears to be specific for demonstrating the neurolobe hormones. Brightman (1955) reported that there was less of the neurosecretory material (as demonstrated by the above method) in the pituitaries of mice killed immediately after nursing their young. However, Drager and Rennels (1955) and Rennels et al. (1955) have been unable to demonstrate a relationship between the Gomori-positive material and conditions which should cause depletion of oxytocin in the pituitary.

Several workers have reported the results of electrical stimulation of the pituitary and hypothalamus. Cross and Harris (1950) reported that an electrical stimulation of the pituitary stalk caused a flow of milk from a cannulated duct in an anesthetized rabbit which was similar to that obtained by injection of 0.2 IU. of posterior pituitary extract. In 1952 the same workers reported similar results on stimulation of the supraoptical-hypophysial tract, which supplies nerves to the posterior pituitary. Andersson (1953) reported milk let down in sheep following electrical stimulation of the anterior hypothalamus.

Cross and Harris (1952) also showed that electrolytic lesions in the supraoptico-hypophysial tracts of lactating rabbits caused a marked diminution in the quantity of milk obtained by their litters.

In the light of the above reported evidence, and other data, there can be little doubt that the release of oxytocin from the posterior pituitary takes place as a result of nervous stimuli.

In connection with the role of the pituitary, it should be mentioned that recent work has established that the hormones of the neurohypophysis are actually produced in the supraoptic and paraventricular nuclei of the hypothalamus and that the pituitary only serves as a source of storage until the hormones are released. This work has been reviewed by Scharrer and Scharrer (1954).

The nature of the effector tissue.

The elucidation of the nature of the contractile tissue responsible for the phenomena of let down has been difficult. Hammond (1913) presented evidence that the pituitary extracts acted directly upon the glandular epithelium. However, Schafer (1914) proposed that contractile tissue which he called "plain muscle" in the walls of the alveoli was responsible for let down.

Schafer's view persisted for some time; Turner and Slaughter (1930) attributed the effects of oxytocin to action on smooth muscle surrounding the alveoli. Swanson and Turner (1941) reported the presence of smooth muscle cells in the udder of the cow to which they attributed the action of squeezing out the milk.

Richardson (1949), using a silver staining technique, was the first to clearly demonstrate that an abundance of myoepithelial tissue existed in the udder. It was shown to be arranged in such a manner that it could actively squeeze the milk from the alveoli. Linzell (1952) confirmed the results of Richardson, and also demonstrated that there was not enough smooth muscle present in the udder to cause contraction of the alveoli. He also reported that the myoepithelial cells are not innervated, therefore they can respond only to direct stimuli such as that produced by hormones. Silver (1954) criticized silver impregnation techniques as being rather capricious, but confirmed the earlier work of Richardson (1949) and Linzell (1952) by demonstrating the presence of myoepithelial cells with an alkaline phosphatase stain.

The above conclusions have been further substantiated by Linzell (1953 & 1955) through direct examination of the mammary gland of living mice. He observed contraction of the alveoli following topical application of oxytocin or vasopressin. He also reported that the smaller ducts, around which the myoepithelium is arranged longitudinally, shortened and widened in response to oxytocin. He presented evidence that this shortening and widening is not due to pressure of the milk alone.

Changes in intramammary pressure.

Turner (1935) cited the work of Tgetgel (1926) who found that the intramammary pressure in the cow before let down ranged from 25 to 35 mm. of mercury and after let down the intramammary pressure ranged from 40 to 60 mm. of mercury. Whittlestone (1955) reported similar pressures, and reported only a slight drop in pressure after 22 minutes if the cow's udder was unmilked. He stated that this is in contrast to the sow (which he has studied extensively) in which a rapid rise and fall in pressure is noted. He suggested some type of non-return mechanism which is responsible for the sustained pressure after the effects of oxytocin are presumed to be dissipated. However, such a mechanism has not yet been demonstrated anatomically.

Baxter et al. (1950) proposed that changes in internal pressure in the gland could be responsible for small differences in rate of flow from milking to milking.

Duration of let down.

The time during which let down persists following stimulation has not been definitely established. Ely and Petersen (1941) reported that blood from the donor cow was not effective in eliciting a let down in the perfused udder if more than eight minutes elapsed between stimulation and perfusion. Miller and Petersen (1941) and Ward and Smith (1948) reported

decreased production if more than eight minutes elapsed between stimulation and the time milking began. They presented this as evidence for the rapid dissipation of oxytocin; however, the validity of conclusions based upon these experiments will be discussed in greater detail in a later section. Petersen (1944b) stated that not more than seven minutes should elapse between preparation and completion of milking if all of the milk is to be obtained.

Additional information is required to reconcile these results with those of Tgetgel (1926) and Whittlestone (1955). Tgetgel reported that the pressure in the gland cistern had not fallen to the expected pre-let down pressure level within 10 to 60 minutes, while Whittlestone reported that the pressure had fallen but little within 22 minutes following stimulation of let down. The possibility that the continued stimulation of milking causes a constant release, or stimulates several releases of the hormone sufficient to maintain the contraction of the myoepithelium should not be overlooked.

Frequency of let down.

The frequency with which a let down may occur has been the subject of some controversy. Smith (1947) reported that milking cows at 2-hour intervals resulted in extreme milking-to-milking variation which he attributed to the inability of

the cows to respond to the normal stimulus with a let down of milk. However, Whittlestone et al. (1952b) demonstrated that if the normal milking routine was maintained and the regular milker was present, cows did respond with a normal let down when milked at 2-hour intervals.

In this connection, a comparison of the amounts of oxytocin stored in the pituitary and the possible amount required to elicit a let down is of interest. Whittlestone et al. (1952a) reported that the oxytocic activity of the whole pituitary of mature cows ranged from 23 to 178 I.U. Donker et al. (1954) reported let down on injection of 1.5 I.U., but doses smaller than that were not tried. Evidence presented by Denamur and Martinet (1954) in which 10^{-4} I.U. produced a response, and 10^{-2} I.U. produced a maximal response in the goat indicates that amounts smaller than those reported above may be effective, when released by the pituitary of the cow. In a later publication, Donker (1958) reported let down in the cow with as little as 0.06 I.U. of oxytocin and normal responses with 0.12 and 0.25 I.U. of oxytocin. Thus the pituitary apparently stores enough hormone to elicit many let downs.

Several workers have reported a "second let down" of milk which results in an increased rate of flow after a period of low rate of flow following the first let down. Whittlestone (1949) first reported a second let down which

was elicited by the additional stimulus of stripping. He attributed this phenomenon to a faulty original let down. Whittlestone concludes that too much stripping may cause some cows to become slow milkers by producing the second let down while weakening the response to the stimuli which caused the first let down.

Whittlestone (1951) reported that a second let down could be obtained by milking two quarters at a time, if the second let down was stimulated by washing the udder before the second two quarters were milked. In 1955 Whittlestone reported that one cow observed consistently responded to stripping with a second let down following a milking procedure using cannulas which required 16 to 18 minutes milking time before stripping began. He reported that the normal amount of milk was obtained in this way and concluded that procedures which produced a second let down were just as efficient in removing all the milk as faster milking procedures involving a single let down.

Thoele (1954) reported that one cow exhibited a spontaneous second let down on several occasions which were produced without any manipulation of the udder on the part of the milking machine operator. Ace (1957) reported the observation of spontaneous second let downs in three different cows. These reports would indicate that some let down hormone

was released in response to the original stimuli, then a later stimulus caused a second release of the hormone.

Effect on milk composition.

Injection of oxytocin has been used extensively as a tool to get complete evacuation of the udder. The effect of oxytocin injections on the level of production has also been investigated extensively. For a review of this work see Benson and Cowie (1957).

Many workers, Shaw (1942), Knodt and Petersen (1942, 1944), Johansson (1949), Swanson and Hinton (1951), Adams and Allen (1952), Johansson (1952a, 1952b), Donker et al. (1952, 1954), and others, have shown that the "residual milk" obtained by oxytocin injections following normal milking is higher in butterfat.

It has also been amply demonstrated by Johansson (1949, 1952a), Whittlestone (1953), and others that the fat content of the milk increases as milking progresses. Whittlestone attributed the increase in fat percentage in the cow to the clustering of the fat globules. This gives the fat globules a higher viscosity and hence a slower rate of flow through the small ducts, resulting in an increased fat percentage in the last milk drawn. He further stated that if the let down does not persist long enough to enable the cow to be

milked completely at a normal milking, a greater amount of high fat milk will be obtained following the injection of oxytocin.

Johansson (1949) attributed milking-to-milking variations in the fat content of the milk to variations in the degree of completeness of milking. At an incomplete milking the fat content is lower than usual, but at the subsequent normal milking it is higher than usual. This report would indicate that the fat percentage of the milk could be used as an indication of completeness of milking under varying experimental conditions.

Methods of Stimulating Milk Let Down

Various methods of obtaining a satisfactory let down of milk have been reported by several workers. Gaines (1915) demonstrated that the natural stimulus of a kid suckling its mother caused a let down of milk in the unsuckled gland as well.

The effects of various pre-milking preparations have been extensively investigated. Dodd and Foot (1947) reported upon the effect of washing the udder with warm water (115 to 120 degrees F.) and using the strip cup one minute prior to the attachment of the teat cups. The routine previous to this had been to hose all of the animals with

cold water and employ the strip cup to the entire herd prior to the commencing of milking. In this, the usual manner, from 15 minutes to over an hour elapsed between preparation and attachment of the teat cups. They used the experimental regime for five weeks and found very little difference in the rate of flow which they could attribute to the method of preparation. However, it was noted that whereas in the initial control period, the cows failed to let down their milk after washing, most of them did let down their milk following washing in the first few days of the post experimental period. Several days were required before the cows ceased to let down their milk following the cold water wash. This indicates that these cows had been conditioned to washing as a stimulus for let down.

Smith and Petersen (1948) investigated the effect of stimulation of let down by a 10 to 15 second udder wash followed by udder massage two minutes before application of the teat cups. They found that this procedure resulted in higher average rate of removal of milk and shorter milking time than a group which received no stimulation prior to milking.

Knoop and Monroe (1950) also used several methods of pre-milking preparation. The response to washing with cold, warm, or hot water was the same. Variations in amount of water used, ranging from massage with a damp cloth to bathing

the entire udder in hot water gave the same response. Brushing the udder, followed by the use of the strip cup, was not sufficient stimulation to cause milk let down. When brushing the udder was used to promote let down, the milking time was prolonged approximately one minute in comparison to the other methods of pre-milking preparation. They concluded that some type of preparation in addition to use of the strip cup is necessary to promote the initial let down of milk.

Beck and Clayton (1951) found that damp paper towels, damp cloths, or 15 to 20 seconds massage with bare hands, in addition to the use of the strip cup in all cases, were equally effective in the stimulation of let down.

Roark et al. (1952) found that udder massage combined with the use of the strip cup was more effective in stimulating let down of milk than either of the preparations alone. Stimulation by the combined method shortened milking time as much as 27 percent, decreased stripping time and increased yields slightly.

A report by Witt and Andreae (1955) should also be mentioned. They found that rate of milk flow was slightly higher and the duration of milking slightly less when udders were massaged with dry hands in contrast to the usual routine of washing the udder with a damp cloth. They concluded

that warm water has an inhibitory effect on milk production and does not offer any advantage under farm conditions.

These reports indicate that various types of stimuli may be used to stimulate the let down of milk, but that the response to a specific method may vary from herd to herd. However, from the results of the vast amount of research that has been conducted along these lines, it may be concluded that an adequate stimulation of let down is the key to successful removal of milk from the udder.

The Effect of Adding Water to the Concentrate Mix Fed During Milking

The possible effect of adding water to the concentrate mix upon the let down of milk has also been investigated. Dalton (1952) and Dalton et al. (1953) reported the effect of feeding concentrates with different degrees of fineness and water content on the eating and milking times of dairy cattle when they were fed in the parlor during milking. They reported the results of two trials. The first involved 12 Brown Swiss cows and was conducted during the barn feeding season; the second involved 11 Brown Swiss and two Holstein cows and was conducted during the change-over to pasture in the spring. Feed ground to three different degrees of fineness was fed; fine, medium, and coarse ground with one-sixteenth, one-eighth, and five-sixteenths of an inch

screens respectively. Each of the above concentrates was fed for a three-day period, first as air dry and after that water was added at the rate of 0.5, 1.0, or 1.5 pounds of water per pound of feed. One fineness of ground concentrate was fed with each of the three water contents, then another grind was used. A one day adjustment period intervened between each of the 12 three-day periods.

Consumption of the grain was the most rapid with the coarsely ground feed, both wet and dry, although the differences in eating rate due to fineness of grind were not great. With all three degrees of fineness of grind, eating rate increased as the water content of the grain increased. The most rapid eating rate was attained when 1.5 pounds of water was added to each pound of the coarsely ground feed, fed during the barn feeding season. The cows then required an average of 0.61 minutes to consume a pound of grain, which was a decrease of 64 percent from the 1.70 minutes required to eat the air dry grain.

The change in average milking rate closely paralleled the change in eating rate although the percentage change was not as great. The greatest increase in average milking rate was attained when 1.5 pounds of water were added per pound of coarsely ground feed during the pasture season, when 0.26 minutes were required per pound of milk produced. This was a decrease of 37 percent from the 0.41 minutes required to

produce a pound of milk when the cows were eating air dry grain. These workers postulated that the increased milking rate may have been due to a faster let down produced by a conditioned reflex or an increased feeling of satisfaction associated with the ease of eating the watered grain, which resulted in a faster let down.

Thoele (1954) also investigated the effect of adding water to the concentrate mix. The eating rates and milking rates when air dry grain and grain to which water had been added at the rate of 1.5 pounds of water per pound of grain were compared in a double reversal trial involving 15 cows. He confirmed the increased eating rate and average rate of milk flow as reported by Dalton et al. (1953) although the differences were not as marked. However, Thoele found no significant differences in maximum rate of flow or maximum rate of milking time. He advanced no explanation for the increased average rate of flow which was obtained without an increase in the maximum rate of flow.

The Effect of Variation of the Interval Between Preparation and Milking

Several workers have studied the effect of varying the interval between stimulation of let down and the time milking began. Dodd and Foot (1947), Smith and Petersen (1948), Dodd et al. (1949), Knoop and Monroe (1950), and Roark et al.

(1952) have shown that application of teat cups without preparation or immediately following preparation delayed attaining peak flow and resulted in a decreased average rate of flow. However, an effect on peak flow, once it was attained, or on the level of production has not been demonstrated.

The results which different groups of workers have obtained concerning the effect of longer intervals between preparation and milking on the production at that milking have varied. Little has been reported concerning the effect of the longer intervals between preparation and milking upon the rate of flow. Miller and Petersen (1941), Petersen (1945), and Ward and Smith (1948, 1949) have reported decreased production following longer intervals. Dodd et al. (1949) and Roark et al. (1952) have reported slight decreases in production following the longer intervals. However, Knodt et al. (1947, 1949), using a large number of animals, failed to find decreased production due to regular delays in milking. Dodd et al. and Roark et al. reported slower rates of flow following the longer intervals.

The results of an experiment involving 19 cows were reported by Miller and Petersen (1941). They found that manipulation and washing of the udder, a procedure which stimulated let down, 20 minutes before, stripping 15 minutes

before, and massage 10 minutes before milking brought an average decrease in fat production of 8.39 percent. There was great variation in response between cows. Production decreased in 14 of the 19 cows studied, while the changes in production ranged from plus 4.3 percent to minus 33.7 percent. The mean decrease in fat test was 0.13 percentage units.

The effect of milking one quarter at a time has been reported by Miller and Petersen (1941). They found that production decreased with each successive quarter milked. This corroborates the work of Bitting (1901) and is very similar to the results of Babcock (1889), Emery (1895), and Beach (1904) who found the greatest production in the second quarter, followed by the first, third, and fourth. A decrease in butterfat test was also reported by Miller and Petersen. The tests for the first, second, third and fourth quarters, respectively, were 4.76, 4.52, 4.34, and 3.64 percent butterfat. Injections of pituitrin yielded amounts of milk and fat so that the addition of the amount obtained after injection to that obtained before resulted in almost equal amounts of milk and fat for each of the four quarters. They postulated that the reason for lowered production after a period of time following stimulation is due to dissipation of the oxytocic principle or principles in the blood.

Ward and Smith (1948, 1949) reported on an experiment involving five cows in which the control half of the udder was milked two minutes after let down was stimulated by washing the udder and use of the strip cup, and the other half was not milked until intervals of 4, 8, 12, 16, and 20 minutes following stimulation. The differences between the amount produced in the control half milked two minutes after stimulation and the other half milked four and eight minutes after stimulation were not significant. However, a slight decrease was noted after eight minutes. When the experimental half of the udder was milked 12, 16, or 20 minutes following stimulation, significantly less milk was produced than in the control half of the udder.

