EFFECT OF VARIANTS IN PIPELINE INSTALLATIONS ON THE ACID DEGREE OF FAT IN MILK

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Louis Jokay

1956

EFFECT OF VARIANTS IN PIPELINE INSTALLATIONS ON THE ACID DEGREE OF FAT IN MILK

By

LOUIS JOKAY

A THESIS

Submitted to the School of Agriculture of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Dairy

1956

7-10-56
g

ACKNOWLEDGEMENTS

The author wishes to thank Professor J. M. Jensen, under whose direction the project was developed, and for his assistance in the preparation of the manuscript. The writer is also indebted to Dr. G. M. Trout for his words of encouragement and advice. Appreciation is further expressed to both men for their assistance in evaluating the quality of the milk samples.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

INTRODUCTION

The taste quality of milk is one of its most distinguishing attributes. Taste of fresh milk may be damaged severely and rapidly by decomposition of butterfat to fatty acids with resulting rancidity.

Rancidity of milk is not a new problem. Trouble caused by rancidity heretofore has been attributed mainly to the physical conditions affecting cows during the later part of their lactation. Usually not more than one or two cows in a herd were affected. But with the advent of pipeline milking and bulk tank cooling, a considerable number of such instances have plagued producers of large volumes of milk. Investigations made elsewhere have uncovered a number of conditions that stimulate the development of rancidity in raw milk. Considerable data however appear to be contradictory, and solutions frequently must be found on the basis of a particular set of conditions.

This study was made for the purpose of determining the conditions in pipeline milking which produce damage to milk, causing rancidity, and of finding practical solutions of installing and operating pipelines with minimum effects on lipolysis.

REVIEW OF LITERATURE

Description of Rancid Flavor

Rancid flavor, as the term is used in the dairy industry, means a specific flavor, identifiable as the flavor of free butyric acid. Tarassuk and Jack (1949) and Herrington (1950) described rancid flavor as bitter, soapy, "goaty", "wintry", and sometimes resembling the flavor of coconut. In mild cases, rancidity has been identified as stale, old, and unclean. According to the experience of Hileman and Courtney (1935), rancid flavor also might be recognized as the peculiar burning sensation at the back of the tongue when the milk is swallowed. Herrington (1954) stated that rancid flavor is caused by the hydrolyzation of the short chain, water soluble, fatty acids, while the long chain fatty acids have little effect on flavor.

Direct Cause of Rancidity

The principal factors setting off lipolysis in milk are lipase and butterfat. Herrington (1954) stated that it is commonly accepted that cows' milk contains the fat-splitting enzyme lipase. He further made it clear that more than one lipase enzyme is involved and that butterfat can be split apart by enzymatic hydrolysis of lipase to yield glycerine and a mixture of about a dozen different fatty acids. Some of these fatty acids, particularly the short carbon chain groups such as butyric acid, caproic acid, and caprylic acid, have very powerful odors.

There is some disagreement about the phase in which the lipolytic factor is carried. Pfeffer, Jackson, and Weckel (1938) were of the opinion that the lipolytic factor is carried in the serum phase of milk, and the extent of lipolysis depends upon the fat content of milk. However, Frankel and Tarassuk (1955) contend that the lipolytic factor is in the fat phase, since the kind of fatty acids present in rancid milk is related to that of the original composition of the fat.

Lipase in General

A few decades ago, dairy chemists doubted that normal raw milk contained lipase. Through the investigation of the causes of bitter or rancid milk, the presence of lipase in milk has been convincingly demonstrated. Palmer (1922) reported that Harrison, in 1902, believed that the cause of bitter milk might be of bacterial origin. Later Maas (1909) and Rogers and associates (1912, 1913) demonstrated the presence of lipase in raw milk. Palmer (1922) also came to the conclusion that bitter milk of advanced lactation is caused by the secretion of the enzyme lipase, which will hydrolyze milk fat and liberate fatty acids. Furthermore he stated that the lower volatile fatty acids are responsible for bitter taste. Rice and Markley (1922) demonstrated

the presence of lipase by the increase in acidity of milk. The presence of lipase in raw cow's milk has been confirmed also by Rice (1926) and Roadhouse and Koestler (1929). Hileman and Courtney (1935) demonstrated the presence of lipase with an increase in acidity that was accompanied by bitter flavor. They ruled out the idea that milk lipase is of bacterial origin and believed it to be secreted by the cow along with the milk. Tarassuk and Jack (1949) proved that the lipase of naturally lipolytically active milk is present in the milk plasma, prior to cooling.

Experimental data of Kelly (1943) indicate that the tissue of the bovine mammary gland, developed by pregnancy, contains a significant amount of lipase. However, Herrington (1950) stated that milk lipase has very little action on fat inside the udder, and, as a general rule, the lipase in milk seems inactive at the time of milking.

Nature of Milk Lipase

Dairy scientists presently agree that raw cow's milk contains lipase. Herrington (1954) is of the opinion that still very little is known about the lipase as such. According to Davies (1932), milk lipase is a compound of several enzymes. Dorner and Widmer (1932) suggested the presence of two lipases, one of which is extremely heat labile and responsible for the sharp bitter taste in homogenized milk. Herrington and Krukovsky (1939a) found that formaldehyde inhibits lipolysis. They presented data to show that there are present in milk two different lipases, one of which is not affected by formaldehyde. This lipase is believed responsible for the rancid taste in homogenized milk.

Herrington (1950, 1954) stated that lipase enzyme is not a single enzyme, but rather a group of enzymes, and that milk lipase is a group of highly specialized enzymes, some of which can be split into a thermostable coenzyme and a thermolabile apoenzyme.

Causes of Lipolysis

Lipolysis in raw milk may occur spontaneously, or it may be induced by mechanical activation. Under certain conditions, the inactive lipase present in fresh raw milk may be activated or accelerated for enzymatic hydrolysis. Herrington (1954), describing activation in general, stated that it seems probable that activation is more dependent upon changes in the state of fat than upon changes in the lipase.

Dunkley and Kelley (1954b) stated that the so-called fat globule membrane helps to protect fat in milk from the lipase enzyme. If this protective membrane is disrupted or modified, the lipase is able to hydrolyze the fat, freeing the fatty acids .

Spontaneous Rancidity

When samples of milk are drawn from a number of cows and cooled and stored separately, some of them will develop rancidity. This kind of rancidity has been described by

Herrington (1950) as spontaneous. Freeden and Bowstead (1951), in a review of factors causing spontaneous rancidity, reported that spontaneous rancidity varies with the individuality of the cow, stage of lactation, season, and feed. They also reported that temperature, hours of sunshine or artificial light, and the amount of exercise that cows need, have no effect on spontaneous rancidity. As will be shown later, according to the experimental results of numerous workers, there is no definite relationship between breed and milk production of cows and spontaneous rancidity.

Individuality of cows. Experimental data of Herrington and Krukovsky (1939b), Roahen and Sommer (1940), Krienke (1944), and Freeden and Bowstead (1951) indicated that there is a great deal of variation in the rate of lipolysis in the milk from different cows, during the same lactation, in spite of similar conditions of feed and season. Herrington and Krukovsky (1939a) found that the difference in acidity of fat may become pronounced only after a few hours of storage.

According to Roahen and Sommer (1940) and Thomas, Harper, and Gould (1954), there is a variation of fatty acid content not only between different cows but also between successive daily milkings from the same cow.

Stage of lactation. The lipolytic activity of milk of certain cows is accelerated by advanced lactation as reported by Sharp and DeTomasi (1932), Trout (1932a, 1932b), Bailey (1933), and Krukovsky and Sharp (1936).

Palmer (1922) and Hileman and Courtney (1935) believed that spontaneous rancidity in advanced lactation is due to increased lipase secretion. Fouts and Weaver (1936) found that spontaneous rancidity may occur any time within the milking, but it is most likely to appear in late lactation. Hileman and Courtney (1935) and Krukovsky and Sharp (1938) stated that some cows in advanced lactation in winter will produce milk which will become rancid spontaneously upon cooling.

Some workers do not agree that advanced lactation or advanced gestation is the most important factor of spontaneous rancidity. Weaver (1939) believed that advanced gestation was more important than advanced lactation, while Freeden and Bowstead (1951) believed that advanced lactation was the contributing factor, rather than advanced gestation. Herrington and Krukovsky (1939b), Pfeffer, Jackson and Weckel (1938), and Roahen and Sommer (1940), testing a large number of individual cows for a long period of time, found that there was no apparent correlation between the rates of lipolysis and the stage of lactation or gestation. Also Thomas, Harper, and Gould (1954) could not observe any increase in fatty acid content with the progress of lactation.

According to Kelly (1945), there is a close relationship between the stage of the estrous cycle of the cow and the lipase of the milk she produces. Herrington (1954) mentioned in his "Review" on lipase that experimental results indicated a maximum concentration of lipase on the day of oestrus and a maximum acidity of the fat on the day after oestrus.

Season and feed. Several workers have presented evidence that there is a strong relationship between feed and season and between susceptibility of milk to spontaneous rancidity. Csiszar (1933) and Hileman and Courtney (1935) noted that lipolytic activity in milk is more pronounced in winter than in summer. According to Herrington (1950), the number of cows producing milk susceptible to spontaneous rancidity reaches a maximum in late fall and will diminish through the winter.

There are certain indications that the seasonal variations in susceptibility to spontaneous rancidity has some connection with summer and winter feeding. Anderson (1936), Fouts and Weaver (1936), and Freeden and Bowstead (1951) believed that spontaneous rancidity is most common in the fall or winter, due to the lack of green feed or, more specifically, of the carotene therein. Trout, Jensen and Humbert (1955) claimed that green pasture has a stabilizing effect against spontaneous rancidity during the summer.

Breed and milk production of cows. Pfeffer, Jackson, and Weckel (1938) observed less lipolytic activity in milk of individual cows when the milk production was lower. However, Herrington and Krukovsky (1939b) found no relationship between lipolysis and the amount of milk produced by each cow.

Activating factors. Hileman and Courtney (1935) and Tarassuk and Henderson (1942) stated that the only action needed to activate spontaneous rancidity is to cool the milk and hold it for some time under low temperature. According to Tarassuk and Jack (1949), when the milk is cooled, the lipase is adsorbed on the fat globules, and the lipolysis begins immediately. Furthermore, Tarassuk and Henderson (1942) found that the addition of a very small amount of spontaneously rancid milk to a normal milk supply will impart the rancid flavor to the entire mixture.

Prevention and inhibition. Tarassuk and Henderson (1942) found that the development of spontaneous rancidity could be prevented by mixing naturally active lipase milk with normal milk, in a proportion of one part to four parts, within an hour after milking. They believed that in order to insure effectiveness of this method, the milk should be mixed before cooling.

According to the results of several experiments by Fouts and Weaver (1936), Roadhouse and Koestler (1929), Roadhouse and Henderson (1935) and Weaver (1939), from 2 to 22 percent of the cows produced spontaneously rancid milk at any time. Dunkley and Kelley (1954b) recommended the elimination of cows which produce milk that is highly susceptible to spontaneous rancidity.