Dodd et al. (1949) reported the results of two experiments involving varied intervals between preparation and milking. In the first experiment, cows accustomed to preparation one minute before milking showed no change in rate of milking when the interval for a single milking was three minutes and a slight but not statistically significant decrease in the rate of flow and production when the interval was six minutes. In a second experiment, the same workers milked four cows each at one minute or 20 minutes following preparation. No significant differences in rate of milking or milk production were noted. However, it was suggested

that milking immediately after preparation was the more efficient routine, although the difference was slight. Dodd and Clough (1957) in a popular review article cite the above work to substantiate the need for milking within three minutes following preparation, in order to develop a strong conditioned reflex.

Roark et al. (1952) reported varied responses resulting from 3, 5, and 8 minute delays following stimulation of let down. Eighteen cows were used in 18-day experiments, each cow being subjected to each delay for three 2-day periods during the trial. The eight-minute delay resulted in five percent less production in one trial, but in another trial, no significant decrease in production was shown. Delaying milking for eight minutes consistently increased total machine time while a delay of five minutes caused a significant decrease in milking time in one trial. However, in a longer trial in which six cows were subjected to the same treatment for a six-week period, a significant increase in machine time was noted following the five-minute delay. A figure is presented which shows some evidence of a second let down when an eight-minute interval elapsed between preparation and attachment of the teat cups.

Knodt et al. (1947, 1949) reported the results of a series of six trials, involving 66 cows in all, in which

regular delays up to 20 minutes were made from the beginning of washing of the cows udders until attachment of the teat cups. Each cow was milked at the same interval following preparation for the entire test period, some of which were as long as 84 days. No significant differences in production due to variation in interval were noted either in the first week in which the routine was changed, or over the entire period.

In one of these trials the effect of milking the entire udder either 2 or 12 minutes following preparation was compared to the effect of milking half of the udder two minutes after preparation and the other half twelve minutes after preparation. While there was no decline in production if the whole udder was milked 12 minutes after preparation, there was a highly significant decline in production in the half of the udder milked 12 minutes after preparation if the other half was milked two minutes after preparation. This may explain the discrepancy between these results and those which indicate a decline in production in parts of the udder milked at various intervals following preparation. These results cast doubt upon the validity of extrapolation of data based upon halves or quarters of the udder milked at different intervals following preparation, to the effect of milking the entire udder at the same interval following preparation.

The Effect of "Managed Milking" Routines

Several workers, Dahlberg (1941, 1943), Zehner (1943), and Hopson (1944) have advocated restricting the milking time for each cow to a certain length of time in a strict "managed milking" regime. They maintain that the time required to milk a cow can be materially reduced.

Dahlberg (1941) reported the effect of gradually reducing the milking time in a herd in which the initial milking time was 9 to 10 minutes. At the end of a year, the machine was left on the cow for only five minutes. Approximately one-third of the cows required hand stripping, but the amount of milk obtained from most of these was slight. First lactation cows adapted very easily to the shorter milking period when they were milked under this system for calving. Monthly production of butterfat and persistency were equal to that obtained by hand milking and were better than that of the previous period in which machine milking time was longer.

In a later publication, Dahlberg (1943) restated his previous conclusions and emphasized that hard milkers can be trained to become easy milkers. He stated that most slow milkers have been developed by habit and chances are that a slow milker may have been a fast milker as a heifer. He advocated installing a timer on the milker, set to sound at

four and five minute intervals following the attachment of the teat cups, the two intervals being provided to account for the individual differences between cows.

Zehner (1943) advocated an even greater reduction in milking time. He recommended milking each cow for three minutes and suggested the use of a three minute egg timer or similar instrument to measure the proper interval for milking. He stated that two men handling three units can milk 50 cows per hour in a stanchion barn. Zehner reported that most cows rapidly became accustomed to the routine and less strippings were obtained than previously. He stated that 5 to 10 percent of the cows do not respond to the method and should be moved to the end of the line so that the routine of rapid milking will not be interrupted.

Hopson (1944) advocated the use of a routine similar to that presented by Zehner above.

In contrast to the above results, Dodd and his associates have been unable to increase the rate of milk flow through reducing the milking time. In 1947 Dodd and Foot reported the results of an experiment in which they reduced the milking time to 60 percent of normal as determined in an initial control period. The milking time was gradually reduced in increments of 10 percent per week until the 60 percent level was reached. This milking time was maintained

for four weeks. They were unable to produce an increased rate of flow, in spite of the fact that in the shorter milking times, considerable milk was left in the udder when milking was completed. They postulated that the discrepancy between these results and those published by other workers may be in that the reduced time gained by other workers was only an elimination of the common fault of leaving the teat cups on the cow too long after the milking process had actually been completed.

Dodd and Foot (1949) reported the results of an experiment in which a group of 16 animals were subjected to 60 percent of the normal milking time, as determined by a preliminary control period, without any gradual period of reduction. In this experiment the cows on the 60 percent controlled time showed an increased maximum rate of flow during the first week. These workers suggested that this increase in rate probably was due to an increased intramammary pressure caused by the accumulated milk within the gland. After the first week a statistically significant decline in the maximum rate of flow was noted. This decline was probably associated with the decline in production which was brought about by the strict limitation of milking time.

An experiment in which cows in their first lactation were subjected to a rigid control of milking for the entire

lactation was reported by Dodd et al. (1950). Forty cows were paired by calving date as they freshened, and assigned at random to either a four or an eight minute controlled milking period for the entire lactation. No statistically significant differences in the peak rate of flow, or mean yield in the first three minutes were found between the two groups. During the early part of the lactation, the duration of peak flow was shorter in the cows milked for four minutes because the machine was removed during peak flow in some cases. For about one-half of the cows in this group, four minutes was not sufficient time to complete the milking during the early part of the lactation. However, in spite of the incomplete milking of some of the cows in this group, there were no significant differences between the 305 day lactation yields or in the persistency in the two groups.

Thus the above reported work of Dodd and his associates indicates that the milking characteristics of the cow cannot be changed by reducing the milking time and suggests that the results reported by the earlier workers may have only reflected improved milking practices which eliminated idle machine time.

The Role of Teat Morphology

Although let down of milk has received a great deal of attention, many workers maintain that the morphology of the teat plays a very important role in determining the rate at which a cow can be milked.

The transition of the teat cistern from the gland cistern is sharply distinguished by a circular fold of the membrane lining the teat. According to Petersen (1942), this fold may be so extensive as to interfere with the free passage of milk from the gland cistern to the teat cistern. Petersen (1943, 1944a) reported that the morphology of this area affects the ease with which the passage between the gland and the teat cistern may be occluded if the teat cups are allowed to crawl upward when the rate of flow decreases near the end of milking.

The shape and size of the teat cistern vary greatly between cows, and Petersen et al. (1944) state that these variations affect the rate of machine milking.

Turner (1939, 1952) and Espe and Cannon (1942) have described the teat sphincter. The streak canal through the teat sphincter usually varies from 8 to 12 mm. in length and is held closed by the involuntary sphincter papillae muscle. This canal is designed to retain the milk in the udder against the pressure developed in the storage system

during the interval between milkings. Along the axis of the streak canal there extend folds of the mucosa which lie so close together that under ordinary circumstances the streak canal has no free lumen as the 3, 4, or 5 convex epithelial projections touch each other in such a manner as to leave a star-shaped slit, which as a rule is not open.

Espe and Cannon (1942) stated that upon application of pressure to the teat, the length of the canal through the sphincter is reduced from about 12 to 8 mm. in length. At the same time the cistern tends to balloon out as milk in the cistern is put under pressure until the folds in the mucosa disappear, causing the opening of the canal.

The histological structure of the teat sphincter has been described by Turner (1939, 1952), who cited the work of Christ (1905) and Kamm (1925), and by Venzke (1940). In the region of the streak canal under the epithelium of the papillary eminences there is found an inner longitudinal smooth muscle layer. Next there is a circular smooth muscle layer which forms the muscular sphincter papillae. The inner longitudinal muscles are found in small bundles; in females in the prime of life these bundles are abundant and may form a closed circular section, while in young or very old animals only small isolated bundles may be found. Thus the constriction of the canal may be attained by the close elastic network of the tunica propria or by the sphincter muscles.

Many workers, Ace (1957), Baxter et al. (1950), Dodd (1952), Dodd and Foot (1953), Dodd and Kneave (1951), Espe and Cannon (1942), Foot (1951b), Knoop (1948), Knoop and Monroe (1950), Petersen (1942), Smith and Petersen (1946), Stewart and Schultz (1958), Turner (1939, 1952), and others have attributed to the teat sphincter the major role in determining the rate of milk flow under a given set of conditions.

Baxter et al. (1950) have shown that eliminating the effect of the teat sphincter eliminated most of the variation in the rate of flow between cows. When the two hind quarters of 4 cows were milked a number of times with ordinary teat cups the range in peak rate of flow for individual quarters was found to be from 1.1 to 2.9 pounds per minute. The same quarters were then milked at a similar vacuum level through a simple cannula so that the size of the teat orifice was standardized for all quarters. Under these conditions, the rate of milking for all quarters fell within the range 2.6 to 2.9 pounds per minute.

However, to date, attempts to make direct measures of the teat sphincter which can be related to the rate of flow through the sphincter have been unsuccessful. Espe and Cannon (1942) used a standard Tycos sphygmomanometer with a small rubber bladder and sleeve to fit around the teat. The

teat was then closed off at the base with a pair of rubber covered clamps just sufficient to prevent the milk from returning to the gland cistern. Readings were made when pressure on the bladder caused a very small stream of milk to be forced from the teat. They obtained only fair results after considerable practice and considered the method generally unsatisfactory.

Murphy (1944) attempted to estimate teat "patency" by repeatedly applying lateral pressure to the middle of the teat with the thumb and first finger. Care was taken to see that the teat was full of milk to start and vertical motion was avoided as much as possible. No attempt was made to estimate degree of patency, teats were classed as either patent or non-patent. Results by this method were not very repeatable, as frequently a cow would be classed as patent one day and non-patent on another. Although it is not mentioned by the author, let down of milk may have been a complicating factor in determining patency.

Ace (1957) measured the length of the teat, thickness of the teat, and length and width of the teat sphincter and was unable to correlate any of these measures with the maximum rate of milk flow.

Although the teat sphincter plays a major role in determining the rate of flow, apparently little can be done to

alter the sphincter of a slow milking cow. Turner (1939) cited the work of Kraft (1927) who described a technique which could be used to remedy the condition of slow milking. A special knife called a teat bistourie was inserted into the teat; the knife was then unsheathed and carefully drawn downward, making an incision through part of the streak canal and cutting part of the sphincter lying below. For obvious reasons, this technique has not gained wide acceptance.

Another question yet unanswered concerning the teat sphincter is the one posed by Van Dyke et al. (1955). Could oxytocin relax the teat sphincter while contracting the myoepithelium of the udder and the smooth muscle of the uterus? They concluded that sphincter relaxation seems to be primarily under the control of the nervous system, rather than that of oxytocin. However, it is possible for the muscle fibers to be arranged so that contraction of these fibers, or parts of these fibers would open the sphincter, although such an arrangement has not been demonstrated. It is also possible that the leaking of milk observed in many cows is simply a pressure phenomena due to the increased intramammary pressure obtained upon let down, and relaxation of the teat sphincter is not involved.

Other Factors Associated with Rate of Flow

There are several other factors associated with rate of milk flow which need to be considered in evaluating the results of experiments involving the rate of milk flow.

Heredity.

Since the milking response of the individual cow seems to be a characteristic feature which is highly repeatable, several workers, as indicated below, have concluded that the rate of milking is an inherited characteristic. However, the experimental data in support of this conclusion is not abundant.

Several workers, Matthews et al. (1941), Beck et al. (1951b), Dodd and Foot (1953), and Caroulo et al. (1955) showed that statistically significant differences in rate of milking existed between breeds. Beck et al. and Thoele (1954) cited these breed differences as evidence in support of inheritance of the rate of milking characteristic.

Several groups of workers have presented other evidence that the rate of milk flow is an inherited characteristic. Beck et al. (1951b) found statistically significant differences in the rate of milking that could be attributed to sires within a breed. These were based on 102 daughters of 31 sires. However only 14 of these had more than one daughter.

Therefore the data are actually based on 85 daughters of 14 sires. Dodd and Foot (1953) reported significant correlations of 0.37 on 40 dam-daughter pairs and 0.37 on 35 pairs of sibs and half-sibs. They also reported one sire with 8 daughters, all of which were slower milkers than their dams; and another sire with 8 daughters, whose rate of milking was very similar to their dams. Both of these reports were cited as preliminary observations, but neither group has presented supplementary evidence.

Hansen (1952 to 1956) has presented data showing a large range in rates of flow of progeny groups of different sires tested in the Danish cow testing associations; however no statistical analysis of the data have been made.

Thoele (1954) presented data on 33 daughters of four sires, the mean maximum rate of flow for the daughters of each sire were 8.2, 7.8, 7.6, and 6.2 pounds per minute. No statistical analysis was presented. However these data are reported to substantiate the differences between sires as shown by Hansen. Brumby (1956) reported data from identical and fraternal twins that showed the maximum rate and the average rate of flow to be strongly inherited, with a great deal of genetic variation existing between twin sets.

However, evidence has also been presented that rate of milk flow is not a characteristic, in which the role of heredity has been clearly elucidated.

Hupp (1956) reported statistically significant differences in the maximum rate of flow in one herd, while the differences between sire groups were not significant in two other herds. In the latter, the variance was greater within sire groups than between sire groups. In the herd where the means of sire groups were significantly different, there was a great variation within sire groups.

Ace (1957) reported that only the mean maximum rate of milk flow of Holsteins differed significantly from the other major dairy breeds in the herd studied. He reported significant differences between sire means, based upon 117 daughters of 28 sires with two or more daughters each. However, the intra-class correlation, or index of repeatability, among daughters of sires was 0.174 which is not statistically significantly different from zero. This indicates that large variation exists among individuals in the subsample. Ace also reported an intraclass correlation of 0.389 for 22 daughter-dam pairs. While this is not statistically significant, he concludes that a correlation coefficient of this magnitude indicates that the dam-daughter relationship may be greater than that of the sire to his daughters.

In view of the many factors which can contribute to the rate of machine milking, it is not surprising that heritability of rate of flow per se is hard to demonstrate, but

heritability of a single factor which might in some cases limit rate of flow could be high.

Stage of Lactation.

Somewhat conflicting views have been presented as to the effect of stage of lactation upon rate of milking. In many cases the effect of stage of lactation upon rate of milking has been confounded with the effect of the decline in level of production associated with progressing stage of lactation.

Matthews et al. (1941) found that the mean maximum rate of flow for 1.5 minutes at peak flow in the sixth month of lactation was only 62.6 percent of the rate when measured in the third month of lactation. The mean maximum rate of flow and production was rather low in both cases; 4.38 pounds of milk per minute and 30.6 pounds per day, respectively, in the third month and 2.74 pounds per minute and 17.3 pounds per day, respectively, in the sixth month of lactation.

Beck et al. (1951b) found that the differences in average and maximum rate of milking between early, middle, and late stages of lactation were highly significant. The differences in rate between the early and middle part of the lactation were less pronounced than between the middle and late part of lactation. However, the mean yields of milk

per milking for the three periods were 17.0, 11.3, and 6.1 pounds, respectively. Thus a large part of the differences reported by these two groups could be due to low levels of production at the later milking periods. At the earlier period, rate of flow could have been primarily dependent upon the teat sphincter, while at the later periods, rate of drainage of the milk into the teat cistern may have been the controlling factor.

Brumby (1956) and Stewart et al. (1957) also reported decreased average rates of flow with progressive stages of lactation. However, Stewart et al. reported that the average rate of flow decreased less rapidly than level of production, so total milking time decreased.

Dodd (1953), through analysis of data by covariance techniques, concluded that lactation decline in milking rate is related both to change in milk yields and to interval since calving.

On the other hand, Gregoire et al. (1954) found that in cows in their first lactation, the rate of flow increased slightly, but not significantly as the lactation progressed when milked at a vacuum level of 13 and 17 inches of mercury. There was no increase in rate of those milked at a vacuum level of 10 inches of mercury.

Caroulo et al. (1955) found that the linear change in rate of milking from the fourth to the forty-fourth week of lactation was not appreciable. This was based upon 48 cows, 24 of which were in the first lactation and 24 of which were in the second or subsequent lactation.