Induced Rancidity

If the milk is subjected to certain treatments, the action of lipase upon fat is increased greatly. According to Krukovsky and Sharp (1940a) and Tarassuk and Henderson (1942), certain mechanical activation such as violent shaking of raw milk, warming precooled milk and cooling it again, and various methods of handling raw milk will cause a change in the fat globule. These investigators concluded that the change in the fat globule is responsible for mechanical activation. Tarassuk and Jack (1949) also concluded that the activation treatments of induced lipolysis lead to the disruption, partial displacement, or distortion of the natural adsorption layer on the fat globules, and lipase is able to split the fat partially, liberating fatty acids responsible for the rancid flavor.

Mechanical agitation by shaking. It has been known for a number of years that shaking of warm raw milk will induce lipolysis. Krukovsky and Sharp (1938), Roahen and Sommer (1940), and Herrington (1950) agreed that vigorous shaking of raw milk while the butterfat is even partially in the liquid state, will induce lipolysis upon cooling. They agree that vigorous shaking of warm milk partially destroys the fat globule membrane and makes the fat available for lipolysis. Holland and Herrington (1953) and Herrington (1954) believed that effectiveness of agitation depends on the fluidity of the butterfat, the rate of lipolysis increasing rapidly as the temperature is increased up to 75°-85°F.

Activation by cooling-warming-cooling. Krukovsky and Herrington (1939) found that lipolysis in cold raw milk could be activated by cooling milk to 41°F. or lower, rewarming to 86°F. and then recooling below 50°F. The length of time the milk was held at the activation temperature was less important than the actual temperatures employed.

Mechanical activation by handling of raw milk. Some methods of handling raw milk created favorable conditions for mechanical agitation and induction of rancidity. Such methods of handling milk are: (1) the changes in temperature of separation of cream, (2) homogenization, and (3) the introduction of pipeline milkers and farm bulk tanks.

(1) Cold separation of cream.

Sharp and DeTomasi (1932), Roahen and Sommer (1940), and Krukovsky and Herrington (1939) found that the incidence of rancidity increased when raw milk was separated at 80°-90°F. The latter investigators believed that the cause might be warming activation.

(2) Homogenization.

Dorner and Widmer (1931), Halloran and Trout (1932), Trout (1933), and Gould and Trout (1936) found that homogenization of raw milk will speed up lipolysis within a few minutes. This fast increase in rancidity was attributed to a radical change in the surface of fat globules and to increased contact between fat and lipase.

(3) Use of pipeline milkers and farm bulk tanks. Since the introduction of pipeline milkers and farm bulk tanks, the incidence of rancidity has increased throughout the main fluid milk producing areas. Research workers agree that, under certain conditions, pipeline milking systems will produce activation in the raw milk sufficiently violent to cause lipolysis.

Herrington (1954), Dunkley and Kelley (1954b), and Thomas, Nielsen, and Olson (1955b) reported several cases of rancidity in raw milk handled by pipeline milkers and bulk tank installations. The same authors reported that, in several cases, the trouble was caused by the pipeline "risers," vertical sections connecting pipelines at different levels. In a riser, the milk is carried upward by a stream of air.

Dunkley and Kelley (1954b) found that milk hoses which carry milk from the cow to the line could have an activating effect if excess air bubbles through them. Tarassuk and Frankel (1955) believed that air agitation will create foaming and will induce rancidity more than any other mechanical agitation. They explained that bubbling air through warm milk could cause a partial transfer of the fat surface material, creating conditions favorable for lipolysis. Dunkley and Kelley (1954b) conducted trials using horizontal pipe sections fitted with risers and fittings, and they observed activation only when air was admitted.

Air agitation in milk pipelines has been found to be influenced by a number of factors. Dunkley and Kelley (1954b) found that milk flow rate had a marked influence on the activating effect of air. They found that higher flow rates decreased agitation in the risers, thereby reducing activation. The effect of agitation is also found to be influenced by the temperature of raw milk. Holland and Herrington (1953) and Herrington (1954) believe that as milk cools, it passes through a critical temperature, where it is most susceptible to churning. Herrington is of the opinion that the effectiveness of agitation in the role of inducing rancidity is influenced by other conditions, particularly temperature, effecting fluidity of the fat. He found sensitivity to activation increased rapidly as the temperature increased to 75° or 85°F.

Since the milk pump and inline filter are parts of the pipeline bulk tank system, their effect on raw milk must not be overlooked. The experimental data of Dunkley and Kelley (1954b) show that agitation of warm raw milk might occur through the continuous operation of the centrifugal pump at a flow rate below its capacity. The same authors reported that considerable rancidity occurred when a bag or a plate-type

filter was used in the vertical section of the vacuum line. However no rancidity occurred when the filter was installed in the vertical discharge line from the pump.

Herrington and Krukovsky (1939) found that when storing normal milk, some lipolysis will take place with increase in free fatty acid degree. However, the rate of the lipase action was retarded by fast and efficient cooling. According to Herrington (1954) and Dunkley and Kelley (1954b), activation might occur in a bulk tank if fresh warm milk is added to cold milk. Herrington (1954) found that when the temperature of milk in the tank exceeds 68°F., lipolysis might be induced due to temperature activation.

The agitator of the bulk tank has been considered as possibly having some influence on induced rancidity. According to Herrington (1954), excess agitation might occur when warm milk enters the bulk tank and only partially covers the agitator. Dunkley and Kelley (1954b) suggest that an optimum condition of stirring milk should be employed to get minimum agitation. This would be accompanied by rapid cooling of the incoming milk in order to get the least induced lipolysis.

Herrington (1954) and Dunkley and Kelley (1954b) warned that with the introduction of farm tanks and tank truck transportation, there will be a growing

interest in alternate day pick-up from the farms. This would necessitate an increased effort to control lipase action. Herrington (1954) suggests that some raw milk supply, which will not develop rancidity during a short period of storage, might do so if held over 24 hours. None of the data show conclusive evidence that bulk tank cooling is a serious factor in induced milk rancidity.

Factors of Induced Rancidity

Apparently, milk responds to induced lipolysis because of the nature of several conditions that affect the fat in milk. Krukovsky and Sharp (1940a) mentioned some important factors influencing the rate of induced lipolysis, such as, the surface of the fat, the melting point of the fat, and the fat:plasma ratio.

The surface of the fat globule. Dunkley and Smith (1951) stated that the nature of the surface of the fat globule appeared to be the most important factor in determining whether milk will develop rancidity. Rimpila and Palmer (1935) and Tarassuk and Palmer (1939) theorized that a natural surface "membrane" surrounds the surface of the fat globule. They described this layer as being composed of protein, phospholipids, and ether extractable non-phospholipid material.

Bird, Breazeale, and Bartle (1937) concluded that two distinct protective materials are adsorbed on the fat globules.

One is a phospholipin-protein complex lying closer to the fat surface. The second material is located on the water side of the fat globule surface, and casein is its most important constituent. The same investigators found that the protective materials do not cover the globule surface in the form of a continuous membrane, but they are held at force centers distributed unevenly on the fat globule surface. According to Tarassuk and Richardson (1941), the partial denaturation and distortion of the fat globule membrane protein will leave the surface of fat globule exposed to the action of lipase. The same authors and Krukovsky and Sharp (1940a) found that the replacement of the original fat globule membrane by some other surface active material in raw milk will cause extensive lipolysis. Herrington (1954) stated that it appeared that at least two kind of activations must exist. The original surface material may be removed irreversibly by mechanical forces, or the adsorptive and reactive properties of the fat may be changed by the phase transformations which follow cooling.

The melting point of fat. Krukovsky and Sharp (1940a) found that the rate of lipolysis depends upon the melting point of fat. As the temperature required for crystallization of fat was lowered, a greater increase occurred in the fatty acids.

Fat:plasma ratio. Pfeffer, Jackson, and Weckel (1938) found that greater lipolytic activity is observed in the skim phase than in any cream phase of milk. As the fat

content of the cream increased, the lipolytic activity decreased. Krukovsky and Sharp (1940a) stated that: "Total lipolytic action increases with fat content up to 35-45 percent, but acidity per unit of fat and acidity per unit of plasma increases with fat content up to 8-10 percent of fat and then remains constant or decreases." Johnson and Gould (1949a) presented experimental evidence showing that the acid degree of the fat decreases with increases in the fat content of the product.

Herrington and Krukovsky (1939a) found that copper, in a small concentration as low as 0.2-0.4 p.p.m., will reduce lipolysis in the presence of oxygen. According to Krukovsky and Sharp (1940b), dissolved copper will not inactivate lipase in the absence of oxygen. Gould (1941) presented evidence showing that copper has no effect on the extent of lipolysis induced by homogenization. Herrington (1950) believed that the destructive action of copper may be due to its oxydative ability.

Inactivation of lipase by formaldehyde. Herrington and Krukovsky (1939a), Roahen and Sommer (1940), and Herrington (1950) stated that formaldehyde will lessen the extent of lipolysis in normal raw milk. However, it will not inactivate all the milk lipases, since a part of the milk lipase is not affected by formaldehyde.

Preventing Activation During Handling

Investigators have reported means of decreasing the incidence of induced lipolysis during handling of milk. Dunkley and Kelley (1954b) suggested that by studying the different sections of a pipeline during operation, one might detect the place where activation occurs. They reported that the activating effect of risers could be decreased by eliminating them or reducing their height. They also reported that the rate of activation in the pipeline and risers could be decreased by increasing the flow of milk and reducing air intake to the pipeline as completely as possible. The same authors found that a higher rate of milk flow could be secured by using high producing cows, several milking units, and fast milking. To avoid turbulence and foaming in the pipelines and risers, Dunkley and Kelley (1954b) and Thomas, Nielsen, and Olson (1955b) suggested the use of a minimum amount of air necessary to remove milk, while maintaining uniform vacuum. They further advised the elimination of all air leakage and reduction of the number of fittings and elbows to the least possible number.

Very little evidence is found in literature that bulk milk tank cooling has produced activation of lipolysis. However, Herrington and Krukovsky (1939a, 1942) found that very rapid cooling of the milk will retard lipolysis during storage. These workers found that refrigeration of the bulk tank must be adequate during storage to prevent rewarming

of cold milk by addition of milk during a later milking.

Tests Used for Measuring Hydrolysis of Butterfat

Chemical and physical tests have been used in the study of fat lipolysis. Chemical tests have been the most useful, since values have been established by which the degree of lipolysis may be measured.

The most commonly used methods are organoleptic examination, surface tension measurements, and measurements of fat soluble acids by different kinds of titrations (acid degree values).

Herrington (1950, 1954) stated that the above mentioned methods measure different things. He warned that the results must be interpreted with caution, as they will not all yield the same answer in regard to lipolysis.

Organoleptic examination. Herrington (1954) maintains that rancidity detected by organoleptic examination of milk results from short chain, water soluble, fatty acids, while long chain acids have little effect on the flavor or odor of the milk. He believes that organoleptic examination is of most significance in terms of consumer reaction, although it does not yield numerical data, and the method is of low sensitivity.

Surface tension measurements. Trout, Halloran, and Gould (1935) used surface tension studies to measure the changes in raw homogenized and pasteurized homogenized milk. Tarassuk and Smith (1939, 1940) found that as the hydrolytic

rancidity increased, the surface tension of milk decreased gradually. They claimed that the lowering of surface tension is due to fatty acids set free by hydrolysis. Tarassuk and Henderson (1942), Dunkley (1951), and Dunkley and Kelley (1954a) used surface tension measurements to detect rancidity. They found a marked relationship between surface tension changes and rancid flavor of milk. Herrington (1954) concluded that the change in surface tension is most sensitive to the longer water soluble acids (capric, caprylic), while butyric acid, the most important factor in the organoleptic measurement, has little effect on the surface tension of milk. These workers also considered the possibility that monoglycerides and diglycerides were the constituents causing reduction of surface tension, which, if so, would result in depression of surface tension nearly independent of the nature of the acid liberated. Herrington believed that surface tension measurements are difficult to interpret, because a number of factors will cause variations in surface tension values when tests are made by different investigators.