Hupp and Plum (1957) reported that the first lactation cows increased in maximum rate of flow in a four-month period during the portion of the lactation in which production remained over 30 pounds per day. Cows in a second or subsequent lactation did not show a significant change in rate of flow in the same period.

Level of production.

The work of Matthews et al. (1941), Harshbarger (1950), Beck et al. (1951b), Brumby (1956), and Sandvik (1957), and others indicates that a decreased rate of flow is associated with the decrease in level of production as the lactation progresses. Hupp (1956) reported that in the period while the level of production remained above 15 pounds per milking, at the milking measured, there was no significant change in rate of flow that could be associated with level of production.

Hupp (1956) also reported correlation coefficients of 0.131 and 0.147, between the maximum rate of milk flow and the level of production at that milking, when production was

above 15 pounds per milking. Neither of these correlation coefficients are statistically significant. However, if they were the true correlation coefficients, variations in level of production would account for only about two percent of the variation in rate of flow.

Several workers have also investigated the relationship between milking rate and the yield of milk in a standard lactation. An analysis of the data on rate of milking collected in the Danish cow testing work (Hansen, 1954 to 1956) shows a high correlation between the average production of the daughters of a sire and the average maximum rate of milking of these daughters. If the amount of milk produced in the second minute is used to represent the maximum rate, the coefficient of correlation is found to be 0.72, based upon the daughters of 142 sires measured in the years 1952 to 1955. This statistic is significant at the one percent level of probability.

Clough and Dodd (1957) report a highly significant regression of standard lactation yield on peak rate of flow, based upon a total of 352 cows. Records of 135 animals with yields between 15.0 and 17.9 pounds per milking gave a regression value almost identical with the one based on all the cows. This indicates that any differences in yield due to level of production at the time the recording was made

did not bias the results to any marked degree. These data support preliminary results reported earlier by Dodd and Foot (1953). They attribute the differences in standard lactation yield to the failure to remove all the milk from the slow milking cow during the time oxytocin is effective in expelling milk from the alveoli.

Two workers have reported results in conflict with the above. Brumby (1956) was unable to demonstrate any relationship between milking rate and milk yield on a between animal basis. He postulated that this may have been due to good milking techniques, so that all of the milk was removed from the slow milking cows in this study. Sandvik (1957) reported that when the effect of milk yield at the recorded milkings on the observed characteristics was eliminated, through the use of a correction factor, the milking character had no significant effect on the lactation yield, the maximum daily yield, or the persistency. The same results were obtained when only the data from observations on the milking characteristics in which the yield was between 6.1 and 7 Kg. were used. From this he concluded that slow milking cows are not necessarily poor producers.

Age of the cow.

Matthews et al. (1941) found that in cows which were studied in two successive lactations, the milking rate for

1.5 minutes at peak flow was 8.29 percent lower in the later lactation. The average age of the cows at the earlier lactation was 4.6 years, and at the subsequent lactation, 6.2 years.

A tendency for the maximum rate of milk flow to decrease with increasing age of the cow was reported by Korkman (1948). The decrease was significant at the six percent level of probability.

However, the maximum rate of milk flow in the first lactation has been reported to be significantly less than in the second lactation (Dodd, 1953). The cows milked slightly faster with each subsequent lactation, but the differences between these subsequent lactations were not significant. Hupp (1956) reported that the mean maximum rate of milk flow of cows in their first lactation was slightly greater than the mean maximum rate of cows which were in their second through ninth lactations. With the relatively small number of animals involved, the differences were not statistically significant.

Differences between morning and evening milking.

Matthews et al. (1941), Dodd and Foot (1947), and Brumby (1956) have shown that if the differences in interval between milking are great, such as 9 and 15 hour intervals or 8 and 16 hour intervals, differences in the rate of flow

between the two milkings occur. However, Thoele (1954) has shown that differences in rate of flow between morning and evening milkings were slight and not statistically significant when 12 hours intervened between milkings. Hupp (1956) reported that no significant differences occurred in the rate of flow when 12 hours intervened between milkings, or when 11 and 13 hours intervened between milkings.

Differences due to length of milking time.

In cows in their first lactation, in which half of the udder was milked for twice normal periods for 40 weeks, Gregoire et al. (1954) found a significantly faster average rate of flow in the half which was milked the twice normal period. One possible explanation was that the prolonged milking over the 40 week period stretched the teat sphincter, causing a larger opening and a greater rate of flow. Thus conceivably, a herd in which the machine is consistently left on the cow too long might be capable of a higher rate of flow due to the prolonged milking.

Relationship to mastitis.

Dodd and Kneave (1951) reported a high correlation between milking rate and incidence of clinical and sub-clinical mastitis in cows in their first lactation. They postulated that bacteria can gain entrance to the udder more easily

through the slackened teat sphincter of the more rapid milking cows. They suggested that a portion of the increased incidence of mastitis in the fast milking cows could be due to udder injury resulting from leaving the machine on the cows too long after they were milked out. In contrast to the above report, Caroulo et al. (1955) found that in 24 cows in their first lactation and 24 cows in their second or subsequent lactation, cows with a previous history of mastitis milked at a slightly lower rate. Thus the exact relationship between mastitis and rate of milk flow has not been demonstrated.

OBJECTIVES

1. To investigate the effect that the addition of water to the concentrate mix which is fed during milking may have upon the milking rate and eating rate.
2. To investigate the effect of injected oxytocin upon the rate of milk flow.
3. To investigate the effect of variation in the interval between preparation of the udder and attachment of the teat cups upon the rate of milk flow, level of production, and milk composition.
4. To determine the accuracy of the milk measuring and weighing devices used in these studies.

The procedures and results of these studies will be presented in two sections. Section A includes the study of the effects of several variables as outlined in objectives 1 to 3. Section B comprises a validation of the milk measuring and weighing devices used in this research (objective 4).

S E C T I O N A

EXPERIMENTAL PROCEDURE

The methods used in this section will be presented in three parts. Part I describes the methods used to investigate the effect of addition of water to the concentrate mix fed during milking. Part II describes the procedures used to investigate the effect of oxytocin injections, while Part III describes the procedures used to investigate the effects of varying the interval between preparation of the udder and attachment of the teat cups.

Part I. The Effect of Adding Water to the Concentrate Mix

In this experiment, 16 registered Brown Swiss cows, a part of the Michigan State University Dairy herd, were used. They were housed and milked in a loose housing steel barn. The milking room used was a four stall side opening U-type. This parlor was equipped with a two unit Chore-Boy pipeline milker which operated at a vacuum level of 10.6 inches of mercury. Ranges in vacuum level of from 10.4 to 10.8 inches of mercury were noted during the course of the experiment.

Each milking unit included a weigh pail suspended from a spring scale so that the amount of accumulated milk could be readily noted. An evaluation of the accuracy of the milk weights obtained by this method will be presented in Section B.

A concentrate mix consisting of 60 parts shelled corn, 15 parts soybean oil meal, 15 parts oats, 10 parts barley, 1 part salt and 1 part di-calcium phosphate was fed during milking. The grain had been ground to a coarse consistency using a B. J. Humdinger hammer mill with a $3/16$ inch screen. The concentrate mix was stored in an overhead automatic feeder, and was measured into each individual feed trough with a crank that delivered two pounds with each turn. When water was added to the concentrate mix, the water was poured into the trough; then the concentrate mix was added. About 30 seconds were required for the water and grain to become thoroughly mixed. Preliminary experiments indicated that hand mixing did not hasten the mixing, so no hand mixing was done.

In the normal milking routine, the cows entered the parlor from a holding pen, usually two at a time. Then the udders were washed with warm water and the strip cup was used to check for abnormal milk. Two cows were usually prepared at a time. The average interval between preparation and attachment of the teat cups was 2.65 ± 1.20 minutes during the period when dry grain was fed and 2.81 ± 1.20 minutes during the period in which water was added to the grain. The standard deviation is quite large because the first cow prepared usually had the machine stripping time of one cow between preparation of the udder and attachment

of the teat cups, while the second cow prepared had the additional interval while another cow was machine stripped before the teat cups were attached.

The following observations were taken for each cow milked:

1. The time the udder was washed.
2. The time of application of the first teat cup. The concentrate mix was fed by the person recording the data, to coincide with the application of the teat cups.
3. The time at which each pound of milk accumulated in the weigh bucket.
4. The time concentrate eating was completed.
5. The time stripping started and the pounds of milk in the weigh bucket at that time.
6. The time at completion of milking.
7. The total pounds of milk weighed with the claw hanging in the same position at which the scale was adjusted to zero with the bucket empty.

These observations yielded data for each cow from which the average eating rate, average milking rate, and a milk flow curve could be computed. The average eating rate was obtained by dividing the pounds of grain eaten by the total eating time. The average milking rate was determined by

dividing total pounds of milk produced by total milking time. The milk flow curve was obtained by computing the time required to produce each successive pound of milk.

Although most other workers who have made measurements of milking rate during the course of milking by other than graphic means have determined flow rates from measurements of pounds of milk produced in a fixed period of time, these data were obtained as the time required to produce each pound of milk. There is less error in reading the scale in this way than when the accumulated amount of milk must be noted at an exact instant. In that case, the swinging dial of the scale must be read instantly, while in the method used in this experiment, by observing the swinging dial, it can be determined quite accurately when each pound of milk is reached. At that instant the watch, the hand of which is moving at a constant rate, can be easily read. Flow rates, computed as seconds required per pound of milk produced, were converted to pounds per minute before presenting the results so that they can be more readily compared with the other data in the literature.

This experiment was conducted in November, 1957. Six control observations, three of which were morning and three evening milkings were made during which the normal milking routine prevailed. Following the control observations, water

was added to the concentrate mix at the rate of $1\frac{1}{2}$ pounds of water per pound of concentrate mix for a three day adjustment period, during which no observations were taken. Then observations were taken for six more milkings. The procedure was similar to the control observations, except for the addition of water to the feed trough just before the concentrate mix was added. Following this observation period, watering the concentrate mix was stopped. After a four-day adjustment period, two additional control observations were made.

Part II. The Effect of Oxytocin Injections

Registered Holstein-Friesian and Brown Swiss cows, comprising a portion of the Michigan State University Dairy herd, housed and milked in the main tie-stall barn on the Michigan State University campus, were used in this study. In the normal milking procedure, the cows were milked in the stalls by one man operating two units of a DeLaval pipeline milker. The udders were washed and the strip cup employed to check for abnormal milk approximately two minutes before the teat cups were attached. Since two cows were usually prepared at once, this interval varied considerably. Milk-O-Meters were used with both milker units. The meters were hung on mounts which were located below each inlet in

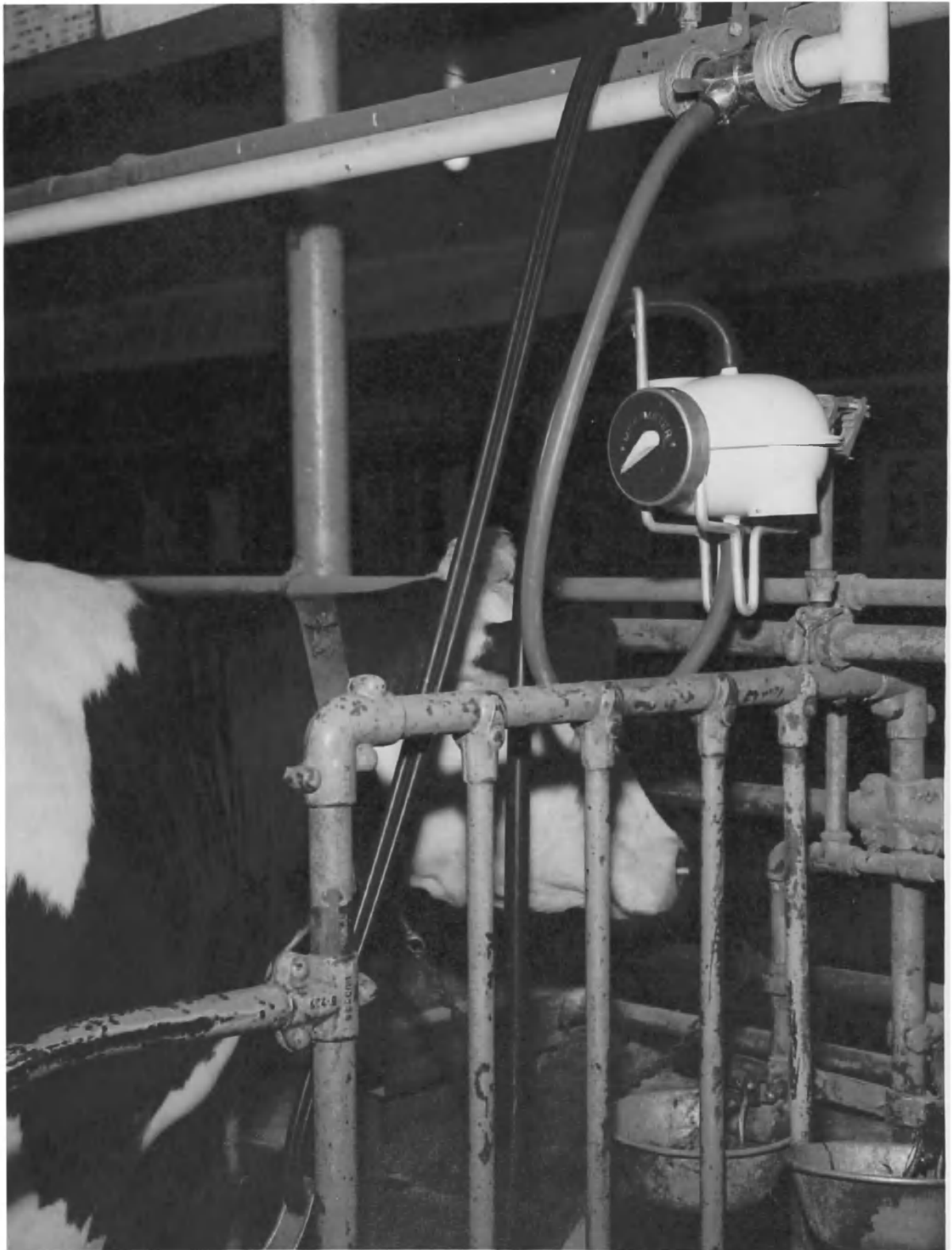
the pipeline, one of which was located between each two cows. The milk from the cow passed through the meter and directly into the pipeline. A Milk-O-Meter in operation is shown in Figure 1.

In Trial 1, seven Holstein-Friesian cows were used. They were selected on the basis of their slow milking characteristics, as determined by preliminary observations. Meter No. 1-1460 was used for the pre-treatment observations, except for three observations in which meter No. 1-1454 was used. Meter No. 1-1553 was used for the treatment and post-treatment observations.

Two control observations were taken, in which the normal milking procedure was followed, except that all cows in the experiment were milked with one milker unit to facilitate taking the observations. The following data were taken for each cow which was included in the experiment:

1. The time the udder was washed.
2. The time the last teat cup was applied--this is starting time.
3. The time each pound of milk accumulated, as indicated by the Milk-O-Meter dial.
4. The time stripping started and the pounds of milk produced up to that time.
5. The time the teat cups were removed and the total pounds of milk as indicated by the meter dial.

Figure 1. The Milk-O-Meter in operation in the Tie-stall
main dairy barn.



Following the control observations, the seven cows were given injections of 20 I.U. of oxytocin (Parke-Davis Pitocin) preceding each milking for three milkings. The cows were tied in the stanchions at the south end of the barn and given the injections of oxytocin intrajugularly. Each cow was returned to her tie-stall, immediately after injection, the udder washed, strip cup employed, and the teat cups attached. The interval between the time the oxytocin entered the jugular vein and the time the last teat cup was attached was timed which averaged 99.5 ± 9.1 seconds. The same data were taken as in the control observations, except that the time the udder was prepared was not noted.

Three days later two more control observations were made. The same procedures were used as in the control observations made before the treatment milkings.

The procedures used in Trial 2 were similar to those used in Trial 1. Seven Holstein and one Brown Swiss cow were selected to cover the range in rate of milk flow encountered within the herd. Meter No. 1-1460 was used throughout, but was equipped with the modified baffle plate rather than the pin-type baffle plate used in Trial 1. The time between injection and attachment of the last teat cup was 110.4 ± 20.6 seconds, as compared to 99.5 ± 9.1 seconds in Trial 1. The other procedures followed were the same as

in Trial 1. However, in the three day interval between the injection period and the post-injection control observations, difficulties in the operation of the milker necessitated repairs. These repairs produced a greater vacuum potential without changing the vacuum level and may have affected the pulsation pattern as well.