Chemical measurements of fat soluble acids. Several procedures are used to measure acid degree values. Hileman and Courtney (1935) and Reder (1938) titrated the milk with 0.1 normal alkali. Gould and Trout (1936) titrated 10 gram lots of churned, melted, and filtered fat with N/10 NaOH. They expressed the results in terms of free fatty acid degrees or milliliters of normal alkali required to neutralize the free fatty acids in 100 grams of fat. They expressed the opinion that direct titration of milk fat, to measure free

fatty acids, is a far more sensitive method for detecting lipolysis than by titration of the milk. Some years later, Herrington and Krukovsky (1939a) reported extensive experimental results on lipase action, using the fat titration method, expressing the titration values on the same basis as used by Gould and Trout.

During the 1940's, several workers attempted to develop a standard test for measuring the extent of lipolysis. Roahen and Sommer (1940) developed a method which measured only the volatile soluble fatty acids. Hollander, Rao, and Sommer (1948) developed a method which can be applied to the estimation of free fatty acids in powdered milk, cream, and other high fat dairy products. Hillig (1947) presented a method for determining the water insoluble fatty acids. This method was later modified by Hillig (1953) and Armstrong and Harper (1954).

Johnson and Gould (1949a, 1949b) developed a solvent extraction method of recovering free fatty acids from rancid milk. The same workers found that the solvent extraction method was far superior to the churning method for recovery of fatty acids, inasmuch as the water soluble fatty acids remained in the buttermilk. Johnson and Gould (1949b) also found an improved recovery of butyric, caproic, capric, and oleic acids, when the milk was adjusted to pH 2 prior to extraction. Harper, Basset, and Gould (1954) modified the solvent extraction procedure for testing homogenized milk, and Thomas, Harper, and Gould (1954), using the modified solvent extraction procedure, were able to determine minor variations in free fatty acid degree of fresh milk.

Workers at Minnesota, Thomas, Nielsen, and Olson (1955) used the B. D. I. detergent test to recover fat. According to the authors, this method is rapid and adaptable for field use. Frankel and Tarassuk (1955) recently published a simplified extraction titration method, wherein the mixture of solvent and fat was titrated.

Harper, Schwartz, and El-Hagarawy (1956) developed a rapid silica gel method for measuring total free fatty acids in milk. The authors claim that this method is more quantitative in recovery of free fatty acids than any of the previous methods.

Tarassuk and Frankel (1954) and Frankel and Tarassuk (1955) commented that no perfect method is yet available for recovering all the free fatty acids. The authors believe that solvent extraction methods give the highest recovery and will give the highest titration values. Herrington (1954) recognized the advantage and usefulness of solvent extraction method by stating: "Measurements of fat soluble acids have the advantage that they yield numerical results which are reproducible and which reveal very small changes in the fat." He concluded: "Consequently, the effect of minor changes in handling milk can be detected easily by this method."

EXPERIMENTAL PROCEDURE

Description of Pipeline Installations

Six pipeline milker installations from which milk was sampled and tested for free fatty acid degree in this study are identified and designated as follows:

Line "A". This is found in the main dairy barn at Michigan State University. This was the installation with continuous pyrex glass pipeline along the stanchions, a length of 360 feet and with aggregate riser height of 85 inches. The risers measured consecutively as follows: 14 - 7 - 14 - 25 - 25 inches. The slope of the line was 1.5 inches per 10 lineal feet. The milk was pumped continuously with a diaphragm pump. Air was admitted to the line with a control device at the far end of the line and through claw air inlets. (See Figure 1)

Line "A_1". This was also found at the main dairy barn, with line "A" altered to decrease the length of the line to 200 feet and aggregate riser height to 24 inches. The line slope was decreased 0.5 to 0.8 inch per 10 feet. The milk was pumped intermittently from a full accumulation tank. Air was admitted to the line only through the claw air valve inlets. (See Figure 2)

Line "B". This was found at the Coe farm barn, with continuous pyrex glass pipeline along the stanchions, a

length of 190 feet, with 2 risers with total riser height of 23 inches in 8 and 15 inch lengths. The milk was pumped intermittently from a full receiver tank. Air inlets were similar to "A_1". (See Figure 3)

Line "B_1". The Coe farm barn line was altered to eliminate one riser and reduce riser height to 8 inches and line slope to approximately 0.5 inch per 10 linear feet. The milk was pumped intermittently from a full receiver tank. Air inlets were similar to "A_1". (See Figure 4)

Line "C". The Stran steel milking parlor at Michigan State University was used. This had a one inch diameter metal line, 24 feet in length with one 34 inch riser. Single cow milkings were drawn into line in volumes. No special air inlets were provided.

Line "D". This was the Clinton farm barn line, a continuous pyrex glass pipeline, 210 feet in length, without risers. Slope of the line is 1 inch per 10 lineal feet. The line was without specific air inlets. Milk accumulated in a receiver tank and pumped intermittently into a bulk tank.

One bulk tank milk supply, produced by bucket milking, without pipeline, was tested periodically as a matter of control. This installation is designated as tank installation "E".

For the purpose of simplifying presentation of material, the term free fatty acid degree is expressed as "F.F.A.$^{\circ}$"

Sampling Procedure

Samples of milk were examined during an eleven month period. The samples were collected in half pint bottles, iced immediately, and held for 18-24 hours at 35-40°F., then pasteurized at 145-150°F., holding for 30 minutes. Bulk tank samples were taken immediately after milking was completed. Pipeline samples were drawn directly from line milk valves as well as from the ends of the lines.

Analytical Methods

The free fatty acid degree of milk was determined by the procedure of Harper, Basset, and Gould (1954), and Thomas, Harper, and Gould (1954). This procedure is outlined.

a. Fifty-five to sixty milliliters of milk was measured into a 250 milliliter Fisher Centrifuge bottle. The sample was adjusted to room temperature and to a pH of 2 with sulphuric acid.

b. The acidified sample was mixed with 65 milliliters of 95 percent ethanol and shaken vigorously for 60 seconds. After a 5 minute reaction period, 40 milliliters of ethyl ether and 60 milliliters "Skellysolve F" were added, and the mixture was shaken vigorously for 30 seconds.

c. The milk and solvent mixture was centrifuged at 2000 revolutions per minute for 20 minutes in a size 2, model V, International Centrifuge, after which

the ether layer was siphoned into a Mojonnier fat evaporating dish.

d. The solvent was removed by heating at 135°C. on the fat evaporating hot plate of a Mojonnier tester until bubbling ceased. The last traces of solvents were removed in the solids oven of a Mojonnier tester, heating for 5 minutes at 100°C. under 20 inches vacuum.

e. Exactly 1 gram fat, at room temperature, was weighed into a 50 milliliter beaker on a chainomatic balance. The fat was dissolved in 10 milliliters of purified absolute alcohol and 20 milliliters of "Skellysolve F." The solvent, previous to mixing with the fat, was slightly heated and neutralized to the phenolphthalein end point.

f. The warm butterfat-solvent mixture was titrated with 0.01 Normal absolute ethanolic KOH, using 5 drops of 1 percent alcoholic phenolphthalein indicator. The endpoint was determined according to Breaseale and Bird (1938). The first definite color change, compared with a sample not titrated, was taken as the endpoint. The titration value was expressed as free fatty acid degree, defined by Gould and Trout (1936).

Preparation of Reagents

Preparation of purified absolute alcohol. Absolute alcohol was purified using Triebold's method (1949). Absolute ethanol was refluxed for one hour over solid KOH

and aluminum metal, (using 10 grams KOH and 6 grams aluminum metal per 1,200 milliliters of alcohol) and distilled from these reagents.

Preparation of ethanolic KOH. Purified absolute ethanol was used to prepare 0.01 Normal KOH. The solution was standardized with potassium acid phthalate and restandardized biweekly.

"Skellysolve F". The petroleum ether, having a boiling range of 30-60°C., was obtained from the Skelly Oil Company, Kansas City, Missouri.

Organoleptic Examination

Organoleptic examinations were made of all samples while determining the fatty acid degree. According to the recommendation of Nelson and Trout (1951), the milk was adjusted to body temperature, 98.6°F., to volatilize the odors present.

Surface Tension Measurement

Surface tension determinations were made with an Cenco Du Nouy tensiometer. All samples prior to testing were stored under refrigeration temperature. The milk was tempered to 20°C. when tested, as recommended by Tarassuk and Smith (1940), Tarassuk and Henderson (1942), Dunkley (1951), Costilow and Speck (1951), and Dunkley and Kelley (1954a). Determinations were made in duplicate. The tensiometer was standardized and rechecked periodically, according to the instructions of the manufacturer.