Part III. Variation in Interval from Preparation to Milking

The same Holstein-Friesian herd used in the experiments described in Part II was used in this experiment. The normal milking procedure was also the same. The data obtained in this experiment were taken with the recording Milk-O-Meter. The operating parts of this meter are the same as in the regular meter, except that two electrical contacts have been added so that each time the weigh tray trips an electrical impulse is sent to the recorder. This impulse from the meter is carried by a wire which is plugged into a jack. One jack is located behind each Milk-O-Meter mount in the barn. These jacks are connected to a low voltage wire which goes all the way around the barn and leads to the recorder. Thus the recording meter can be used for any cow milked in the main barn while the recorder is located in one place. Each time the recorder receives an impulse from the meter, it makes a mark with an indelible marker on a tape which is driven past the marker at a constant speed.

Figure 2 shows the recording Milk-O-Meter with the sampler attached, plugged directly into the recorder. In the barn an additional length of wire would separate the meter and recorder. Figure 3 shows the inside detail of the recorder.

In addition to the graphic record made of each milking by the recorder, a stop watch synchronized with the recorder, was used to obtain additional data to complete the flow curve. The following observations were made:

1. The time the udder was washed.
2. The time the last teat cup was applied--this is the starting time.
3. The time stripping started.
4. The time the teat cups were removed and the total pounds of milk as indicated by the meter dial.

A total of ten cows were selected for this experiment on the basis of rather high milk production and freedom from recent clinical cases of mastitis. They covered the range in rate of flow of the cows in the herd which had high current levels of production. Each of these cows was milked at 0, 4, 8, 12, 16, and 20 minutes following preparation of the udder by washing the udder and using the strip cup. In the milking designated as the zero interval, 0.58 minutes actually elapsed between the time preparation of the udder

Figure 2. The recording Milk-O-Meter with the butterfat sampler attached, and the Recorder. In actual operation, both pieces are mounted in the barn and the wire leading from the meter to the Recorder is much longer.

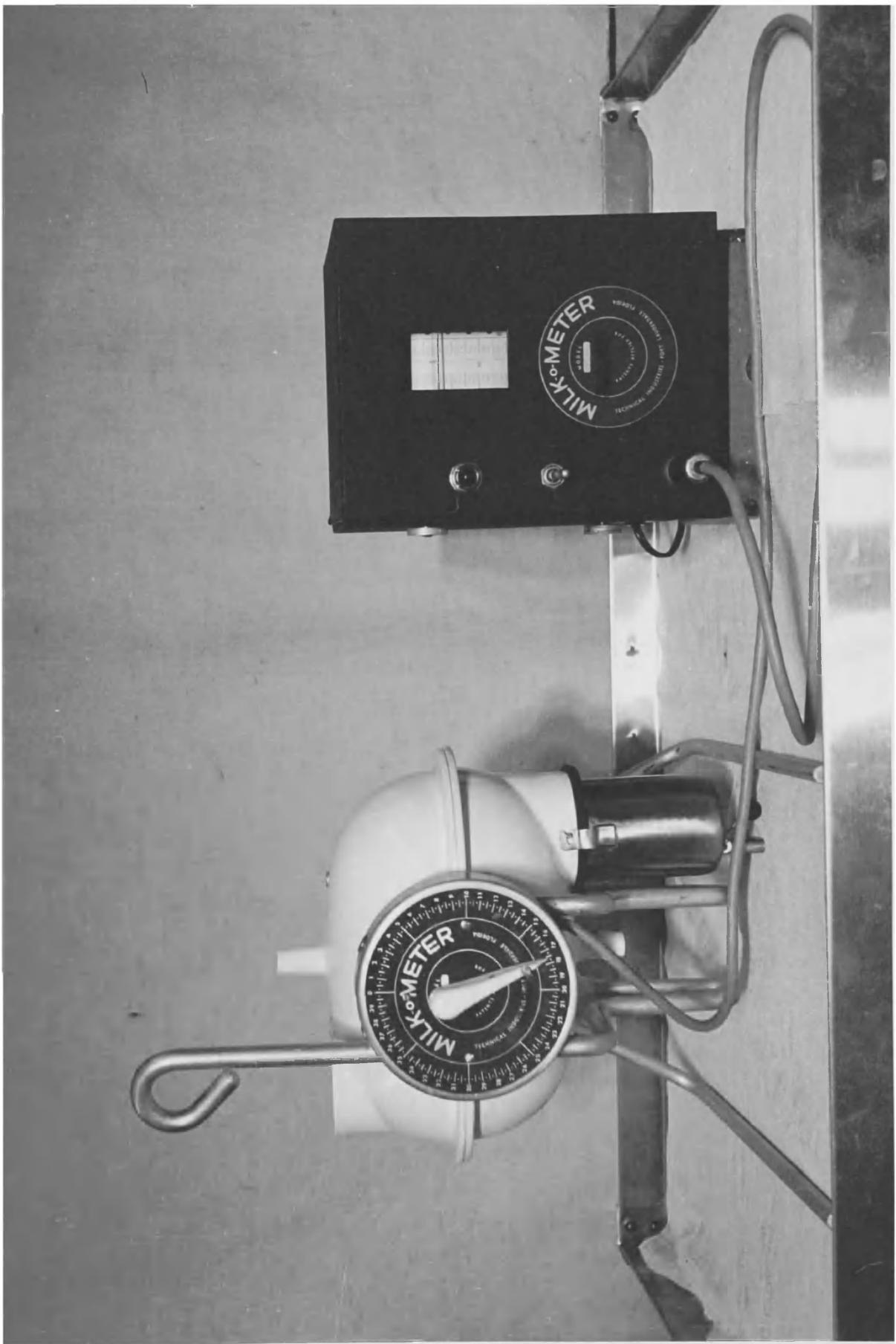
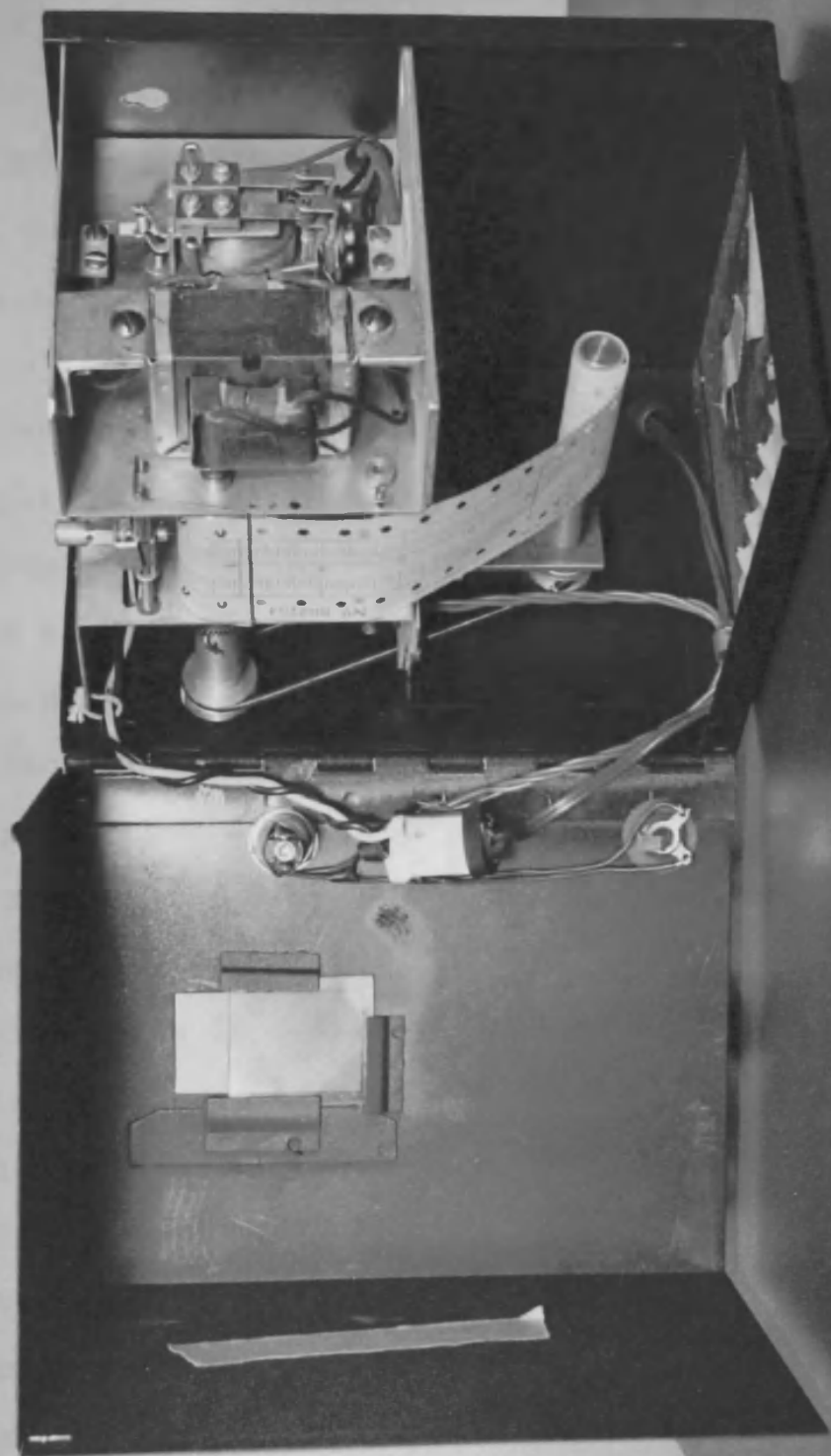


Figure 3. Inside detail of the Recorder used with the
Recording Milk-O-Meter.



began and the time the last teat cup was attached. This mean time had a standard deviation of 0.40 minutes. The means and standard deviations for the other intervals are as follows: 4.37 ± 0.52 minutes; 8.22 ± 0.44 minutes; 12.15 ± 0.41 minutes; 16.32 ± 0.58 minutes, and 20.43 ± 0.78 minutes.

The order of the treatments was randomized for each cow for each replication, using a table of random numbers. There were three replications, so that in the entire experiment, each cow was milked following each interval three times. All observations were made at the evening milking so that any residual effect of the treatments would be obtained at the morning milking. The first, second, and third replications were taken May 26 to 31, June 1 to 11, and June 22 to 30, 1958, respectively.

The only change in the regular milking routine was that the recording meter was substituted for one of the regular meters, and the cows used in the experiment were milked with the milking unit which had this meter. The cows were milked in the regular order as nearly as possible. However, at times when the longer intervals between preparation of the udder and attachment of the teat cups were used, the cow was prepared quite a distance up the milking line so that the desired interval would have elapsed by the time her turn came in the line.

In the first replication, the meter was used without the sampler; in replications two and three, the sampler was used with the meter, and the entire volume withdrawn by the sampler was removed for use in composition analysis.

The percent butterfat in these samples was determined by the Babcock method. The percent protein was determined by Richardson's modification of the Formol titration (Richardson et al., 1953). Total solids were determined by the small Watson Lactometer, the accuracy of which has been reported by Madden and Brunner (1958).

RESULTS AND DISCUSSION

The results obtained in these experiments and a discussion thereof will be presented in three parts. In Part I the effect of addition of water to the concentrate mix will be presented. In Part II, the effects of injected oxytocin upon the rate of milk flow and level of production will be presented, while Part III presents the results obtained when the interval between preparation of the udder and attachment of the teat cups was varied.

Part I. The Effect of Adding Water to the Concentrate Mix

The object of this experiment was to investigate the effect that addition of water to the concentrate mix fed at milking time might have on the rate of milk flow and also on eating rate.

The effect on average and maximum rate of milking and eating rate.

In Table 1 data are presented showing the effect of addition of water to the concentrate mix on the average rate of flow, maximum rate of milk flow and the average eating rate. The average rate of milk flow and average eating rate were computed as described in the procedures. The maximum

TABLE 1

THE EFFECT OF FEEDING A WATERED CONCENTRATE MIX
ON THE MAXIMUM RATE OF MILK FLOW, AVERAGE RATE
OF MILK FLOW AND AVERAGE EATING RATE

	Maximum Rate of Flow (lbs./min.)	Average Rate of Flow (lbs./min.)	Eating Rate (lbs./min.)
Dry Grain	3.73	2.19	0.63
Watered Grain	3.60	1.92	0.90
Difference	-0.13	-0.27**	+0.27**

** Significant at the one percent level of probability, as analyzed by the "T" test for paired observations.

rate of flow was determined from the flow curve. It is the rate of flow in which from two to five pounds of milk were produced at the fastest rate during that milking. In most cases the period encompassed the time required to produce five pounds of milk. However in some cases, due to low levels of production or the particular flow curve of the cow, the maximum rate of flow did not persist that long. In that case, the time required to produce two or three pounds of milk was used. However, the period measured encompassed the same number of pounds for all milkings of each individual cow.

The increased eating rate with the watered grain, as reported by Dalton et al. (1953) and Thoele (1954) was

confirmed (Table 1). However, the increase in eating rate was not as marked as that reported by Dalton et al. The time required in this experiment to eat a pound of grain to which water had been added was only 70 percent of that required to eat the dry grain. This difference is significant at the one percent level of probability.

The maximum rate of milk flow decreased slightly with the watered grain. This decrease was not statistically significant. In nine of the 16 cows, the maximum rate was slower and in seven it was faster. In contrast to the results of Dalton et al. (1953), who reported an increased average milking rate, the average rate of milk flow actually decreased 12 percent with the watered grain. This change was significant at the one percent level of probability.

The effect on the components of the milk flow curve.

In order to further investigate the decreased average rate of flow, the milk flow curve was broken into three component parts. These components are as follows: Part 1 is from the time the last teat cup was applied to the time that the rate of flow decreased to half of the maximum rate of flow at that milking. Part 2 is the interval beginning at the end of Part 1 and continuing until machine stripping begins. (This includes the idle time before stripping began.)

Part 3 is the interval from the time machine stripping began until the teat cups were removed.

The average production, average milking time, and average rate of flow for each of these three components and the entire curve are reported in Table 2. This table shows

TABLE 2

THE EFFECT OF FEEDING A WATERED CONCENTRATE MIX ON
AVERAGE MILK PRODUCTION, AVERAGE MILKING TIME AND AVERAGE
RATE OF MILK FLOW FOR THE THREE COMPONENT PARTS
OF THE MILKING CURVE

	Average Production (lbs.)	Average milk- ing Time (min.)	Average Rate of Flow (lbs./min.)
Part 1			
Watered Grain	9.46	3.26	3.42
Dry Grain	9.96	3.31	3.54
Difference	-0.50	-0.05	-0.12
Part 2			
Watered Grain	2.02	2.72	0.74
Dry Grain	2.22	2.49	0.87
Difference	-0.20	+0.23	-0.13
Part 3			
Watered Grain	3.06	1.91	1.50
Dry Grain	3.07	1.69	1.80
Difference	-0.01	+0.22	-0.30**
Entire Curve			
Watered Grain	14.54	7.89	1.92
Dry Grain	15.25	7.49	2.19
Difference	-0.71**	+0.40	-0.27**

** Significant at the one percent level of probability, as analyzed by the "T" test for paired observations.

that the production was slightly less with the watered grain while the total milking time increased an average of 0.4 minutes per cow. This resulted in the significant decrease in average rate of flow.

In Part 1 of the milk flow curve, production with the watered concentrate mix was 0.5 pound lower while the milking time decreased only slightly. The resulting decrease in average rate of flow was not significant. Since less milk was produced in Part 1 with only a slight change in milking time when watered concentrate mix was fed, this could indicate a slight effect on let down. Therefore the time required to reach a high rate of flow was determined. Since the maximum rate of flow persisted for only a short period of time, another criterion, the high rate of flow, was established. It is defined as the interval during which a pound of milk is produced in up to two seconds more than the time required to produce a pound at the maximum rate. This latter period should correspond closely to the period of maximum rate of flow reported by other workers. During the period in which the dry concentrate mix was fed, an average of 60.5 seconds elapsed before a high rate of flow was reached. When water was added to the concentrate mix, an average of 59.7 seconds elapsed before a high rate of flow was reached. These times are almost identical and

the slight difference is not statistically significant. Therefore no indication of an effect on let down is noted in this part of the curve.

In Part 2 of the milk flow curve, the idle time before stripping began, production decreased 0.2 pounds while milking time increased 0.22 minutes. Due to wide variation between cows, the resulting decrease in average rate of flow was not statistically significant. The increased idle time in Part 2 reflects the increased stripping time which was responsible for the highly significant decrease in average rate of flow in Part 3.

Discussion.