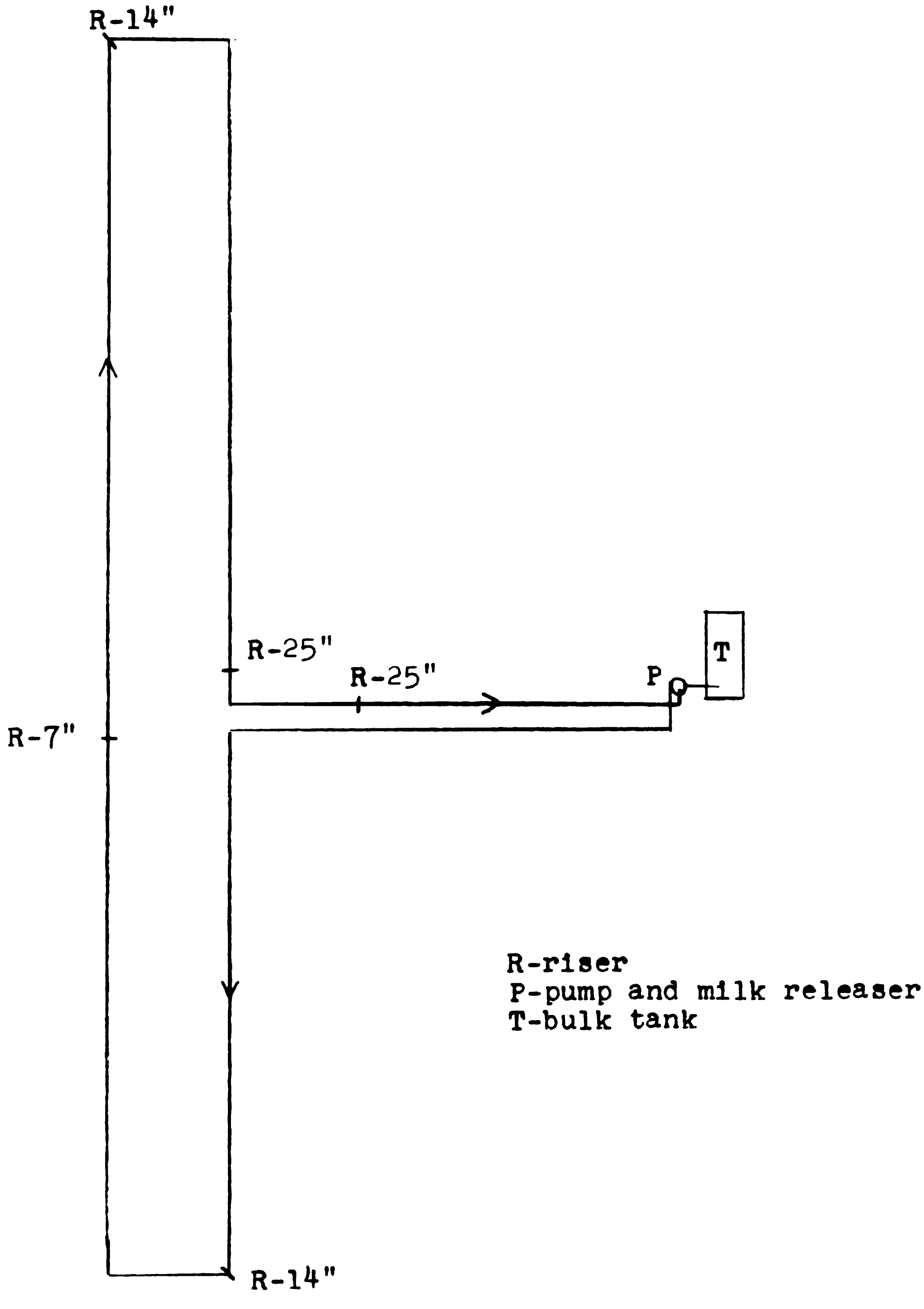
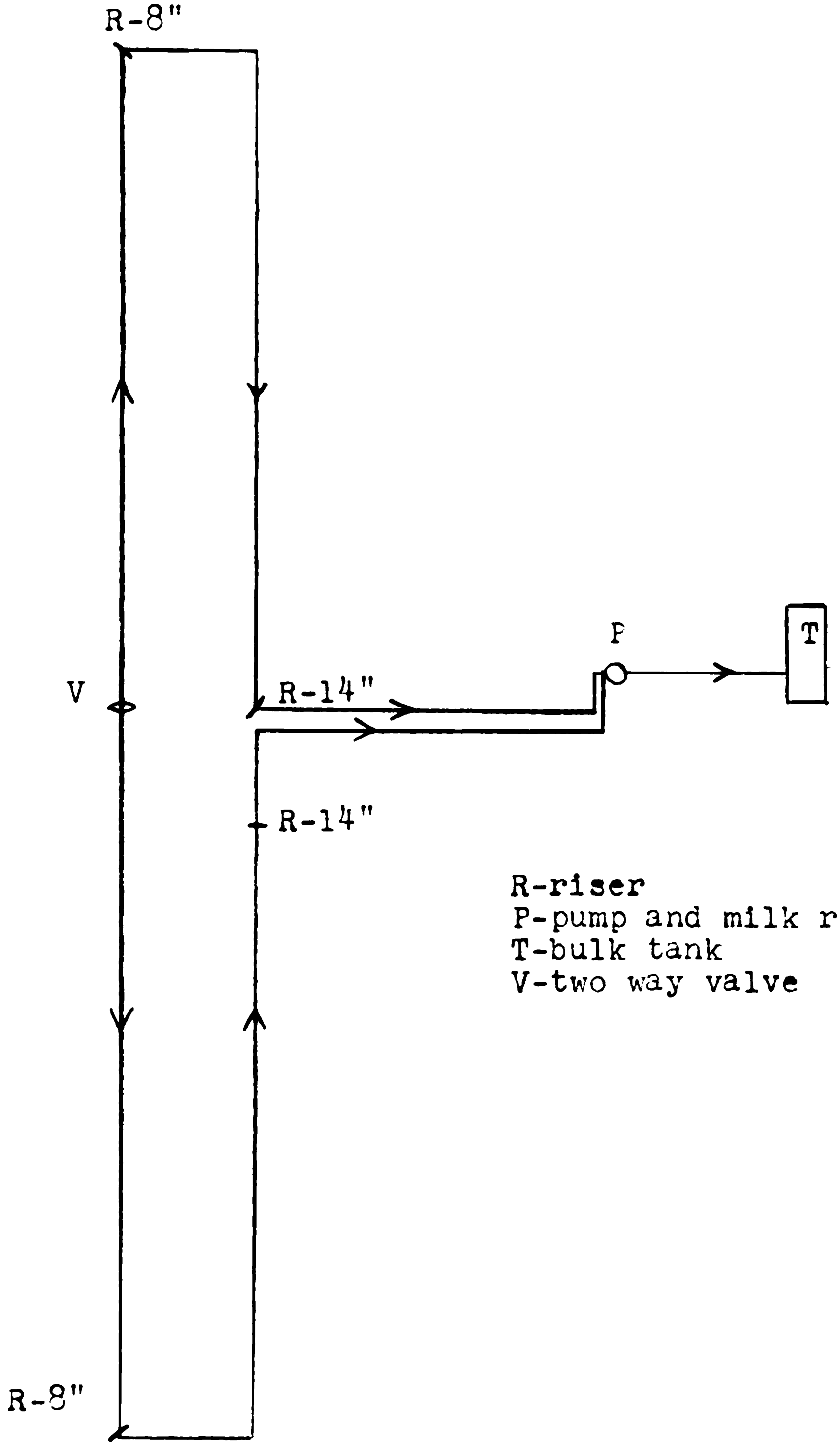
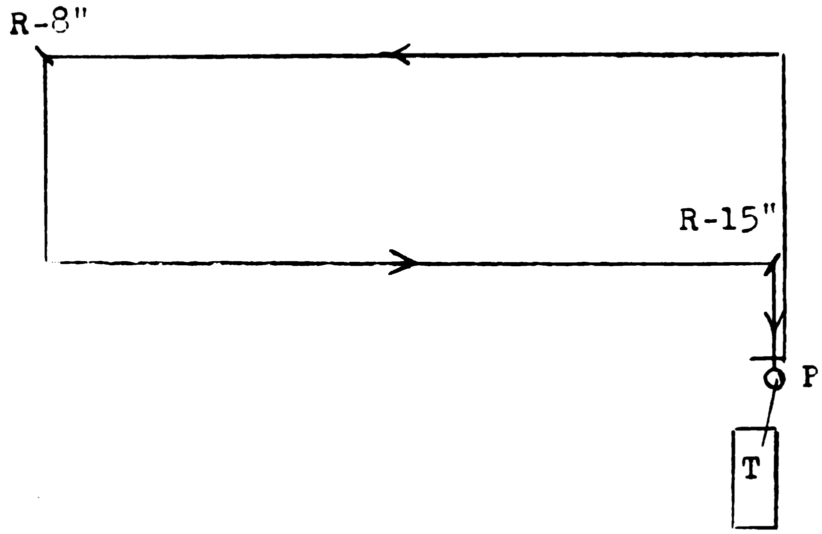


Figure 1. Pipeline Installation "A"
(1/2"=10')



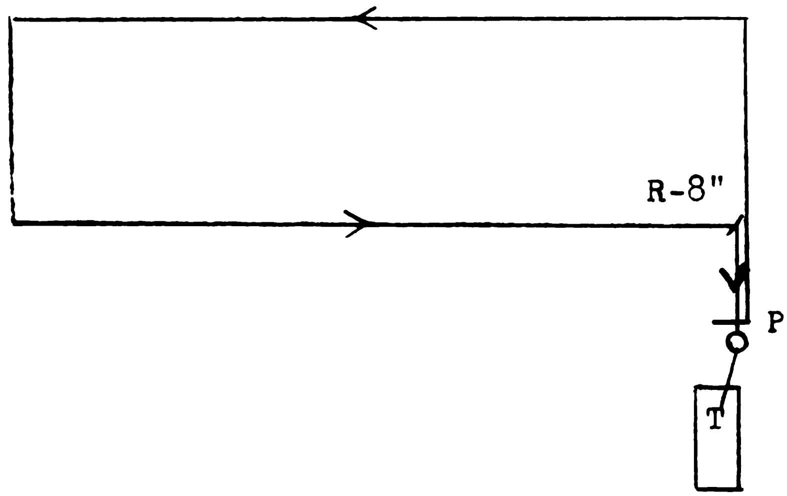
R-riser
P-pump and milk releaser
T-bulk tank
V-two way valve

Figure 2. Pipeline Installation "A_1"
(1/2"=10')



R-riser
P-pump and milk releaser
T-bulk tank

Figure 3. Pipeline Installation "B"
(1/2"=10')



R-riser
P-pump and milk releaser
T-bulk tank

Figure 4. Pipeline Installation "B_1"
(1/2"=10')

EXPERIMENTAL

Effect of Installation "A" on F.F.A.° of Milk

A description of milker pipeline system "A" is given on page 23 and is shown by Figure 1 (page 28). This was the original system installed in the main dairy barn of Michigan State University. Frequent occurrences of rancid flavor and odors of milk produced by the system had been observed. During the study of this line, butter particles were found regularly on the milk filter medium, indicating excessive churning action.

The appearance of milk flowing through the line and over the risers was marked by abundant foaming and continual turbulent action of the milk in the risers. The result of F.F.A.° determinations, made at designated points in the line, is shown in Tables I through V inclusive.

Data in Table I show that when the milk passed through a 330 foot section of pipeline with an aggregate riser height of 85 inches, the F.F.A.° of milk fat, in five out of seven trials, increased by 3.00 to 4.00 F.F.A.°. Only two trials gave increases of less than 1.00 F.F.A.°.

Data in Table II show that when milk passed through a 300 foot section of pipeline, with aggregate riser height of 85 inches, the F.F.A.° of milk fat, in four out of five trials, generally increased by 2.00 to 3.00 F.F.A.°. One trial shows an increase less than 2.00 F.F.A.°.

TABLE I

INFLUENCE OF LENGTH OF LINE AND HEIGHT OF RISERS ON F.F.A.° OF MILK IN PIPELINE "A" HOLSTEIN BREED

Trial No.	Month	F.F.A.° of Milk				
		30' H[1] 0" V[2]	107' H 14" V	273' H 35" V	330' H 85" V	Total Inc.
1	Sept.	1.84	2.72	3.29	5.69	3.85
2	Sept.	1.68	2.66	3.38	4.88	3.20
3	Oct.	2.02		3.79	5.38	3.36
4	Nov.	2.75		3.00	3.64	.89
5	Dec.	2.12		4.84	6.19	4.07
6	Dec.	3.54		4.05	4.29	.75
7	Dec.	2.83		5.55	6.68	3.85

1 Horizontal section of pipeline
2 Vertical section of pipeline

TABLE II

INFLUENCE OF LENGTH OF LINE AND HEIGHT OF RISERS ON F.F.A.° OF MILK IN PIPELINE "A" BROWN SWISS BREED

Trial No.	Month	F.F.A.° of Milk			
		0' H[1] 0" V[2]	243' H 35" V	300' H 85" V	Total Inc.
1	Sept.	2.91	4.24	5.10	2.19
2	Oct.	1.70	3.70	4.99	3.29
3	Nov.	2.40	4.10	5.68	3.28
4	Dec.	2.03	3.37	4.46	2.43
5	Dec.	2.03	3.05	3.68	1.65

1 Horizontal section of pipeline
2 Vertical section of pipeline

Data in Table III show that when the milk passed through a 200 foot section of pipeline with an aggregate riser height of 71 inches, the F.F.A.° of milk fat in one trial was 5.3. Three other trials ranged from 0.65 to 2.71.