The above results indicate that the highly significant decrease in the average rate of flow was due primarily to increased time spent by the operator during stripping. Apparently this was in an attempt to overcome the slight decrease in production which was encountered. This increased milking time is a function of the machine operator and cannot be attributed to the effect of addition of water to the concentrate mix upon the milk flow characteristics of the individual cow. The fact that the maximum rate of flow, average rate of flow before the machine stripping should have begun, and the time required to reach a maximum rate of flow were not changed significantly by the addition of water to

the concentrate mix shows that this procedure did not have an effect on the rate of milk flow as controlled by the cow.

Part II. The Effect of Oxytocin Injections

Although the primary role in control of rate of milk flow has been attributed to the teat sphincter, several workers (Whittlestone, 1954; Turner, 1954; Dodd and Clough, 1957; and others) have stated that some cows may be slow milkers because of an insufficient let down of milk. In order to investigate the relative importance of these two factors, in controlling rate of milk flow, injections of oxytocin were used to assure an adequate level of oxytocin in the blood.

Maximum rate of flow.

Differences between cows. An analysis of the sources of variation in maximum rate of flow in Trial 1 is presented in Table 3. Each milking is considered separately. A similar analysis was carried out for each characteristic investigated. In Trial 2 the data from only six cows were used in the analysis. There were highly significant differences between cows in maximum rate of flow. It has been shown repeatedly by other workers that differences in maximum rate exist between cows, but these data show that these differences

can be demonstrated even in a group selected for their slow milking characteristics. Significant, or highly significant differences between cows were also noted for average rate of milk flow, pounds of milk produced, seconds before a high rate of flow began and seconds that a high rate of flow persisted in Trials 1 and 2 and stripping time in Trial 2. The differences between cows were not significant for the seconds between the end of a high rate of flow and the time stripping started in Trials 1 and 2, and stripping time in Trial 1. A lack of significant differences for these characteristics indicates that they are primarily under the control of the machine operator, rather than the cow.

Differences between treatment and control. The data in Table 3 also show that there were no significant differences in the maximum rate of flow between the seven milkings in Trial 1. Thus oxytocin injections did not change the maximum rate of flow significantly for these seven slow milking cows. The mean maximum rates of flow, and their order, from the slowest to the fastest rate are presented in Table 4.

Eight cows were used in Trial 2; however, one cow developed mastitis following the treatment period. Thus post-treatment control observations could not be made, so the

TABLE 3
ANALYSIS OF VARIANCE
SOURCES OF VARIATION IN MAXIMUM RATE
OF MILK FLOW IN TRIAL 1

Source of Variation	Degrees of Freedom	Mean Square	"F"
Total	48	15.00	--
Cows	6	90.20	14.09**
Treatment	6	7.95	2.18
Error	36	3.64	--

**Statistically significant at the one percent level of probability.

data from the other five milkings on this cow were eliminated. The one Brown Swiss cow showed great variation in maximum rate of flow between milkings. This resulted in within-cow variation that was not compatible with that of the other cows. The data from this cow were eliminated from the group comparisons, but will be presented separately at the end of this section. Thus the group comparisons in Trial 2 are based upon observations on six cows.

Analysis of variance showed highly significant differences in maximum rate of milk flow between milkings in Trial 2. The means were tested by Duncan's multiple range test (Duncan, 1955) to see which differed significantly. The mean rates of flow ranked from slowest to fastest are

TABLE 4
MILKINGS ARRANGED IN ASCENDING ORDER BY
MAXIMUM RATE OF FLOW FOR THE TWO OXYTOCIN TREATMENT TRIALS

Order:	1	2	3	4	5	6	7
Trial 1: (7 cows)							
Milkings ^a	A-1	O-2	O-3	B-1	A-2	O-1	B-2
Mean Rate ^b	3.16	3.47	3.51	3.64	3.66	3.75	3.64
Significance ^c							
Trial 2: (6 cows)							
Milkings ^a	B-2	O-2	B-1	O-1	O-3	A-1	A-2
Mean Rate ^b	4.81	5.08	5.14	5.68	5.84	6.76	6.84
Significance ^c							

a. A = after treatment; 1 = the first milking in the period, etc.

B = before treatment; 1 = the first milking in the period, etc.

O = oxytocin treatment; 1 = the first milking in the period, etc.

b. The mean of the maximum rate of flow is expressed in pounds per minute.

c. Those means underscored by the same line are not significantly different.

presented in Table 4. Those means underscored by the same line are not significantly different. (All other characteristics in which significant differences were shown between milkings by analysis of variance were analyzed in a similar manner.) In the tables presented, those means shown to be not significantly different by the analysis of variance were

not tested by Duncan's multiple range test. They are underscored by a single line to indicate that they are not significantly different.

The results in Table 4 show that the maximum rate of flow in the two post-treatment observations is significantly faster than the other milkings. This is due to the repairs made on the milking machine in the period between the treatment and post-treatment controls. The rate of flow in the third oxytocin treatment is significantly faster than the two pre-treatment controls and the second oxytocin treatment. The first oxytocin treatment is significantly faster than the second pre-treatment control and the second oxytocin treatment. The second oxytocin treatment is not significantly different from either of the pre-treatment controls. These results indicate that the oxytocin had a slight effect on these cows, some of which milked quite rapidly. This slight effect of rate of flow could be due to a slightly greater increase in pressure within the gland and the teat cistern due to a more rapid let down caused by the high level of oxytocin injected. This increased pressure was indicated by the fact that more of the cows leaked milk from the teats following injections of oxytocin, than following let down induced in the normal manner. If there was an increased pressure, the higher pressure could be reflected more fully in the faster milking cows in which there is a

larger teat orifice and also possibly less tension in the sphincter. Thus the teat would open to a larger degree under the increased pressure. This could explain the slightly increased rate of flow obtained in Trial 2 and not in Trial 1 in which slower milking cows were used.

Average rate of flow.

The average rates of milk flow for each of the milkings in Trials 1 and 2 are presented in Table 5. There were no significant differences in average rate of flow between milkings in Trial 1, but there were significant differences, as indicated by the means not underscored by the same line, in Trial 2. As was shown with the maximum rate of flow, the two post-experimental control observations were significantly faster. The other milkings are in much the same order as the maximum rate of flow, but the differences are not as marked. The average rate of flow also indicates that the oxytocin injections had a slight effect on the rate of flow. However, the effect is not as large, since average rate of flow is partially a function of the machine operator and does not reflect changes in the rate of flow of the cow quite so sharply.

Level of Production.

The average production at each of the milkings in Trials 1 and 2 is presented in Table 6. In Trial 1,

TABLE 5

MILKINGS WITH AND WITHOUT OXYTOCIN TREATMENT
ARRANGED IN ASCENDING ORDER BY AVERAGE RATE OF FLOW

Order:	1	2	3	4	5	6	7
Trial 1: (7 cows)							
Milking ^a	0-2	A-1	A-2	B-1	B-2	0-3	0-1
Mean Rate ^b	2.46	2.56	2.66	2.67	2.69	2.86	3.00
Significance ^c							
Trial 2: (6 cows)							
Milking ^a	B-2	B-1	0-2	0-3	0-1	A-1	A-2
Mean Rate ^b	3.37	3.46	3.58	3.86	4.21	4.24	4.46
Significance ^c							

a. A = after treatment; 1 = the first milking in the period, etc.

B = before treatment; 1 = the first milking in the period, etc.

0 = Oxytocin Treatment; 1 = the first milking in the period, etc.

b. The mean of the average rate of flow is expressed in pounds per minute.

c. Those means underscored by the same line are not significantly different.

production at the two pre-treatment milkings was highest. However, it was significantly higher than only the production at the second and third treatment milkings. In Trial 2, the production at the first treatment milking was considerably higher than the other milkings. However, there were no significant differences between the production at the different milkings in the trial.

TABLE 6

MILKINGS WITH AND WITHOUT OXYTOCIN TREATMENT
ARRANGED IN ASCENDING ORDER BY LEVEL OF PRODUCTION

Order:	1	2	3	4	5	6	7
Trial 1: (7 cows)							
Milking ^a	0-2	0-3	A-1	A-2	0-1	B-2	B-1
Mean Production ^b	17.75	17.96	18.29	18.32	19.00	19.93	20.18
Significance ^c							
Trial 2: (6 cows)							
Milking ^a	B-1	0-2	0-3	B-2	A-1	A-2	0-1
Mean Production ^b	18.54	18.79	19.83	20.20	20.33	20.88	21.67
Significance ^c							

- a. A = after treatment; 1 = the first milking in the period, etc.
 B = before treatment; 1 = the first milking in the period, etc.
 O = Oxytocin Treatment; 1 = the first milking in the period, etc.
- b. The mean production is expressed in pounds per milking.
- c. Those means underscored by the same line are not significantly different.

The components of the milking curve.

The milking curve was divided into four component parts, in order to see if the injection of oxytocin had an effect on any of these components. The components are as follows:

Part 1 - The time required to reach a high rate of flow.

(The high rate of flow, as defined earlier, is the interval during which a pound of milk is produced in up to two seconds more than the time required to produce a pound of milk at the maximum rate.)

Part 2 - The time a high rate of flow persisted.

Part 3 - The interval from the completion of the high rate of flow to the time machine stripping began.

Part 4 - The machine stripping time.

The above parts of the milking curve do not correspond directly to those listed in Part 1 of the thesis. In Part 1 of the thesis, the three components were designed primarily to eliminate the time in which the machine was idle, while in this section, the curve is broken into 4 parts by flow characteristics.

Table 7 shows the number of seconds which elapsed following attachment of the last teat cup, before a high rate of flow was reached. Although a high rate of flow was reached sooner, following injection of oxytocin in both trials, the differences were not statistically significant in Trial 1, and not significantly different from all of the control observations in Trial 2. The greatest and most consistent effect of the oxytocin injections is shown in

TABLE 7

MILKINGS ARRANGED IN ASCENDING ORDER OF THE
NUMBER OF SECONDS BEFORE A HIGH RATE OF FLOW WAS REACHED,
WITH AND WITHOUT OXYTOCIN TREATMENT

Order:	1	2	3	4	5	6	7
Trial 1: (7 cows)							
Milking ^a	0-2	0-3	0-1	A-2	A-1	B-1	B-2
Mean Time ^b	37.14	42.27	42.57	51.14	60.71	73.86	81.86
Significance ^c							
Trial 2: (6 cows)							
Milking ^a	0-1	0-3	A-2	0-2	B-1	A-1	B-2
Mean Time ^b	19.33	23.67	30.50	31.67	41.33	42.33	54.00
Significance ^c							

- a. A = after treatment; 1 = the first milking in the period, etc.
B = before treatment; 1 = the first milking in the period, etc.
O = Oxytocin Treatment; 1 = the first milking in the period, etc.
- b. The mean time is expressed in seconds.
- c. Those means underscored by the same line are not significantly different.

this portion of the curve. This indicates that the milk was let down more completely at the start of milking following the oxytocin injections, than at the control milkings. Thus the high rate of flow started sooner.

The mean number of seconds during which a high rate of flow persisted is shown in Table 8. One milking in each

TABLE 8

MILKINGS ARRANGED IN ASCENDING ORDER OF THE
NUMBER OF SECONDS A HIGH RATE OF FLOW PERSISTED,
WITH AND WITHOUT OXYTOCIN TREATMENT

Order:	1	2	3	4	5	6	7
Trial 1: (7 cows)							
Milking ^a	A-2	O-2	B-2	O-1	O-3	B-1	A-1
Mean Time ^b	154.57	166.57	189.86	193.00	198.86	204.86	264.29
Significance ^c							
Trial 2: (6 cows)							
Milking ^a	A-1	A-2	B-1	B-2	O-2	O-3	O-1
Mean Time ^b	115.5	126.0	148.2	149.3	155.8	157.7	193.2
Significance ^c							

- a. A = after treatment; 1 = the first milking in the period, etc.
B = before treatment; 1 = the first milking in the period, etc.
O = Oxytocin treatment; 1 = the first milking in the period, etc.
- b. The mean time is expressed in seconds.
- c. Those means underscored by the same line are not significantly different.

trial is significantly different from the others. The high rate of flow persisted significantly longer in the first post-treatment control observation in Trial 1, that milking had the slowest maximum rate of flow in that trial; this indicates that machine factors may have been responsible for the slow rate of flow and consequent longer duration of the

high rate of flow. At the first milking at which oxytocin was injected in Trial 2, the high rate of flow persisted significantly longer than in the two post-treatment controls. A portion of the difference is due to the increased rate of flow in the post-treatment control period resulting from the machine repairs. However, the average time during which the high rate of flow persisted in this milking is considerably, although not significantly, longer than in all the other milkings. A large portion of this difference is due to one cow whose production was very high at that milking. Thus the high rate of flow persisted longer.

Tables 9 and 10 present the mean number of seconds between the high rate of flow and the time stripping started, and the stripping time, respectively. Although large differences are shown, due to the large within milking variances, there are no significant differences between the means. However, as the analysis of individual cow differences shows, these two parts of the curve are primarily under the control of the machine operator, thus a lack of significant differences here does not give strong evidence for a lack of an effect of oxytocin injections upon this portion of the flow curve.

TABLE 9

MILKINGS ARRANGED IN ASCENDING ORDER OF THE
NUMBER OF SECONDS BETWEEN THE END OF A HIGH RATE OF FLOW AND
THE TIME STRIPPING STARTED WITH AND WITHOUT OXYTOCIN

Order:	1	2	3	4	5	6	7
Trial 1: (7 cows)							
Milking ^a	0-3	A-1	0-1	B-2	B-1	A-1	0-2
Mean Time ^b	30.0	65.0	68.0	70.4	82.4	99.9	100.3
Significance ^c							
Trial 2: (6 cows)							
Milking ^a	0-1	A-2	0-3	B-1	B-2	A-1	0-2
Mean Time ^b	-7.7	31.7	32.3	41.8	54.2	56.7	67.3
Significance ^c							

- a. A = after treatment; 1 = the first milking in the period, etc.
 B = before treatment; 1 = the first milking in the period, etc.
 O = Oxytocin treatment; 1 = the first milking in the period, etc.
- b. The mean time is expressed in seconds.
- c. Those means underscored by the same line are not significantly different.

An example of a faulty let down.

Figure 4 presents two milking curves for the Brown Swiss cow No. 3006. Number 1 is a normal control milking, taken at the second post-treatment control observation. Number 2 is a control milking at which the cow failed to let down her milk normally. This was at the first post-treatment control observation. Although this cow was a

TABLE 10

MILKINGS ARRANGED IN ASCENDING ORDER OF
STRIPPING TIME IN SECONDS WITH AND WITHOUT OXYTOCIN TREATMENT

Order	1	2	3	4	5	6	7
Trial 1: (7 cows)							
Milking ^a	A-2	B-1	O-1	A-1	B-2	O-3	O-2
Mean Time ^b	61.1	75.9	76.3	76.3	87.3	101.3	101.4
Significance ^c							
Trial 2: (6 cows)							
Milking ^a	O-2	A-2	O-3	O-1	B-1	A-1	B-2
Mean Time ^b	62.3	66.3	68.6	98.7	99.0	106.0	150.3
Significance ^c							

- a. A = after treatment; 1 = the first milking in the period, etc.
 B = before treatment; 1 = the first milking in the period, etc.
 O = oxytocin treatment; 1 = the first milking in the period, etc.
 b. The mean time is expressed in seconds.
 c. Those means underscored by the same line are not significantly different.

slow milker at even the fastest milking, at which the maximum rate of flow was 4.5 pounds per minute, the maximum rate of flow at the milking at which let down was faulty was only 3.0 pounds per minute. This rate was not attained until late in the milking, during machine stripping.

Curve number 2 illustrates the type of curve which is obtained when let down is faulty. It is readily seen that

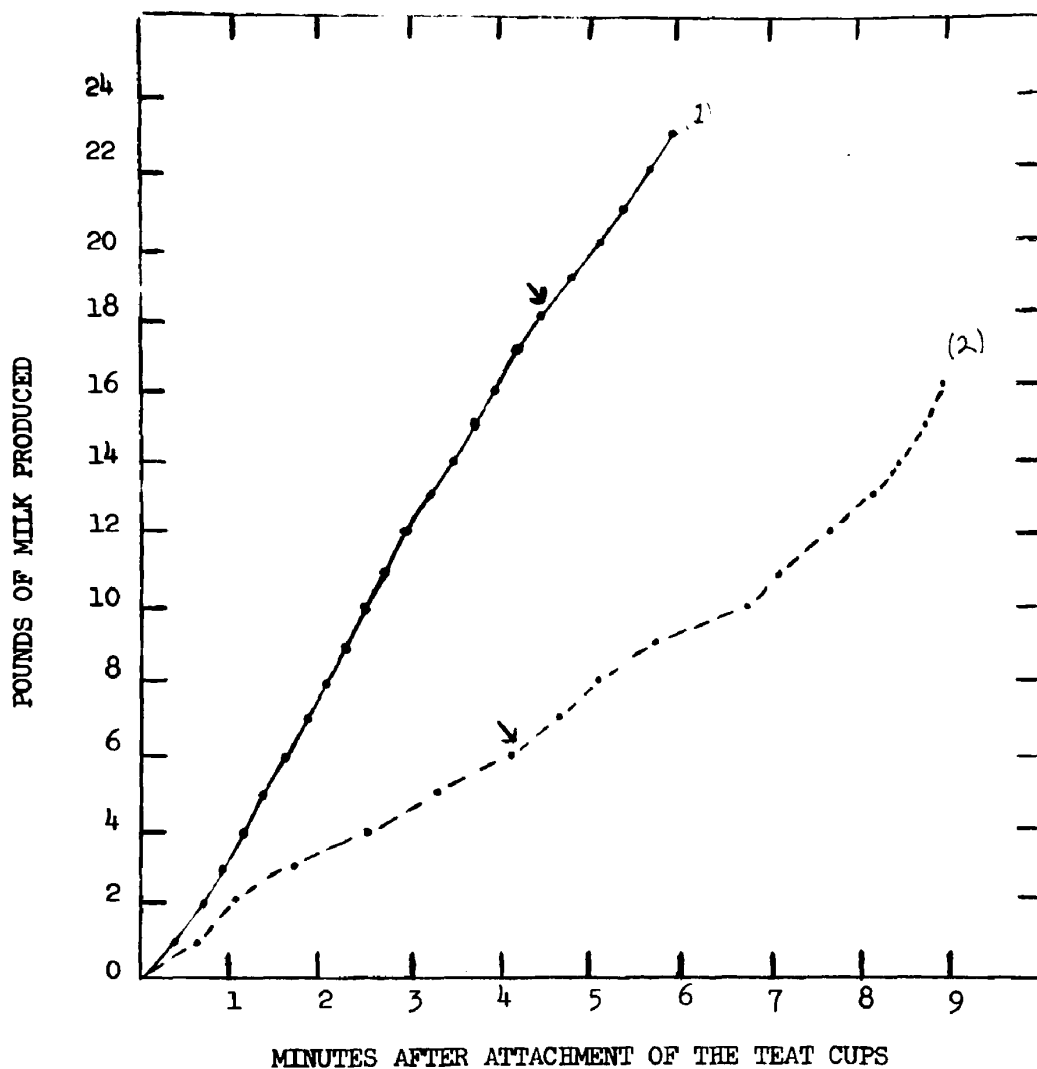


Figure 4. Two milking curves for cow No. 3006. Curve No. 1 represents a normal milking. Curve No. 2 illustrates the type of response obtained when a faulty let down occurs. The arrow indicates the time stripping began.

the rate of flow is slowed by the let down failure. The operator began machine stripping when only six pounds of milk had been removed. The highest rate of flow was attained during stripping, which substantiates the report of Whittlestone (1954) that in the case of faulty let down a release of more oxytocin may be induced by manipulation of the udder. This type of response should not be confused with one in which let down is normal, but rate of flow is confused with one in which let down is normal, but rate of flow is slow due to the morphology of the teat. Oxytocin injections did increase the rate of flow of this cow over that of the faulty let down but did not cause an increase over that when let down was normal. The response of this cow to oxytocin injections was also variable. This raises the question whether the udder may have been somewhat refractory to oxytocin, rather than an insufficient let down by the cow. However, variations in sensitivity of the mammary gland from milking to milking would be difficult to explain.

Discussion.

The question of what effect the struggling of the cow during injection may have should be posed at this time. Cross (1955) reported that the primary effect of nervous inhibition of let down is through a block of the reflex arc;

since this arc is not needed when oxytocin is injected, no effect of a block of this arc would be noted. Adrenalin, which may be released at this time, can also affect the mammary gland. However, the work of Cross (1953) and a series of reports reviewed by Benson and Cowie (1957) indicate that adrenalin affects let down by vaso-constriction, reducing the amount of blood to the udder, rather than a direct effect on the gland. The doses injected in this experiment should have been high enough to insure a blood level of oxytocin high enough to overcome the effect of any decrease in the amount of blood reaching the udder. The work of Turner and Cooper (1941) and Donker et al. (1954a) indicates that if the animal is excited, larger doses of oxytocin are needed to obtain a response, but the response is the same as if smaller doses are given without struggling on the part of the animal. Thus, very probably, the struggling of the cows had no effect on the let down caused by the oxytocin injected. It might be profitable to investigate further the effect of injected oxytocin in unexcited animals through the use of a continuous intravenous arrangement, so that the cow would not be disturbed at the time the oxytocin was given.

The major portion of the evidence from this experiment indicates that let down failure was not responsible for the

slow rate of flow of all but one of the cows studied. The curves for the Brown Swiss cow illustrate a case where let down failure caused an extremely slow rate of flow in a cow that had a slow rate of flow following a normal let down.

Part III. Variation in Interval from Preparation to Milking

In this experiment, the interval between the time let down of milk was stimulated by preparation of the udder and the time milking began was varied. The purpose of the experiment was to ascertain the effect which this variation in interval might have on the rate of milk flow, level of production, and milk composition.

Maximum rate of flow.

An analysis of variance of the effect of variation in interval from preparation to milking upon maximum rate of flow is presented in Table 11. The data are based upon 180 milkings, 18 on each of 10 cows. Each interval--0, 4, 8, 12, 16, and 20 minutes--was used for each cow three times, once in each of three replications. The order of the observations within each replication was randomized for each cow. (A similar analysis was also carried out for average rate of flow, production and the first two of the four components of the milk flow curve as described in

TABLE 11
ANALYSIS OF VARIANCE
SOURCES OF VARIATION IN MAXIMUM RATE OF FLOW
WHEN THE INTERVAL FROM PREPARATION TO MILKING WAS VARIED

Source of Variation	Degrees of freedom	Mean Square	"F"
Total	179	4.74	---
Cows	9	84.03	186.7**
Interval	5	1.68	4.2**
Cow x Interval	45	0.41	0.91
Replication	2	0.78	0.70
Rep. x Cows	18	1.12	2.49**
Rep. x Interval	10	0.25	0.56
Residual (error)	90	0.45	---

**Significant at the one percent level of probability.

Part II. This analysis was also carried out for the percent butterfat and total solids, except that samples were taken for composition analysis only in the second and third replications. Thus only 120 samples were available for analysis.)

The highly significant differences between cows for maximum rate of flow, as shown in Part II, were also shown in this experiment. All other criteria analyzed, including milk composition data also, showed significant differences between cows.

There were highly significant differences in maximum rate of flow between the different intervals between preparation and milking. Table 12 shows the means, arranged in order of increasing maximum rate of flow. This table shows that, in general, the maximum rate of flow decreased

TABLE 12

THE INFLUENCE OF THE TIME ELAPSING BETWEEN PREPARATION OF THE UDDER AND THE ATTACHMENT OF THE TEAT CUPS UPON THE MILK FLOW. MILKINGS ARRANGED IN ASCENDING ORDER OF MAXIMUM RATE OF FLOW.

Order:	1	2	3	4	5	6
Interval ^a	20	16	8	12	4	0
Mean Rate ^b	6.32	6.42	6.45	6.53	6.59	6.80
Significance ^c						

a. The figure listed is the time in minutes which elapsed between preparation of the udder and attachment of the teat cups.

b. The mean of the maximum rate of flow for the three observations on each of ten cows is expressed in pounds per minute.

c. Those means underscored by the same line are not significantly different.

with increasing interval from preparation of the udder to milking. The rate of flow when the udder was prepared and the teat cups attached immediately afterward was significantly faster than all of the other intervals except the four-minute interval. The rate of flow with the four-minute interval was significantly faster than when 20 minutes intervened.

There was also a significant replication by cow interaction for maximum rate of flow. This indicates that the maximum rate of flow for some cows changed significantly from one replication to the other. This significant interaction is probably due to a rather marked decrease in production for two cows between replications two and three. Thus their rate of flow may also have decreased. With the sharp decrease in production, rate of drainage into the teat and gland cistern, rather than the teat sphincter may have become the controlling factor.

Average rate of flow.

There were no significant differences in average rate of flow between the different intervals between preparation and milking. However, an inspection of Table 13 shows that the means are in approximately the same order as the means

TABLE 13

THE AVERAGE RATE OF FLOW AND THE MEAN PRODUCTION FOR EACH OF THE SIX INTERVALS BETWEEN PREPARATION AND MILKING

	0	Interval expressed in minutes				
		4	8	12	16	20
Ave. Rate (lbs/min)	4.69 ^a	4.82	4.76	4.61	4.58	4.60
Production (lbs.)	27.3	26.0	25.6	26.1	25.4	26.2

a. Each figure represents the mean of 3 observations on each of 10 cows.

of the maximum rate of flow, except for the zero interval, in which the teat cups were attached immediately after preparation of the udder. The average rate of flow for the milking following this interval was less, due to a delay in the start of a high rate of flow, as will be shown later. The smaller magnitude of the other differences can probably be attributed to the fact that average rate of flow is partially controlled by the machine operator, thus any effect upon the cow is reflected less sharply in the average rate of flow.

There was a significant difference between replications in average rate of flow. The average rate of flow for the third replication was significantly slower; this may be due in part to a decrease in production on the part of all of the cows, although it was more marked in some than others. The decreased production results in a decreased average rate of flow, while it may not result in a decrease in maximum rate of flow, because a smaller proportion of the total production is produced at a high rate of flow.

Level of production.

Table 13 presents the mean production of the cows following each of the six intervals between preparation. There were no significant differences in the production between

TABLE 14

THE MEAN NUMBER OF SECONDS IN EACH OF THE FOUR COMPONENTS
OF THE MILK FLOW CURVE FOR EACH OF THE SIX INTERVALS
BETWEEN PREPARATION AND MILKING

Component	0	Interval Expressed in minutes				20
		4	8	12	16	
	Sec.	Sec.	Sec.	Sec.	Sec.	Sec.
Part 1	33.9 ^a	24.4	23.9	29.4	29.0	30.6
Part 2	162.8	157.5	152.0	145.6	143.6	157.2
Part 3	91.4	73.8	92.0	81.4	76.8	97.3
Part 4	60.5	71.0	70.8	78.4	75.2	82.2

a. Each figure represents the mean of 3 observations on each of 10 cows.

the various intervals between preparation and milking, although the production when milking began immediately after preparation was considerably higher.

There were significant differences between replications; the mean production was significantly less in replication three and was especially lowered for two cows. The lowered production for these two cows contributed to the significant replication by cow interaction which was also shown. The decreased production contributed to the decreased average rate of flow in replication three and the greater decrease for the two cows probably contributed to the replication by cow interaction for maximum rate of flow.

The milk flow curve.

The milk flow curve for each milking was broken into four component parts as described in Part II of this thesis. The time between attachment of the teat cups and the start of high rate of flow, and the time during which high rate of flow persisted were analyzed in detail as described earlier. Since the time from the end of a high rate of flow to the time stripping started, and the stripping time are less closely associated with the individuality of the cow, a less detailed analysis, using the means of the values obtained for the three replications, was carried out for these criteria.

The mean number of seconds in each of the four components of the milk flow curve for each of the six intervals are presented in Table 14. There are no statistically significant differences in the number of seconds between treatments for any of these components. However, the time before a high rate of flow was reached following the 0, 12, 16, and 20 minute interval was considerably greater than the 4 and 8 minute intervals. The time for the zero interval would be expected to be longer, because the let down reflex may not be completed until after the teat cups have been applied. The fact that the time for the 12, 16, and 20 minute intervals is nearly as long may indicate that

the effect of the original let down may have been dissipated. The high rate of flow persisted somewhat longer with the zero interval than the other intervals.

In Table 15 the mean number of pounds produced during each of the four components of the milk flow curve is presented. There were no statistically significant differences

TABLE 15

THE MEAN NUMBER OF POUNDS OF MILK PRODUCED DURING EACH OF THE FOUR COMPONENTS OF THE MILK FLOW CURVE FOR EACH OF THE SIX INTERVALS BETWEEN PREPARATION AND MILKING

Component	0	Interval expressed in minutes				20
		4	8	12	16	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Part 1	2.1 ^a	1.5	1.5	1.9	1.9	2.0
Part 2	17.5	16.7	16.7	15.6	15.4	15.4
Part 3	5.1	4.6	4.3	5.0	4.5	5.3
Part 4	2.6	3.2	3.1	3.6	3.6	3.5

a. Each figure represents the mean of three observations on each of 10 cows.

in the pounds produced between treatments for any of these components. However, the amount produced at a high rate of flow following the zero interval between preparation and attachment of the teat cups was considerably higher than any of the others. The "F" value obtained in analysis of variance approaches significance. The differences between

the means of the other components were slight.

The average rates of flow for each of the four components of the milk flow curve for each of the six intervals are presented in Table 16. There are no significant differences in the average rates of flow between treatments

TABLE 16

THE AVERAGE RATE OF FLOW DURING EACH OF THE FOUR COMPONENTS OF THE MILK FLOW CURVE FOR EACH OF THE SIX INTERVALS BETWEEN PREPARATION AND MILKING

Component	0	Interval expressed in minutes				
		4	8	12	16	20
	lb/min.	lb/min.	lb/min.	lb/min.	lb/min.	lb/min.
Part 1	3.75 ^a	3.66	3.75	3.88	3.96	3.92
Part 2	6.85	6.56	6.63	6.68	6.66	6.13
Part 3	3.36	3.74	2.81	3.68	3.51	2.66
Part 4	2.57	2.70	2.63	2.75	2.88	2.55

a. Each figure represents the mean of three observations on each of 10 cows.

for any of the components, although the average rate of flow following the zero interval in Part 2 of the curve is slightly higher. This reflects the significantly higher maximum rate of flow for the milkings following this interval between preparation of the udder and attachment of the teat cups.

Composition analysis.

In replications two and three, samples of milk were taken from each cow for each milking to see if changes in milk composition occurred which could be related to the rate of milk flow or production.

The mean percentage of butterfat, total solids, solids non-fat, and protein are presented in Table 17. An analysis of variance was made for percentage of butterfat and total

TABLE 17

THE PERCENTAGE BUTTERFAT, TOTAL SOLIDS, SOLIDS NON-FAT AND PROTEIN OF MILK FOLLOWING SIX DIFFERENT INTERVALS BETWEEN PREPARATION AND MILKING

Constituent	0	Interval expressed in minutes				
		4	8	12	16	20
	%	%	%	%	%	%
Butterfat	3.8	3.6	3.6	3.7	3.5	3.5
Total Solids	12.5	12.3	12.3	12.4	12.1	12.1
Solids Non-fat	8.7	8.6	8.7	8.6	8.7	8.6
Protein	3.4	3.4	3.4	3.3	3.4	3.4

solids, as already described. No significant differences between the means of the samples from the milk obtained for these two components. Since protein percentage is closely correlated with total solids, and solids non-fat is related to total solids and butterfat, these two components were

not analyzed statistically. However, an inspection of Table 17 shows that there is little difference between treatment means. Although the difference was not statistically significant, the percentage butterfat and total solids was higher following the zero interval between preparation and milking. Since solids non-fat changed but little, the difference in total solids was due to the difference in butterfat percent. This higher butterfat percentage with the zero interval indicates that more of the residual milk was obtained following the shorter interval. This interval which yielded the highest butterfat percentage also yielded the highest production, and although differences between the means are not statistically significant, they indicate that more of the residual milk may have been removed at the milking after the shorter interval following preparation. The normal amount of residual milk has been reported to be approximately 20 percent by Swanson and Hinton (1951) and Espe and Smith (1954). Thus changes in the amount of residual milk would be quite small in relation to the total amount produced. The many other variables that affect milk production at each milking make these rather small changes difficult to demonstrate statistically.

Discussion.

The results of this experiment indicate that a slightly faster maximum rate of flow is obtained when the teat cups are attached immediately after preparation. However, there is little difference in average rate of flow. In the case of attachment of the teat cups immediately after preparation, the lack of a change in average rate of flow is accounted for by the increased time before the maximum rate of flow is reached. These results indicate that let down may have a slight effect upon the rate of flow, but again, as pointed out in the section on oxytocin injections, these differences are slight in contrast to the differences between cows. However, the results of these two experiments indicate that differences in completeness of let down may have some effect on day to day variation in rate of flow.

Although the differences are not statistically significant, the production and butterfat tests indicate that the shorter interval between preparation of the udder and attachment of the teat cups did result in a more complete evacuation of the udder. The differences are small and not as marked as those reported by Miller and Petersen (1941) and Ward and Smith (1948, 1949) but appear to be comparable to the results reported by Dodd et al. (1949) and Roark et al. (1952). Thus it would seem that increasing the interval

between preparation and milking beyond the time required for let down to occur has a slight deleterious effect on milk production and fat test. Therefore, the most desirable milking routine would include attachment of the teat cups to the udder as soon after let down has occurred as possible.