Data in Table IV show that when the milk passed through a 138 foot section of pipeline with an aggregate riser height of 64 inches, the F.F.A.° of milk fat generally increased by 1.00 to 1.50 F.F.A.°.

Data in Table V show that when the milk passed through a 57 foot section of pipeline with an aggregate riser height of 50 inches, the F.F.A.° of milk fat generally increased by 1.00 to 2.00 F.F.A.°.

Data presented in Tables I through V show that the F.F.A.° of the milk fat increased with the increase of distance the milk flowed in the horizontal and vertical sections of the line. In the 27 trials shown in these tables, the acid values were the lowest at the point nearest to the milkers, but increased with the distance traveled and with the risers encountered.

In all the trials, the data show that the F.F.A.° was the highest at the discharge end of the line. The acid degree of the milk drawn from all the intermediate points practically increased continuously as the distance of flow increased.

TABLE III

INFLUENCE OF LENGTH OF LINE AND HEIGHT OF RISERS
ON F.F.A.° OF MILK IN PIPELINE "A"
AYRSHIRE BREED

Trial No.	Month	F.F.A.° of Milk			
		0' H[1] 0" V[2]	163' H 21" V	220' H 71" V	Total Inc.
1	Sept.	1.90	2.67	7.20	5.30
2	Oct.	2.09	3.34	4.80	2.71
3	Nov.	1.38	2.31	3.45	2.07
4	Dec.	1.72	1.72	2.37	.65

1 Horizontal section of pipeline
2 Vertical section of pipeline

TABLE IV

INFLUENCE OF LENGTH OF LINE AND HEIGHT OF RISERS
ON F.F.A.° OF MILK IN PIPELINE "A"
GUERNSEY BREED

Trial No.	Month	F.F.A.° of Milk			
		0' H[1] 0" V[2]	81' H 14" V	138' H 64" V	Total Inc.
1	Sept.	1.25	1.68	2.89	1.64
2	Oct.	.87	1.50	2.09	1.22
3	Nov.	1.28	1.48	2.19	.91
4	Dec.	1.30	1.60	2.73	1.43
5	Dec.	1.78	1.91	3.11	1.33

1 Horizontal section of pipeline
2 Vertical section of pipeline

TABLE V

INFLUENCE OF LENGTH OF LINE AND HEIGHT OF RISERS ON F.F.A.° OF MILK IN PIPELINE "A" JERSEY BREED

Trial No.	Month	F.F.A.° of Milk 0' H[1] 0" V[2]	57' H 50" V	Total Inc.
1	Sept.	1.33	3.38	2.05
2	Sept.	1.16	2.69	1.53
3	Oct.	.97	1.89	.92
4	Nov.	1.36	3.55	2.19
5	Nov.	1.64	3.34	1.70
6	Dec.	2.00	4.23	2.23

1 Horizontal section of pipeline
2 Vertical section of pipeline

Effect of Line "A" on "F.F.A.°" of Milk Fat

When Milk is Admitted in Volume

at Distant End of Line

In the previous trials, milk was drawn directly into the milk line from the cows in their respective locations. That manner of sampling permitted observation on the effect of certain distance of flow and risers encountered on the milk drawn at the subsequent locations. By this means, the amount of milk in the line was not uniform and was influenced by the production of the cows being milked. Furthermore, the method did not permit a comparison of milk from different breeds, which were located in group positions around the stable. Additional trials were therefore made to observe the influence of distance of flow and height of risers on the

F.F.A.°, when all milk was milked into milker pails and dumped into a transfer can at the distant line end, and from where milk was drawn into the line in ten gallon volumes. Samples for testing were drawn at the various points, as shown in Table VI.

Nineteen trials, each consisting of four samples, were taken at points shown by Table VI. The F.F.A.° values show that some increase in F.F.A.° occurred with respect to horizontal and vertical distances of flow. The average initial value of 1.75 increased, only insignificantly however, to a value of 1.76, when the horizontal distance of flow was 62 feet and no risers were encountered. With a flow distance of 302 feet horizontal and 35 inches vertical, the average F.F.A.° had mounted to 2.12, yielding an average increase of 0.37 F.F.A.°. At the end of the line, with a flow distance of 361 feet horizontal and 85 inches vertical, the samples had an average F.F.A.° of 2.36, a total increase of 0.61 F.F.A.°. This was a slight increase in F.F.A.°, when compared with the values of the milk shown in Table I, where milk was drawn directly into the line as each cow was milked. The lowest increase in F.F.A.° in Table I was 0.75, and the general increase ranged from 3.2 to 4.07 F.F.A.°.

When the milk was released in ten gallon volumes at the far end of the line, the amount of milk in the line increased and flowed continuously through the entire length of the line, passing over the risers smoothly and without excessive turbulance.

TABLE VI

EFFECT OF DISTANCE AND RISERS ON F.F.A.°
ADMITTING 10 GALLON VOLUMES OF MILK
INTO DISTANT END OF LINE "A"

Trial No.	F.F.A.° of milk				
	0' H[1] 0" V[2]	62' H 0" V	302' H 35" V	361' H 85" V	Total Inc.
1	1.75	1.62	1.73	2.52	0.87
2	2.50	2.35	3.00	3.18	0.68
3	2.30	1.93	2.16	2.27	-
4	1.94	1.88	2.50	2.29	0.35
5	2.31	2.50	2.78	3.31	1.00
6	2.00	2.33	2.43	2.72	0.72
7	2.00	2.32	2.65	2.80	0.80
8	1.66	1.80	1.73	2.16	0.50
9	2.49	2.58	3.90	5.37	2.88
10	1.58	1.65	2.29	2.10	0.52
11	1.80	1.80	2.36	2.40	0.60
12	1.29	1.43	1.70	2.01	0.72
13	1.15	1.17	1.25	1.66	0.45
14	1.07	1.09	1.60	1.39	0.32
15	1.35	1.20	1.66	1.66	0.31
16	1.28	1.42	1.56	1.69	0.31
17	1.28	1.31	1.48	1.50	0.22
18	1.40	1.38	1.68	1.72	0.32
19	1.78	1.77	1.82	1.89	0.10
Average	1.75	1.76	2.12	2.36	0.61

1 Horizontal section of pipeline
2 Vertical section of pipeline

Influence of Breed on F.F.A.° in Line "A"

The F.F.A.° in milk from cows of different breeds and the effect of flowing through line "A", with samples drawn initially and after various distances of flow is shown in Table VII.

It is noted that the highest initial average, 2.18, occurred in Holstein milk. This was followed in order of F.F.A.° average by the milk of Brown Swiss, 2.06; Ayrshire, 1.88; Jersey, 1.43; and Guernsey, 1.21. The Jersey and Guernsey milk samples were consistently and considerably lower in F.F.A.° than milk from the other breeds. After flowing through pipeline and over 85 inches of risers, susceptibility to activation was found to be greatest in the Ayrshire milk with an average F.F.A.° of 3.0, followed in order by milk from Brown Swiss, 2.78; Holstein 2.65; Guernsey 1.68; and lowest Jersey with 1.70 F.F.A.°. This influence of activation by pipeline flow is also shown by the percentage F.F.A.° increase column of Table VII. The Ayrshire milk showed an increase in F.F.A.°of 37.3 percent, Brown Swiss 25.8 percent, Guernsey 22.0 percent, Holstein 17.7 percent, and Jersey 15.0 percent.

Effect of Altering Line "A" to "A_1" on F.F.A.° of Milk

Pipeline "A" was altered to reduce the distance of flow and height of risers. Simultaneously, the degree of line slope was decreased, and the air intake limited to

TABLE VII

BREED INFLUENCE ON F.F.A.°
WHEN MILK WAS ADMITTED INTO LINE "A"
IN 10 GALLON VOLUMES

Breed	Month	F.F.A.° of Milk				Total % F.F.A.° Inc.
		0' H[1] 0" V[2]	62' H 0" V	302' H 35" V	361' H 85" V	
Holstein	Sept.	1.75	1.62	1.73	2.52	
	Oct.	2.50	2.35	3.00	3.18	
	Nov.	2.30	1.93	2.16	2.27	
Average		2.18	1.96	2.29	2.65	17.7
Brown Swiss	Sept.	1.94	1.88	2.50	2.29	
	Oct.	2.31	2.50	2.78	3.31	
	Nov.	2.00	2.33	2.43	2.72	
	Dec.	2.00	2.32	2.65	2.80	
Average		2.06	2.25	2.59	2.78	25.8
Ayrshire	Sept.	1.66	1.80	1.73	2.16	
	Oct.	2.49	2.58	3.90	5.37	
	Nov.	1.58	1.65	2.29	2.10	
	Dec.	1.80	1.80	2.36	2.40	
Average		1.88	1.90	2.57	3.00	37.3
Guernsey	Sept.	1.29	1.43	1.70	2.01	
	Oct.	1.15	1.17	1.25	1.66	
	Nov.	1.07	1.09	1.60	1.39	
	Dec.	1.35	1.20	1.66	1.66	
Average		1.21	1.22	1.55	1.68	22.0
Jersey	Sept.	1.28	1.42	1.56	1.69	
	Oct.	1.28	1.31	1.48	1.50	
	Nov.	1.40	1.38	1.68	1.72	
	Dec.	1.78	1.77	1.82	1.89	
Average		1.43	1.47	1.63	1.70	15.0

1 Horizontal section of line
2 Vertical section of line

that entering from the claw air-ports. The description is shown by Figure 2 and under "Description of Pipeline Installations," on page 23. The risers were limited to only two per line, with an aggregate height of 22 inches. Results on this line are shown in Table VIII.

TABLE VIII

INFLUENCE OF LINE "A_1" ON F.F.A.° WITH VARIOUS DISTANCES OF FLOW

Section of Line	Trial No.	F.F.A.° of Milk			
		20' H[1] 0" V[2]	142' H 8" V	200' H 22" V	Total Inc.
North	1-n	1.65	1.70	1.66	0.01
	2-n	1.60	2.34	1.70	0.10
	3-n	1.60	1.88	1.90	0.30
	4-n	1.53	1.50	1.72	0.19
South	1-s	1.13	1.57	1.42	0.29
	2-s	1.28	1.70	1.52	0.24
	3-s	1.50	2.40	1.80	0.30
	4-s	1.92	2.23	2.88	0.96

1 Horizontal section of pipeline
2 Vertical section of pipeline

The data presented in Table VIII show that only a very small increase in F.F.A.° occurred as the milk flowed in line "A_1." The results show that, as the milk passed through a 200 foot section of pipeline with an aggregate riser height of 22 inches, the F.F.A.° of milk fat, in six out of eight trials, mostly increased by 0.10 to 0.30 F.F.A.°. Trial 1-n of Table VIII shows no increase in acid values. Trial 4-s shows an F.F.A.° increase from 1.92 to 2.88, or 0.96 F.F.A.° change. During that trial, some air leakage occurred in the south line section, causing foaming and turbulence in the milk.

In line "A_1," a definite change was observed in milk flow, along with reduction of foaming and turbulence of milk. The change greatly reduced the incidence of churning as noted by the absence of butter granules on filtering media.

In line "A_1," the milk appeared to foam up, then move over the risers with a low velocity and a rhythmic flow.