It is also possible that if the interval between preparation and milking is too long, or is too irregular, the cow may fail to let down her milk upon stimulation by preparation of the udder. This could be responsible for the faulty let down illustrated in Part II. This possibility is another reason that the teat cups should be attached as soon after let down has occurred as possible.

S E C T I O N B

DETERMINATION OF THE ACCURACY OF MILK MEASURING DEVICES¹

Part I. The Milk-O-Meter

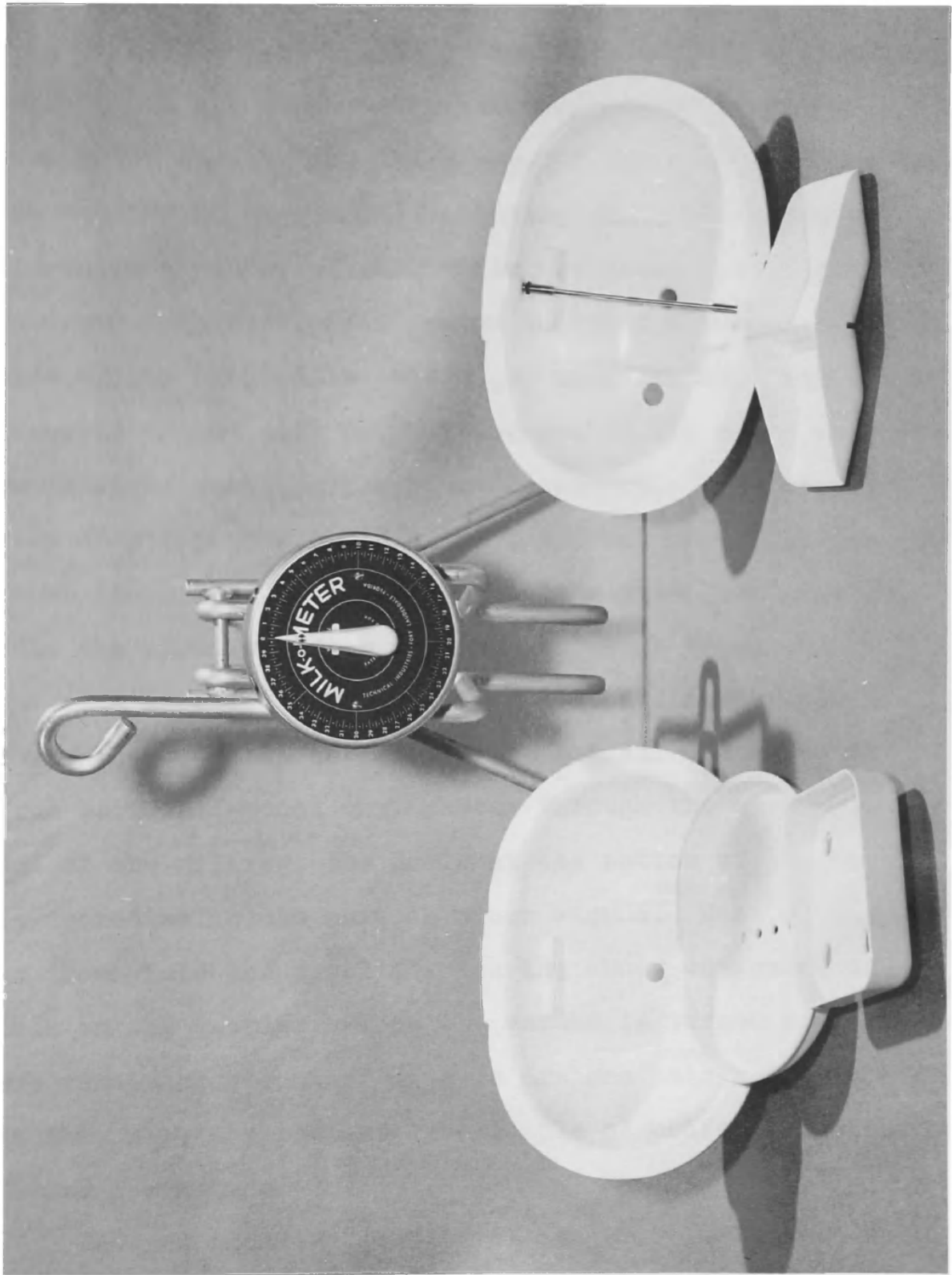
The Milk-O-Meter was used to measure rate of flow and milk production in the experiments which were conducted in the main dairy barn on the Michigan State University campus. Prior to this experiment, consideration was given to installing weigh buckets suspended from spring scales. However, this installation did not appear to be practical, and the availability of the Milk-O-Meter prompted its testing.

Description of construction and operation of the Milk-O-Meter.

The Milk-O-Meter is constructed of Plexiglas, and the entire device weighs about five pounds. The shell of the meter is designed in two pieces held together by vacuum when the meter is in operation. The weighing receptacle is a two-compartment tray which operates on a rocker arm like a "teeter-totter." The rocker arm extends outside the shell to the dial portion of the meter which contains two magnets and the mechanism that turns the pointer. The meter and its component parts are illustrated in Figure 5.

¹A portion of these data have already been published. See Hupp et. al. (1957).

Figure 5. The Milk-O-Meter, showing component parts. The upper shell and baffle plate are on the left; the lower shell with rocker arm and weigh tray are on the right.



Milk entering the top of the meter flows into one compartment of the tray. When the tray contains slightly less than 4 ounces of milk, the weight of the milk pulls against the tension of one magnet, allowing it to rock downward and discharge 4 ounces of milk while the other end of the tray is moved into position to catch the next 4 ounces. As one side of the tray fills, the other side drains. The downward movement of the milk tray on the rocker arm moves the dial to indicate each quarter-pound increment. Milk weights are read directly from the dial on the front of the meter. Because the system is under vacuum, the milk goes directly into the pipeline after leaving the weigh tray.

The sampler, which can be attached directly to the lower shell of the meter, removes a small amount of milk from each half-pound that passes through the meter. At the end of the milking, the drain at the bottom of the sampler is opened while the unit is under vacuum. Most of the milk is drawn into the pipeline, leaving about one ounce of milk in the sampler. Then the vacuum is turned off, and the remaining amount of milk is drained into a sample bottle. In this way, a representative sample of uniform size is obtained for each cow.

Several modifications of the meter were tested, and although only two of the types were used to obtain data on rate of milking characteristics, the results of tests on all

types will be presented, since they indicate the general accuracy of the meter.

The meter which will be referred to as Type A was designed for zero error at a rate of flow of six pounds per minute. Type B meter, designed for zero error at a rate of flow of three pounds per minute, was available commercially at the time it was tested. Meters of Types C and D were both designed for zero error at a rate of flow of four pounds per minute. Meter D was a modified model which was available commercially at the time of its testing. It had an improved type of baffle plate designed to reduce the error due to differences in rates of milk flow between cows.

Method of testing under operating conditions.

In the earlier trials, conducted in the main dairy barn, which is equipped with a DeLaval pipeline milker, the milk from the cow was passed through the meter and into a milker bucket so that it could be weighed on a Toledo platform balance, the accuracy of which had been verified. The weights then were compared with the meter reading.

The maximum rate of milk flow of the individual cows was determined in each trial by noting the time required to produce the 5 pounds of milk in the interval between 5 and 10 pounds. The sampling device was tested by taking a two-milking composite sample from the sampling device on the

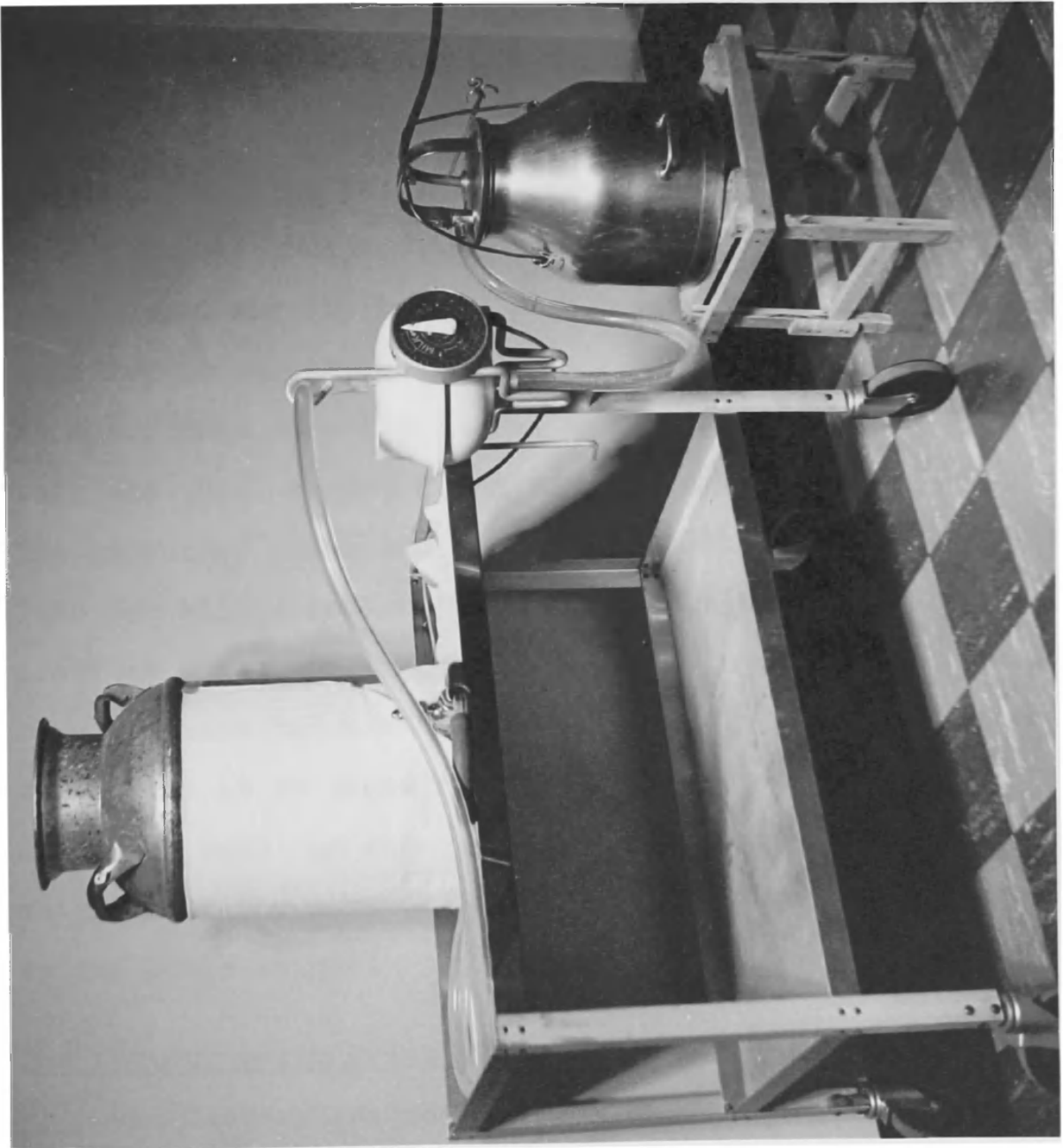
meter. A duplicate sample was dipped from the bucket in the usual manner. Routine Babcock tests were run on these samples and the results were compared.

After the tests in the barn had been completed, a flow device was constructed which delivered water to the meter at constant rates of flow so that further tests could be made under more optimum conditions.

The test apparatus consists of a reservoir for the water, a series of glass tubings with openings of various sizes which are changed to regulate the rate of flow, an air inlet into the hose leading from the reservoir to the meter, a mounting bracket for the meter, a milker bucket to receive the water from the meter, and a source of vacuum. The test apparatus is shown in Figure 6.

The reservoir has a valve at the bottom which is used to turn the water on and off at the beginning and end of each test. The air inlet into the hose leading from the reservoir to the meter is provided so that the water goes into the meter in a manner simulating the flow of milk from the cow. The four rates of flow used and their standard deviations were 2.9 ± 0.15 ; 5.2 ± 0.20 ; 7.2 ± 0.27 ; and 11.5 ± 0.59 pounds per minute. The variation in rate of flow was primarily due to the fluctuations in vacuum level. It was not possible to control the vacuum level adequately.

Figure 6. The flow apparatus for testing the Milk-O-Meter. From left to right are the 10 gallon reservoir with the shut off valve, the removable glass tubing which controls rate of flow, the hose leading to the meter, the Milk-O-Meter, the bucket which receives water from the meter and a hose leading to the source of vacuum.



Vacuum levels ranged from 13 to 18 inches of mercury. However, the effect on rate of flow was not large, as indicated by the relatively small standard deviations about each rate of flow.

The meters were tested by running water through the meter for a fixed period of time for each rate of flow. Then the meter reading was recorded. Next, the weigh pan was tripped and the amount of water in the weigh pan was measured in the calibrated hose leading to the milker bucket. This amount was added to the meter reading to obtain the total amount of water as indicated by the meter. The amount of water that had passed through the meter and into the milker bucket was weighed on an accurate Dayton platform scale, or in some cases a spring scale, the accuracy of which had been checked repeatedly by comparing the weights on it to those on the Dayton scale. The percent error for each run was calculated by subtracting the scale weight from the meter weight and dividing the difference by the scale weight.

The factory recommended method of testing.

The factory recommended method for testing the Milk-O-Meter was also used to check its accuracy during the course of the experiments. The method is as follows: place the Milk-O-Meter on the pipe clamp bracket and make sure that

it is level, then install the lower shell and weigh tray, leaving the upper shell and baffle system removed. Pour water in both sides of the weigh tray and trip to drain naturally. Using a standard volumetric pipette graduated to deliver 125 mls. or a 100 ml. volumetric pipette plus a 25 ml. graduated pipette, fill one side of the weigh tray and note the exact milliliter at which the rocker tripped; repeat for the other side. The combined capacity of the two sides in tripping should be between 218 and 230 mls. If the total required is outside these limits, the meter will not yield results of acceptable accuracy and should be recalibrated. In these tests a 100 ml. volumetric flask and a 25 ml. graduated pipette were used.

Results of tests conducted under operating conditions.

A total of 545 observations were made in the main tie-stall barn in which milk from the cow was passed through the meter and into a milker bucket so that it could be weighed on a platform balance. These observations were made in a series of seven trials on four types of meters. The results of these observations are presented in Table 18.

The gross error as expressed in the table is the mean of the errors encountered in each individual milking. The net error is obtained by subtracting the negative deviations from the positive deviations and dividing by the total number

TABLE 18

THE GROSS AND NET ERROR OF FOUR TYPES OF MILK-O-METERS
IN ESTIMATING THE PRODUCTION AT A SINGLE MILKING

Trial no.	Meter ^a	Observa- tions	Average production per milking	Gross error	Net error
	Type	No.	lb.	%	%
1	A	54	21.3	1.37	-0.74
2	A	40	14.4	1.46	-0.47
3	A	26	24.9	2.07	-1.62
4	B	36	14.7	1.52	-0.31
5	C	108	15.9	2.89	-0.53
6	D	62	16.1	2.36	-0.06
7	D	219	15.4	2.28	-0.52
All		545	16.5	2.20	-0.53

a. Type A was designed for zero error at a flow rate of 6 pounds per minute.
 Type B was designed for zero error at a flow rate of 3 pounds per minute.
 Type C was designed for zero error at a flow rate of 4 pounds per minute.
 Type D was designed for zero error at a flow rate of 4 pounds per minute and has a modified type of baffle plate.

of observations within the trial. The net error represents the amount the meter was in error in estimating the total amount of milk produced in a trial. In all cases the net error, or bias, was negative.

With the Type A meter, the smallest amount of error was found in Trials 1 and 2. Trial 1 was conducted with a group of 10 cows with random rates of flow. In Trial 2, a group of 10 cows was selected for their slow rate of milk flow. In Trial 3, using the same meter as for Trial 2 on cows selected for rapid rate of flow, the error was considerably larger. In Trial 4, in which a meter designed for zero error at a flow rate of three pounds per minute was used on cows selected for a slow rate of flow, the error was also quite low; however, preliminary trials had shown this meter to underestimate the production of the faster milking cows.

The mean gross error in Trials 5 through 7, using the meter designed for zero error at four pounds per minute, was somewhat greater than that encountered in the above trials. However, the net error was not increased, indicating that the increased gross error was primarily due to random variation. A portion of the increased error in Trial 5 may have been due to a changed procedure in which more milkers who were not as familiar with the procedure were involved.