Effect of Milker Installation "B" on F.F.A.° of Milk

The description of milker installation "B" is given on page 23 and by Figure 3. This installation was similar to installation "A_1," but the milk was found extremely rancid to taste and smell. The milk was produced by a large Holstein herd. Random samples on which consumers complaints were registered gave F.F.A.° values of 3.14 to 14.89. The milk in the pipeline foamed excessively. Air leaks were discovered to exist at joints, due to faulty milk valves, during the course of the study. The milk line sloped 1.75 inch per 10 lineal feet and to the extent that milk flowed continually toward the riser, causing it constantly to gurgle and churn at that point. The data on F.F.A.° values on milk sampled from various line positions is shown in Table IX.

Data in trials 1 to 5 of Table IX show high F.F.A.° values on 14 of the 16 samples tested. Only two samples, both in trial 2, were below 3.00 in F.F.A.°. One of these samples had a F.F.A.° value of 2.88 and was drawn after a 21 foot horizontal and 8 inch vertical distance of flow. The other had a F.F.A.° value of 2.65, after flowing 95 feet horizontally and 8 inches vertically. The F.F.A.° values in three samples, drawn from the line at the closest point to the milk inlet valve (0"V, 0'H), were 3.05, 4.15, and 4.39. The initial samples drawn were consistently the

TABLE IX

INFLUENCE OF LENGTH OF LINE AND HEIGHT OF RISERS ON F.F.A.° OF MILK IN PIPELINES "B" AND "B_1"

Pipe line	Trial No.	F.F.A.° of Milk								
		0'H[1] 0"V[2]	20'H 14"V	21'H 8"V	80'H 8"V	95'H 8"V	115'H 23"V	154'H 8"V	175'H 23"V	Total Inc.
B	1	3.05	6.40							3.35
	2			2.88		2.65	4.70			1.82
	3	4.39			5.55			5.51	5.89	1.50
	4			3.53		4.37	4.73			1.20
	5	4.15			7.70			7.47	4.19	0.04
	6	3.78	3.60							-
	7			2.04		2.22	2.31			0.27
	8	2.38			2.95			3.00	2.74	0.36

Pipe line	Trial No.	0'H 0"V	20'H 8"V	21'H 8"V	115'H 8"V	175'H 8"V	Total Inc.
B_1	9	2.73	2.73				-
	10			3.10	2.47		-
	11	2.68				3.15	0.47

1 Horizontal section of pipeline
2 Vertical section of pipeline

lowest in F.F.A.°. Subsequent tests did not show consistent increases in F.F.A.° with respect to the distance that milk flowed. This condition is especially apparent in trial 5, where the initial F.F.A.° value was 4.15. After flowing 80 feet horizontally and 8 inches vertically, the milk tested 7.70 F.F.A.°, and, after flowing 154 feet horizontally and 8 inches vertically, the result was 7.47 F.F.A.°. At the end of 175 feet horizontal distance and 23 inches vertical distance, the F.F.A.° of the milk

was only 4.19. The apparent lowering was believed caused by variation in the milk, since it was not possible to entirely control the milk entering the line. The cause of high F.F.A.° values in milk from installation "B" was believed to be partly caused by susceptibility of the milk to spontaneous lipolysis. Consequently, two lots of individual cow samples were taken and tested as described in the section on "Lipolysis of Individual Cow Milk Samples," page 45.

Trial 5 was made after screening out 18 cows that showed a tendency toward spontaneous rancidity. The F.F.A.° results in trial 5 showed increase in value instead of lowered values as had been anticipated. Air leaks were discovered in the line valves at this point in the investigation, and valves in 20 positions were replaced. At the same time, workers discovered a milk line coupling without gasket, which was also repaired. Trials 6, 7, and 8 of Table IX show the F.F.A.° of milk from indicated points in line "B" after being refitted with new valves and gasket. Nine samples were tested for F.F.A.° in trials 6 through 8. With only two exceptions, the values ranged between 2.04 and 3.00. The exceptions involved milk from the same group of cows taken from the line at 0'H, 0"V, and 20'H, 14"V distances, with respective F.F.A.° values of 3.78 and 3.60.

Effect of Altering Line "B" to "B_1"

After line "B" was altered by removing two vertical pieces and lowering the riser height to only 8 inches and the line slope to 0.5 inch per ten feet of line, trials 9, 10, and 11 were made. Trial 9 yielded F.F.A.° values of 2.73, at distances of both 0 and 20 feet of horizontal flow. Trial 10 gave F.F.A.° values of 3.10 and 2.47 at the respective distances of 21 and 115 feet horizontal and 8 inch vertical, representing a loss. Trial 11 at 0 and 175 feet horizontal flow distance gave respective values of 2.68 and 3.15 F.F.A.°. The milk was observed to dam up in the line, then flow without foaming. The milk flowed quietly and without apparent turbulent action over a 8 inch riser in the line. Apparently this herd of cows produced milk that was more than normally susceptible to lipolysis.

Lipolysis of Individual Cow Milk Samples

Because of the presence of unusually high F.F.A.° in milk secured from line "B", individual cow samples were taken from milker pails, directly after each cow was milked. The samples were taken, cooled, and held, similarly to the usual procedure for sampling, described on page 25. Each sample was also tested for surface tension and for rancidity by organoleptic test as described under "Experimental Procedure" on page 27. Upon completion of' the surface tension test and the organoleptic test, the samples were grouped according to flavor intensity and tests were made on pooled milk lots from these groups. The results are shown in Table X.

TABLE X

RELATIONSHIPS BETWEEN SPONTANEOUSLY RANCID FLAVOR, SURFACE TENSION, AND F.F.A.° OF MILK FROM INDIVIDUAL COWS

Flavor	No. Samples	Surface Tension						Ave. F.F.A.° of Combined Samples	
		< 46 dynes per cm.		46-48 dynes per cm.		> 48 dynes per cm.		< 48 dynes per cm.	> 48 dynes per cm.
		No.	%	No.	%	No.	%		
Satisfactory	84	-	-	29	59	55	100	2.62	2.32
Rancid	22	2	100	20	41	-	-	3.51	-
Total	106	2	100	49	100	55	100		

Eighty-four samples from individual cows were determined satisfactory by organoleptic test. Of those tested, 55 gave surface tension measurements of more than 48 dynes per centimeter, 29 samples tested between 46 and 48 dynes per centimeter, and none tested less than 46 dynes per centimeter. Of 22 samples that were rancid to taste, none tested higher than 48 dynes per centimeter, 20 tested 46-48, and 2 were below 46 dynes per centimeter. With a surface tension of 46 to 48 dynes per centimeter, 59 percent of the samples were determined satisfactory by tasting, and 41 percent were rancid. Pooled milk samples, having surface tension tests of more than 48 dynes per centimeter, had an F.F.A.° value of 2.32. The combined samples of milk, with satisfactory taste and with surface tension values of less than 48 dynes per centimeter, yielded an

F.F.A.° of 2.62. Pooled samples of rancid milk, with a surface tension less than 48 dynes per centimeter, tested 3.51 F.F.A.°.

Effect of Line "C" on F.F.A.° of Milk

Milk produced in milking parlor line installation "C" was tested for F.F.A.°. The milk was produced by a herd composed of Holstein and Brown Swiss cows and was drawn into weight cans. After milking and weighing, the milk was drawn by vacuum through the line to the cooling tank. One high, 2 feet 10 inch riser, and a one inch diameter steel line, with standard fittings and without gaskets, was used, making the line somewhat different from those used in the stanchion type line. The F.F.A.° on three trials are shown in Table XI.

The data presented in Table XI show a very slight increase in F.F.A.° as the milk passed through the overhead pipeline installation "C". The data of the three trials show an increase from 1.53 to 1.74 or 0.21, from 1.83 to 2.16 or 0.33, and from 2.02 to 2.18 or 0.16 F.F.A.° respectively. The pipeline, under constant vacuum, drew the milk from the weight jar to the vacuum bulk tank, in one continuous flow without creating foaming or turbulence. Further investigations on installation "C" were discontinued, since all three trials failed to show considerable increase in F.F.A.°.

TABLE XI

F.F.A.° IN MILK FROM MILKING PARLOR WEIGH JARS AND SUBSEQUENT BULK TANK SAMPLES OF LINE "C"

Trial No.	Free Fatty Acid Degree		Increase in F.F.A.°
	Weigh Jar	Bulk Tank	
1	1.53	1.74	0.21
2	1.83	2.16	0.33
3	2.02	2.18	0.16

Effect of Length of Milk Line Without Risers on F.F.A.° of Milk as Observed on Installation "D"

Three milkings were observed, and samples were obtained for F.F.A.° from the "D" pipeline installation. The milk was produced by a large Holstein herd. The milk was observed to flow smoothly and quietly, without foaming. The results are shown in Table XII.

The data show that the F.F.A.° of milk fat in the first trial increased from 1,84 to 1.96 or 0.12, in the second trial from 1,73 to 1.94 or 0.21, and in the third trial from 2.22 to 2.75 or 0.53 respectively. All three trials show a very slight increase in F.F.A.° as the milk passed through the 210 feet stanchion pipeline installation "D". Further investigations on installation "D" were discontinued, since the three trials did not show any considerable increase in F.F.A.°.

TABLE XII

F.F.A.° OF MILK FROM STANCHION BARN PIPELINE "D" NO RISERS

Trial No.	F.F.A.° of Milk					
	20'H[1]	70'H	130'H	180'H	210'H	Total Inc.
1	1.84	1.80	1.84	1.96		0.12
2	1.73	1.90	2.00	2.20	1.94	0.21
3	2.22	1.74	2.07	1.96	2.75	0.53

1 Horizontal section of line

Seasonal Differences in F.F.A.° of Milk

Tests were made of milk for F.F.A.° from samples drawn by milking systesm "A", "C", and "E". Samples for tests were taken from well mixed bulk tanks at fairly even intervals over an eleven month period. The data secured are shown in Table XIII.

It can be shown that the lowest F.F A.° values occurred in late spring and summer, from May until July, while the highest values occurred in the fall, from September until December. Table XIII also indicates that the F.F.A.° values during the winter, from January until March, were only slightly lower than in the fall.

The average F.F.A.° values, in installations "A", "C", and "E", in May through July were 2.77, 1.60, and 1.07 respectively. In September to December, the same installations showed values of 3.62, 2.28, and 1.43 respectively. Pipeline installations "C" and "E" in January through March

TABLE XIII

SEASONAL DIFFERENCES IN F.F.A.°
FROM VARIOUS MILKING INSTALLATIONS

Pipe line	Season	No. Samples	F.F.A.°		
			Average	Highest	Lowest
A	May-July	12	2.77	5.95	1.58
	Sept-Dec	28	3.62	5.41	2.55
A_1	Jan-March	18	1.85	2.22	1.52
C	May-July	8	1.60	2.16	1.21
	Sept-Dec	5	2.28	2.80	1.87
	Jan-March	4	2.22	2.57	2.00
E	May-July	8	1.07	1.20	0.84
	Sept-Dec	5	1.43	1.57	1.26
	Jan-March	4	1.40	1.54	1.31

yielded F.F.A.° values of 2.22 and 1.40 respectively.

Relationship between Rancid Flavor
and F.F.A.° of Milk

F.F.A.° determination was made on 502 milk samples in this study. The same samples also were tested organoleptically for presence of rancid flavor. The data are shown in Table XIV.

All milk of F.F.A.° of 2.0 and less, 200 samples, were satisfactory to taste and free of rancid flavor. When F.F.A.° values ranged from 2.0 to 3.0, as did 144 samples, 75.6 percent were found free of rancid flavor

TABLE XIV

RELATIONSHIP BETWEEN RANCID FLAVOR AND F.F.A.° OF MILK

Flavor	No. Samples	F.F.A.° of Milk							
		< -2.0		2.0-3.0		3.0-4.0		4.0- <	
		No.	%	No.	%	No.	%	No.	%
Satis-factory	310	200	100	109	75.6	5	7.1	-	-
Rancid	192	-	-	35	24.4	65	92.9	88	100
Total	502	200	100	144	100.	70	100.	88	100

and 24.4 percent were found rancid. Of 70 samples with F.F.A.° ranging between 3.0 and 4.0, 92.9 percent were found rancid by taste. All 88 samples, with F.F.A.° of 4.0 and over, were detected as having rancid taste.

Relationship Between Rancid Flavor and Surface Tension Measurement

Surface tension measurement and organoleptic examination were made of 324 milk samples, using the procedure described in "Experimental Procedure," page 27. The results are shown in Table XV.

Two hundred twelve samples were determined satisfactory by organoleptic test. Of those, the majority, or 150, gave a surface tension measurement of more than 48 dynes per centimeter. Fifty-eight samples measured between 46 and 48 dynes per centimeter, and only 4 tested less than 46 dynes per centimeter. Of 112 samples that were rancid to

TABLE XV

RELATIONSHIP BETWEEN RANCID FLAVOR
AND SURFACE TENSION OF MILK

Flavor	No. Samples	Surface Tension < 46 dynes/cm. No.	%	46 to 48 dynes/cm. No.	%	48 < dynes/cm No.	%
Satis-factory	212	4	7.5	58	48.	150	100.
Rancid	112	49	92.5	63	52.	-	-
Total	324	53	100.	121	100.	150	100

taste, none tested as high as 48, 63 tested 46 to 48, and 49 were below 46 dynes per centimeter. Percentagewise, it was calculated that 92.5 percent of the samples with a surface tension of less than 46 dynes per centimeter were determined rancid by tasting, while of the samples with surface tension of 46 to 48 dynes per centimeter, the flavor was satisfactory 48 percent of the time and rancid 52 percent of the time.

DISCUSSION

Rancidity of raw milk, indicated by F.F.A.° values in this study, is generally thought to be caused by the disruption of the fat globule "membrane", causing the liquid fat globules to become exposed to lipase action. Fatty acids are produced in varying amounts depending upon such factors as reaction time, amount of fat exposed, and nature of fat exposed. Fat in liquid state is more subject to lipolysis than is fat in solidified state. Consequently, freshly drawn milk will not tolerate vigorous agitation and soon becomes rancid. According to Frankel and Tarassuk (1955), the necessary condition for activation by air appears to be foaming, with continuous mixing of foam and milk at temperatures that keep milk fat in liquid state. These conditions may be effected in pipeline milkers.

The free fatty acids of milk may be determined to a satisfactory extent by titration, giving a F.F.A.° value that can be interpreted to show the extent of lipolytic action. During the course of this study, it was found that the extraction solvent method of Harper, Basset, and Gould (1954) and Thomas, Harper, and Gould (1954) gave the most reliable data on changes in fat acidity. These findings were supported by various investigators of lipolysis including Herrington (1954) and Frankel and Tarassuk (1955), who believed that the extraction solvent method is the most reliable method for measuring extent of lipolysis.

The difficulty experienced with pipeline installation "A", showing high incidence of rancidity and excessive churning, was apparently quite typical when using long lines with many risers. Similar observations were reported recently by Schulz (1956) on a group study of 127 farms using pipeline milkers. By the data secured during the study of pipeline "A", the F.F.A.° increased directly with the increase in distance the milk flowed in the horizontal and vertical sections of the pipeline. The flow of milk in each section of line "A" was observed to produce violent bubbling. Churning and extensive turbulence was observed in the risers. Churned butter particles on the filter medium gave more evidence of churning due to violent agitation. Excess air in the line was found to be responsible for turbulence, giving rise to induced rancidity.

Increasing the flow of milk in the "A" line, by admitting ten gallon volumes at the distant end in order to have all lots of milk flow through the entire line and over all the risers, limited the extent of air mixing with milk. Foaming and turbulence was reduced in the line and the risers, followed by considerable decrease in F.F.A.° values. Believing that the numerous risers, excess air intake, and excess length of the line was responsible for the excessive agitation and churning caused in line "A", the line was altered. The length of the line was decreased by splitting the line into two separate sections, decreasing the horizontal section from the original 360 feet to a length of 200 feet. The aggregate height of five risers was cut from 85 inches to 22 inches. The slope of the line was decreased from 1.5 inch per ten linear feet to 0.5 to 0.8 inch. The regular air intake valve was completely eliminated. A minimum air intake was provided through the air ports at the milker claws. The change produced uniform vacuum and regular flow in the milk with reduction in foaming and absence of churning and turbulence.

The conditions responsible for increased F.F.A.^{o} in pipeline "A" were undoubtedly due to excess turbulence in the risers, as shown by Dunkley and Kelley (1954a, 1954b) and churning as has been described by Herrington (1954). These conditions were plainly evident during the time of milking.

The severe instances of rancidity, found in installation "B", were also caused by foaming, but without apparent churning to the extent butter granules were produced.

Investigators, including Dunkley and Kelley (1954a, 1954b), have shown that rancidity as expressed by F.F.A.^{o} can be decreased by increasing the fill in the line, such as by milking more cows at a time. Four high yielding Holstein cows were milked regularly at a time with installation "B". In spite of the high intake, a great deal of foaming occurred, accompanied by high F.F.A^{o} values.

However, it became apparent that air leaks in the line were responsible for excess foaming. When the leaks were repaired and the air inlet was limited to only that admitted by the milker claw ports, only limited increases in F.F.A.° took place.

Lines "A_1" and "B_1" were both improved as conveyors of milk by decreasing the slope of these lines. With a more nearly level line, the milk dammed up in the line and flowed in fairly rhythmic volumes. Comparing lines "A_1" and "B_1", (lines "A" and "B" altered) from the viewpoint of length, riser height, and F.F.A.° value of milk, it was shown that line "A_1" (200 feet) was longer than line "B_1" (190 feet), had a higher aggregate riser height (22 inches) than line "B_1" (8 inches), the slope of both lines were approximately alike and milk appeared to flow in the same manner. However, the milk from the "A_1" line yielded the lower F.F.A.° values. The reason can partly be explained on the basis of breed of cows, which had shown that Brown Swiss, Ayrshire, Jerseys, and Guernseys gave milk of lower F.F.A.° than did Holsteins. Approximately three/fourths of the cows milked by installation "A_1" were other than Holsteins, while all cows of installation "B_1" were Holsteins. There was also indication that the higher F.F.A.° produced by "B_1" installation resulted because of an apparent herd susceptibility toward activation lipolysis.

Risers can not be said to be desirable in pipeline installations and evidence generally supports less difficulty in lines without them. It can be stated, however, in defense of risers that milk of low F.F.A.° can be produced with a limited amount of vertical flow. This has been shown by Dunkley and Kelley (1954a, 1954b), who found that risers will not induce rancidity if no excess air was admitted.

In stanchion pipeline milker "D" without risers, where the milk flowed partially by gravity and no risers were encountered, no considerable changes in F.F.A.° occurred. It was found definitely that when the milk flowed through a 200 foot distance, the F.F.A.° of milk increased only by 0.10 to 0.50 F.F.A.°. This indicated that no considerable changes in F.F.A.° could be expected in a stanchion line without risers, unless leaks in the line permit air intake.

The results of the investigations in installation "C" showed that when milk was drawn under vacuum in one continuous volume through a riser and short pipeline section, a very small increase in F.F.A.° occurred. The general increase in F.F.A.°, while the milk was drawn from the weight jar to the vacuum tank, ranged from 0.16 to 0.33. This could be attributed to the fact that no turbulence occurred in the vacuum line to activate rancidity. With the milk line kept full of milk until the container was emptied, there was no chance for air to mix with the warm milk to produce foaming and turbulence, the elements most likely to disrupt the fat surface membrane and cause rancidity.

The results of about 500 organoleptic examinations and solvent extraction titration tests showed that no rancid flavor occurred in milk with an F.F.A.° of less than 2.00. The threshold value ranged somewhere between 2.00 and 3.00 F.F.A.°. Milk with F.F.A.° over 3.00 mostly tasted rancid. Only ten percent of the samples with F.F.A.° of less than 3.00 were determined rancid by tasting. However 97 percent of the samples with F.F.A.° of 3.0 and above were declared rancid. Since the results of organoleptic testing depend on the tasting sensitivity of the judges, it was not feasible to state an exact threshold value for rancid flavor that could be expressed in F.F.A.°.

Surface tension measurements were found not reliable for showing the extent of rancidity in milk. No definite threshold value for rancid flavor could be determined by surface tension measurement. Generally speaking, milk with surface tension of 48 dynes and over tasted satisfactory, while the great majority of milk samples with a surface tension of less than 46 dynes were determined rancid. The threshold value of rancid flavor ranged somewhere between 46 to 48 dynes per centimeter. This finding is not in agreement with that of Dunkley (1951), who found that rancidity seldom was detected in samples with a surface tension above 46 dynes. It is possible that rancidity can be detected organoleptically before it can be measured by surface tension measurement. According to Herrington (1954), butyric acid, the most important factor in organoleptic measurement, has little effect on surface tension.

Spontaneous rancidity in milk from individual cows was determined by surface tension measurements. The threshold value of spontaneous rancidity appeared to range between 46 and 48 dynes per centimeter.

Season had an influence on the F.F.A.° of milk. The lowest F.F.A.° occurred in late spring and summer, while the highest occurred in the fall. The F.F.A.° in winter were slightly lower than those in the fall. These seasonal differences in F.F.A.° are presumed to be due to variations in feeds. However, no data substantiating this assumption were found in the literature.

There were some indications that milk from different breeds show a definite trend in variations in F.F.A.° when subjected to equal agitation. The percentage increase in F.F.A.° indicated that Ayrshire milk was the most susceptible to induced lipolysis through mechanical agitation, followed in order by Brown Swiss, Guernsey, Holstein, and Jersey.

Due to a limited number of samples tested, no definite conclusion can be drawn concerning seasonal variations in F.F.A.°, or to variations in susceptibility to mechanical agitations of the different breeds.

SUMMARY

The free fatty acid degree of milk, produced with pipeline installations, was affected approximately in order of intensity by (a) air intake, (b) number and height of risers, (c) length of line, (d) fill of line, and (e) slope of line.

The threshold value for rancid flavor ranged between 2.00 and 3.00 free fatty acid degree. Ninety-seven percent of the samples tested, with acid degree of 3.00 and above, had rancid flavor, while only 10 percent of the samples with less than 3.00 acid value were rancid. No rancid flavor occurred in milk with a free fatty acid degree of less than 2.00.

Surface tension measurement was not reliable for showing small changes of free fatty acids in milk. All samples with surface tension values of 48 dynes per centimeter tasted satisfactory, while the great majority of samples of less than 46 dynes per centimeter were rancid. The threshold value ranged between 46 and 48 dynes.