When samples were taken for butterfat testing in Trial 5, correcting for the amount of milk removed may have introduced some error. Some of the increased error in Trials 6

and 7 may have been due to the effect of continuous operation of the meter over a period of several months.

Factors contributing to the error of the meters.

Several factors may contribute to the error of the meters. In preliminary observations and during Trial 1, it was noted that the error was greater for the fast milking cows. Therefore the cows in Trials 2, 3, and 4 were selected on the basis of rate of milk flow. The same 10 slow milking cows were used in Trials 2 and 4. The mean of the maximum rate of flow of these cows was 4 pounds per minute. In Trial 2, they were milked with the meter designed for zero error at a rate of flow of 6 pounds per minute. In Trial 4, they were milked with the meter designed for zero error in Trial 2 was 1.26 percent; in Trial 4, it was 0.95 percent. In both cases the errors were small, indicating that the meter was quite accurate for the slower milking cows.

Five cows selected for rapid rate of flow were used in Trial 3. The average of their maximum rate of flow was 9.6 pounds per minute. In this case, the gross error in estimating the daily production was 1.87 percent--quite high in comparison with that obtained on the slow milking cows.

Note that the error in estimating the production of the rapid milking cows was almost all in one direction; the net error or bias was minus 1.63 percent. These results show

that the meter with the original type of baffle plate was less accurate and underestimated the production of the faster milking cows.

In Trial 7, using Type D meters which had a modified baffle plate designed to reduce the bias due to rate of flow, one-half the herd was measured three times, the other half only once. The cows which were measured three times have been divided into groups according to rate of flow for comparison purposes. The results of these comparisons are presented in Table 19.

TABLE 19

THE EFFECT OF RATE OF FLOW ON GROSS AND NET ERROR
IN ESTIMATING DAILY PRODUCTION IN TRIAL 7

Range in rate	Cows	Average daily production	Gross error	Net error
lb./min.	No.	lb.	%	%
2-4	7	40.8	1.13	+0.47
4-6	9	39.4	1.92	-1.37
Over 6	2	54.1	2.63	-1.44

Although the new type of baffle plate apparently reduced the error due to rate of flow, it was not eliminated. The gross and net error both increased as the rate of flow increased. The meter was biased against faster milking cows

and tended to underestimate their production. The fast milking cows measured earlier in Trial 3 were nearing the end of their lactation at the time of Trial 7, so the rapid rates of flow were not attained. It is possible that greater errors would have been met had these rapid milking cows been available for measurement.

The tendency to overestimate the production of slow milking cows and to underestimate that of the faster milking cows is due to differences in the amount of milk which drains into the weigh tray after it begins to trip. The tray is designed to start falling before it contains four ounces. Less than four ounces in the case of slow milking cows, and more than four ounces with fast milking cows, are in the tray before milk begins to flow into the other side. This results in an overestimation or underestimation of the production.

The new baffle plate apparently reduced the error by shortening the effective time required for the weigh tray to fall, but it has not solved the basic problem responsible for the bias due to rate of flow.

The cows which were measured for three days in Trial 7 were divided into three groups according to level of production. Table 20 shows the mean gross and net errors in estimating the daily production of these cows. As the level

TABLE 20
THE EFFECT OF LEVEL OF PRODUCTION
UPON GROSS AND NET ERROR IN TRIAL 7

Level of production	Obser- vations	Production per Day		Gross error		Net error	
		Mean	Range				
	No.	lbs.	lbs.	lb.	%	lb.	%
Lowest 1/3	25	16.7	2.9-27.0	0.38	2.25	+0.06	+0.36
Middle 1/3	26	32.4	27.4-36.8	0.57	1.75	-0.19	-0.58
Highest 1/3	28	48.1	37.4-61.5	0.79	1.66	-0.35	-0.73

of production increased, both the gross and net error in pounds of milk increased. While the percent gross error decreased with increased level of production, the percent net error or bias increased.

During Trial 7, there appeared to be a difference in error between meters. Three meters, all of Type D, were used in this trial. The errors of the individual observations were analyzed by meter. The results of this analysis are presented in Table 21. Two of these meters, No's 1-1460 and 1-1553 were used in the experiments reported in Part II. These results indicate that there is a difference in error between meters; both meters used in Part II had a negative bias.

The accuracy of the sampling device.

Since milk samples were taken for composition analysis in the trial in which the effect of the variation in the interval between preparation of the udder and milking, the results of tests on the accuracy of the sampling device which was used with the meter will also be presented. Two milking composite samples were taken from 54 cows for butterfat testing. The mean test of all the samples taken from the meter was 3.82 percent butterfat, while the samples dipped from the buckets in the usual manner averaged 3.79 percent butterfat. This difference of 0.03 percent butterfat was 0.79 percent of the total amount.

The greatest difference between tests was 0.3 percent which was encountered three times; 15 of the samples differed by 0.2 percent; 28 differed by 0.1 percent, and 8 were identical. The test of the sample removed by the meter was higher in 28 cases and lower in 18 cases.

The above data indicate that the sampling device removes a very representative sample of the milk. Since each half pound produced is sampled under the same conditions, this sample may be more accurate than one obtained in the usual manner.

It was observed that different combinations of the meter, sampler, and gaskets and weigh pan removed different

amounts of milk for each pound of milk produced. The amount of milk removed by several different combinations of meter, sampler, and gaskets and weigh pan is presented in Table 22. Since the capacity of the sampler receptacle is about 280 milliliters (ml.), the combination removing the largest amount of milk from each pound would fill the receptacle when 30 pounds of milk were produced. A cow producing more milk than this probably would be underestimated in fat test since the last milk would not be sampled. If the sampler removed the average amount, 53 pounds would have to be produced before the sampler would be filled. This level of production is seldom attained.

On the other hand, a minimum of about 20 ml. are required for the Babcock test. On several occasions, less than 2.9 ml. of milk were removed per pound of milk. In this case, a minimum production of 7 pounds per day would be required for a butterfat test. If the sampler removed the average amount, daily production of 4 pounds would be sufficient to obtain a butterfat test. However, in the trials in which the sampler was used, production was quite high, so that the latter would not be a problem. The sample was drained into a 240 ml. container which in no case ran over, so the capacity of the 280 ml. sampler was not exceeded.

Although variations exist in the amount of milk removed, a representative sample of milk which was suitable for composition testing was obtained.

TABLE 21

THE GROSS AND NET ERROR OF TWO DIFFERENT MILK-O-METERS

Meter no.	Observa- tions	Average prod. per milking	Gross error	Net error
	No.	lb.	%	%
1-1460	58	13.4	2.09	-0.81
1-1553	110	15.5	2.34	-1.39

TABLE 22

THE AMOUNT OF MILK REMOVED BY DIFFERENT COMBINATIONS
OF METER, SAMPLER AND GASKETS FOR THE MILK-O-METER SAMPLER

Combina- tion	Cows	Average prod. per milking	Milk removed/lb. of milk	
			Mean	Range
	No.	lb.	ml.	ml.
A	4	25.8	9.4	7.0-10.5
B	5	17.6	5.8	4.2-6.4
C	9	13.5	7.2	6.4-8.0
D	6	16.3	4.3	4.0-6.4
E	14	17.3	5.8	4.3-7.6
F	12	18.7	4.5	2.9-6.5
G	15	17.0	4.8	2.9-6.5
H	16	15.9	4.1	2.3-6.4
All	81	17.1	5.3	2.3-10.5

On the basis of the results of Trials 1 through 5, the meter was adopted for use as the measuring device for determining the rate of flow and production in the experiments reported in Part II. Meter trial 6 was conducted following Trial 1 in Part II and Meter Trial 7 was conducted following Trial 2 in Part II. The results of these trials are included to give an indication of the accuracy of the meter at the time it was used in these experiments.

Results of tests in the laboratory.

Although the experiments reported in Part II were conducted in August and September 1957, and the flow apparatus was not completed until March 1958, the meters used were tested on the flow apparatus at this time. The results of tests on the accuracy of the meters used are presented in Table 23. It must be realized that the meters could have become less accurate due to constant use during the intervening period. Two of these three meters required re-adjustment, as indicated by these tests. The accuracy of the meters after re-adjustment is also presented in Table 23.

In evaluating the percentage errors reported in Table 23, it should be pointed out that these errors do not correspond directly to the error which might be expected in measuring production at a given milking. These values are obtained at a constant rate of flow, while that of the

TABLE 23

THE PERCENTAGE ERROR OF THE THREE MILK-O-METERS
USED IN PART II AT FOUR RATES OF FLOW,
BEFORE AND AFTER ADJUSTMENT

Meter No.	Percent Error at a Rate of Flow of: (Expressed in pounds per minute)				Mean Error	Mean Bias
	2.9	5.2	7.2	11.5		
A - Before Adjustment:						
1-1553 ^a	-0.10	+0.64	-1.04	-3.58	1.34	-1.02
1-1460	+2.72	+1.66	-0.28	+0.82	1.37	-0.98
1-1454	+3.02	+0.42	-0.51	+1.62	1.39	+1.14
B - After Adjustment:						
1-1460 ^b	+2.59	+2.04	-0.56	-1.08	1.57	+0.75
1-1454	+2.02	+1.95	+1.72	-1.60	1.82	+1.02

a. Meter No. 1-1553 was not adjusted.

b. The pointer on Meter No. 1-1460 may have been slipping following adjustment, yielding a positive error.

individual cow varies. A period early in the milking and during stripping will be slow while the middle period will be at a faster rate. Thus in meters which have a positive error at the slow rates of flow, and a negative error at the faster rates, there will be some compensation which will reduce net errors in estimating total production. However, the errors presented in the table should correspond closely to the error at a given rate of flow for any cow. These values were obtained under optimum conditions and do not

include errors which may result from vibration, improper leveling of the meter, bursts of air, and other factors. Thus errors in herd operation could be slightly higher. It should also be mentioned that no cows tested had an average rate of flow that even approached 11.5 pounds per minute at the maximum rate. Thus errors in excess of 3 percent at the 11.5 pound per minute flow rate should not be considered as serious as errors of that magnitude at other rates of flow.

The recording meter used in the experiments reported in Part III of the thesis was tested on the flow apparatus before and after the experiments were conducted. The results of these tests are presented in Table 24. The accuracy of the pin-type distribution tray, used in Trial I of Part II was also investigated at this time. The results of this investigation are also presented in Table 24. This table shows that the accuracy of the recording meter changed but little during the course of the experiment, but the results indicate that some negative bias probably was present in all observations during the trial. In this particular laboratory test, the pin-type baffle tray gave greater accuracy than the modified baffle tray that was used in the meter when recordings were made. However, other trials indicated that the overall characteristics of the pin-type baffle tray were

TABLE 24

THE PERCENTAGE ERROR OF THE RECORDING MILK-O-METER
BEFORE AND AFTER THE EXPERIMENTS REPORTED IN PART III, AND
WITH THE PIN-TYPE BAFFLE TRAY

Combin. No.	No. Obser.	Percent Error at a Rate of Flow of:				Mean Error	Mean Bias
		(Expressed in pounds per minute)					
		2.9 %	5.2 %	7.2 %	11.5 %		
1	20	+0.75	-1.56	-2.48	-3.30	2.02	-1.65
2	24	-0.45	-1.30	-2.70	-3.99	2.11	-2.11
3	8	+0.64	+0.22	+0.02	-2.00	0.72	-0.28

Combination 1 is the Meter with the LMB distribution tray before experiments.

Combination 2 is the Meter with the LMB distribution tray after experiments.

Combination 3 is the Meter with the pin-type distribution tray.

not as desirable. These results show that there should be only slight differences in error between Trial 1 in Part II in which the pin-type baffle tray was used and Trial 2 in Part II in which the modified baffle tray was used.

Discussion.

All of the experiments that were conducted to determine the accuracy of the Milk-O-Meter indicate that it is quite accurate and that a portion of the error is random and tends to cancel with repeated observations. The amount of negative bias increases with increased flow rate, but the increase is not rapid, nor does it appear to be strictly linear, so that

it would be difficult to attempt to correct for this bias due to rate of flow. The meter also tends to become inaccurate with continued use.

Tests conducted on the meters immediately after use in the trials reported in Part II indicate that the meters were quite accurate at the time they were used in these trials. The accuracy of the recording meter changed little during the course of the experiments in which it was used. However, it would have been desirable to have had the meter adjusted for zero error at a slightly higher rate of flow, to avoid the negative error which was encountered.

Part II. Spring Scales

Spring scales were used for measuring production and rate of flow in the experiments reported in Part I. Although spring scales have been used extensively by several groups of workers, and Mackay et al. (1958) reported errors ranging from zero to 1.89 percent with an overall average of 0.40% it was considered desirable to make limited tests on the accuracy of the scales which were to be used in this experiment. Three scales were tested, two were Chatillon 60 pound capacity spring scales graduated in tenths of a pound. One was new, the other had seen limited use in production testing. The third scale was a 40 pound capacity scale, also graduated in tenths of a pound.

The three scales were tested by weighing test weights of known mass. Weights ranging from 5 to 30 pounds were used. The weights were placed in a bucket, and the gross weight on the scale noted. At the end of the tests, the tare weight of the bucket was determined and subtracted from the net weight as indicated by the scale to determine the error of the scales.

The accuracy of the scales in determining the amount of milk in the milker bucket with the hoses attached was then investigated. The weigh bucket with the hoses attached was suspended from the spring scale. The amount of milk at the end of milking as indicated by the scale was noted then. The milk was carefully drained into a pail and weighed on the 40 pound capacity scale, which had been shown to have a high degree of accuracy. The weight as indicated by the check scale was subtracted from the weight as indicated by the scale from which the weigh bucket was suspended, to determine the error of the latter.

Results of tests.

In testing the accuracy of the spring scales in weighing test weights of known mass, the greatest error encountered with either scale of 60 pounds capacity was 0.10 pound. The greatest error encountered with the 40 pound capacity scale was 0.05 pound. All errors with all three

scales were positive. The mean error of the new 60 pound capacity scale was 0.39 percent. The used 60 pound capacity scale had an error of 0.47 percent, while the 40 pound capacity scale had an error of only 0.07 percent.

The greatest difference between weight of the milk as determined in the milker bucket with the hoses attached and the weight on the check scale was 0.7 pound, this was an error of 2.94 percent of the total amount of milk weighed. The mean error of the scales in all tests was 1.43 percent. This indicates that the weight of the hoses and the weight of the milk in the hoses accounts for a considerable degree of error in estimating the weight of the milk. It was noted that at the start of the milking, milk accumulated in the milk hose for several seconds before any weight was indicated on the scales. Thus part of the inaccuracy may be reflected in the first pound produced, and less of the error is reflected in each additional pound. These errors are small enough that they should not materially affect the results of the rate of flow determinations based upon these weights.

SUMMARY AND CONCLUSIONS

Addition of water to the concentrate mix fed at milking time reduced the eating time by 30 percent. The maximum rate of milk flow was not changed significantly by the addition of water to the concentrate mix, but the average rate of flow decreased 12 percent. However, this statistically significant decrease was due primarily to increased time spent by the machine operator during stripping and cannot be attributed to the effect of addition of water to the concentrate mix upon the milk flow characteristics of the individual cow.

Oxytocin injections had no effect on rate of flow in one trial involving slow milking cows and only a slight effect on rate of flow in a trial involving average and fast milking cows. This effect on faster milking cows may have been due to a greater increase in intra-mammary pressure following oxytocin injections. These changes in rate of flow are small compared to differences in rate of flow between cows, and indicate that let down failure was not responsible for the slow rate of flow of all but one of the cows studied. One cow did exhibit a faulty let down which was quite different from the normal let down pattern for that cow.

Variation in the interval between stimulation of let down by preparation of the udder, and attachment of the teat cups resulted in slight changes in rate of flow, level of production and butterfat percentage. The maximum rate of flow was significantly faster when the teat cups were attached immediately after preparation. This change in rate of flow is small when compared to the differences between cows, but could be responsible for some milking to milking variation. Production and butterfat test decreased slightly but not significantly as the interval between preparation and milking increased. However, these results indicate that the shorter intervals between preparation of the udder and attachment of the teat cups did result in a more complete evacuation of the udder.

Data were presented to establish the precision of the Milk-O-Meter and milk scales employed in these studies to determine the rate of milk flow. The Milk-O-Meter was shown to be quite accurate. A portion of the error is random and tends to cancel with repeated weighings. The amount of negative bias increased with increased flow rate, but the increase was not rapid. The meters also tended to become less accurate with continued use. Tests conducted on the meters immediately after use in the trials reported in the thesis indicated they were quite accurate at the time

they were used in these trials. Errors encountered when using the milk scales were small enough that they did not materially affect the results of these studies.

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