The lowest free fatty acid values of bulk milk samples occurred in late spring and summer, while the highest occurred during the fall. Winter fatty acid values were slightly lower than those during fall.

Ayrshire milk was the most susceptible to induced

lipolysis through mechanical agitation, followed in order by Brown Swiss, Guernsey, Holstein, and Jersey.

High free fatty acid values were effectively corrected by reducing the length of the lines, reducing air intake, riser height, and decreasing line slope.

BIBLIOGRAPHY

Armstrong, T. V. and W. J. Harper
1954. Modified rapid solvent extraction method for the estimation of water insoluble fatty acids in cream. Milk Products Journal 45 (5):37

Anderson, J. A.
1936. The cause of oxidized and rancid flavors in raw milk. Proc. 29th. Ann. Conv. Internatl. Assoc. Milk Dealers, Lab. Sect: 117-134.

Bailey, Dana H.
1933. Sulphur, bitter milk, and enzymes. Milk Plant Monthly 22 (9):31-32.

Bird, E. W., D. F. Breazeale, and E.R. Bartle
1937. Ia. Agr. Expt. Sta. Res. Bul. 227, (Original not seen. Cited by Hunziker, O. F., The Butter Industry. Third Ed. La Grange, Illinois, Published by the Author. 1940. 821 pp.)

Christiansen, L. J., C. W. Decker, and U. S. Ashworth.
1951. The keeping quality of whole milk powder. I. The effect of preheat temperature of the milk on the development of rancid, oxidized and stale flavors with different storage conditions. Jour. Dairy Sci. 34:404-411.

Costilow, R. N, and M. L. Speck.
1951. Inhibitory effect of rancid milk on certain bacteria. Jour. Dairy Sci. 34:1119-1127.

Csiszar, J.
1933. Milch. Forsch., 14:288 (Original not seen. Cited by Hileman, J. L., and Eleanor Courtney, Jour. Dairy Sci. 18:247-257.)

Davies, W. L.
1932. The inactivation of lipase in dairy products by traces of heavy metal salts. Jour. Dairy Res., 3:254-263.

Dorner, W., and A. Widmer.
1931. LAIT 11:545-567. (Original not seen. Cited by Milk Plant Monthly 21 (7):50-56, 86,88.)

Dunkley, W. L.
1951. Hydrolytic rancidity in milk. I. Surface tension and fat acidity as measures of rancidity. Jour. Dairy Sci. 34:515-520.

Dunkley, W. L., and L. A. Kelley.
1954a. Hydrolytic rancidity induced by pipeline milkers. Jour. of Milk and Food Technol. 17:306-312,319.

Dunkley, W. L., and L. A. Kelley.
1954b. Rancidity Increasing? Milk Plant Monthly. 43 (10):24-26, 54.

Dunkley, W. L., and L. M. Smith.
1951. Hydrolytic rancidity in milk. IV. Relation between trybutyrinase and lipolysis. Jour. Dairy Sci. 34:940-947.

Frankel, E. N., and N. P. Tarassuk.
1955. An extraction-titration method for the determination of free fatty acids in rancid milk and cream. Jour. Dairy Sci. 38:751-763.

Fredeen, H., J. E. Bowstead, W. L. Dunkley, and L. M. Smith.
1951. Hydrolytic rancidity in milk.II. Some management and environmental factors influencing lipolysis. Jour. Dairy Sci. 34:521-528.

Fouts, E. L., and E. Weaver.
1936. Observations on the development of rancidity in sweet milk, cream, and butter. (Abst.) Jour. Dairy Sci. 19:482-483.

Gould, I. A., and G. M. Trout.
1936. The effect of homogenization on some of the characteristics of milk fat. Jour. Agr. Res. 52:49-57.

Halloran, C. P, and G. M. Trout.
1932. The effect of viscolization on some of the physical properties of milk. (Abst.) 27th. Ann. Meeting, Amer. Dairy Sci. Assoc. p. 17.

Harper, W. J., E. W. Bassett, and I. A. Gould.
1954. Solvent extraction procedure for determining the free fatty acid content of homogenized milk. Jour. Dairy Sci. 37:622-623.

Harper, W. J., D. P. Schwartz, and I. S. El-Hagarawy.
1956. A rapid silica gel method for measuring total free fatty acids in milk. Jour. Dairy Sci. 39:46-50.

Herrington, B. L.
1950. Lipase in dairy products with special reference to its effect on flavors and its control. 43rd. Milk Indus. Found. Conv. Proc. Lab. Sect. 4:30-45.

Herrington, B. L.
1954. Lipase: A review. Jour. Dairy Sci. 37:775-789.

Herrington, B. L., and V. N. Krukovsky.
1939a. Studies on lipase action. I. Lipase action in normal milk. Jour. Dairy Sci. 22:127-135.

Herrington, B. L, and V. N. Krukovsky.
1939b. Studies of lipase action. III. Lipase action in the milk of individual cows. Jour. Dairy Sci. 22:149-152.

Herrington, B. L., and V. N. Krukovsky.
1942. Studies of lipase action. VII. The influence of the rate of cooling upon the subsequent rate of lipolysis in milk stored at low temperatures. Jour. Dairy Sci. 25:241-248.

Hetrick, J. H., and P. H. Tracy.
1948. Effect of high-temperature short-time heat treatments on some properties of milk. II. Inactivation of the lipase enzyme. Jour. Dairy Sci. 31:881-887.

Hileman, J. L., and Eleanor Courtney.
1935. Seasonal variations in the lipase content of milk. Jour. Dairy Sci. 18:247-257.

Hillig, F.
1947. Determination of water insoluble fatty acids in cream and butter. Jour. Assoc. Off. Agr. Chem. 30:575-582.

Hillig, F.
1953. Rapid method for the estimation of water insoluble fatty acids in cream and butter. Jour. Assoc. Off. Agr. Chem. 36:1077-1088.

Holland, R. F., and B. L. Herrington.
1953. The churning time of milk fat at different temperatures. Jour. Dairy Sci. 36:850-854.

Hollander, H. A., S. R. Rao, and H. H. Sommer.
1948. The measurement of free fatty acids in dairy products. (Abst.) Jour. Dairy Sci. 31:718-719

Johnson, B. C., and I. A. Gould.
1949a. Milk lipase system. II. Comparison of solvent extraction and churning methods for obtaining fat from milk for free fatty acid measurement. Jour. Dairy Sci. 32:435-446.

Johnson, B. C., and I. A. Gould.
1949b. Milk lipase system. III. Further studies of the solvent extraction procedure for obtaining fat from milk for titration. Jour. Dairy Sci. 32:447-451.

Kelly, P. L.
1943. The lipolytic activity of bovine mammary gland tissue. Jour. Dairy Sci. 26:385-399.

Kelly, P. L.
1945. Milk lipase activity: a method for its determination, and its relationship to the estrual cycle. Jour. Dairy Sci. 28:803-820.

Krienke, W. A.
1944. The relationship of the individuality of the cow to the production of rancid milk. (Abst.) Jour. Dairy Sci. 27:683-684.

Krukovsky, V. N., and B. L. Herrington.
1939. Studies of lipase action. II. The activation of milk lipase by temperature changes. Jour. Dairy Sci. 22:137-147.

Krukovsky, V. N., and B. L. Herrington.
1942. Studies of lipase action. IV. The inactivation of milk lipase by heat. Jour. Dairy Sci. 25:231-236.

Krukovsky, V. N., and P. F. Sharp.
1936. Effect of lipolysis on the churnability of cream obtained from the milk of cows in advanced lactation. Jour. Dairy Sci. 19:279-284.

Krukovsky, V. N., and P. F. Sharp.
1938. Effect of shaking on the lipolysis of cow's milk. Jour. Dairy Sci. 21:671-682.

Krukovsky, V. N., and P. F. Sharp.
1940a. Effect of the properties of the fat and of the fat globule surface on lipolytic activity in milk. Jour. Dairy Sci. 23:1109-1118.

Krukovsky, V. N., and P. F. Sharp.
1940b. Inactivation of milk lipase by dissolved oxygen. Jour. Dairy Sci. 23:1119-1122.

Nelson, J. A., and G. M. Trout.
1951. Judging Dairy Products. 3rd.ed. Olsen Publishing Co., Milwaukee. 480 pp. plus XVI.

Palmer, L. S.
1922. Bitter milk of advanced lactation, a lipase fermentation. Jour. Dairy Sci. 5:201-211.

Pfeffer, J. C., H. C. Jackson, and K. G. Weckel.
1938. Observations on the lipase activity in cow's milk. (Abst.) Jour. Dairy Sci. 21:143.

Reder, Ruth.
1938. The chemical composition and properties of normal and rancid Jersey milk. III. Titratable acidity, hydrogen-ion concentration and lipase content. Jour. Dairy Sci. 21:369-377.

Rice, F. E.
1926. Sweetened condensed milk. V. Rancidity. Jour. Dairy Sci. 9:293-305.

Rice, F. E., and A. L. Markley.
1922. Proof of the presence of lipase in milk and a new method for the detection of the enzyme. Jour. Dairy Sci. 5;64-82.

Rimpila, C. E., and L. S. Palmer.
1935. Substances adsorbed on the fat globules in cream and their relation to churning. IV. Factors influencing the composition of the adsorption "membrane." Jour. Dairy Sci. 18:827-839.

Roadhouse, C. L., and J. L Henderson.
1935. Calif. Agr. Expt. Sta. Bul. 505. 30 pp. (Original not seen. Cited by Weinstein, B. R., and G. M. Trout. Mich. Agr. Expt. Sta. Quart. Bul. 32 (3):311-318.)

Roadhouse, C. L., and G. A. Koestler.
1929. Contribution to the knowledge of the taste of milk. Jour. Dairy Sci. 12:421-437.

Schultz, W. G.
1956. Rancidity problem may be solved. Hoard's Dairyman. 101:349, 372.

Sharp, P. F., and J. A. DeTomasi.
1932. Increase in non-lactic acidity in raw cream and its control. Proc. 25th Ann. Meeting, Internatl. Assoc. Milk Dealers. Lab, Sect. pp. 3-20.

Tarassuk, N. P., and E. N. Frankel.
1954. Evaluation of the acid degree of fat and extraction-titration methods for the estimation of free fatty acids in rancid milk and cream. (Abst.) Jour. Dairy Sci. 37:646.

Tarassuk, N. P., and E. N. Frankel.
1955. Technical notes on the mechanism of activation of lipolysis and the stability of lipase systems of normal milk. Jour. Dairy Sci. 38:438-439.

Tarassuk, N. P. and J. L. Henderson.
1942. Prevention of development of hydrolytic rancidity in milk. Jour. Dairy Sci. 25:801-806.

Tarassuk, N. P., and E. L. Jack.
1949. Lipolytic flavors of milk. (Abst.) Milk. Plant Monthly 38 (10):48.

Tarassuk, N. P., and L. S. Palmer.
1939. Study of physical and chemical properties of the adsorption "membrane" around the fat globules in cream. I. The effect of the adsorption "membrane" of synthetic creams on curd tension of cow's milk. Jour. Dairy Sci. 22:543-558.

Tarassuk, N. P., and G. A. Richardson.
1941. The significance of lipolysis in the curd tension and rennet coagulation of milk. I. The role of fat globule adsorption "membrane." II. The effect of the addition of certain fat acids to milk. Jour. Dairy Sci. 24:667-677.

Tarassuk, N. P, and F. R. Smith.
1939. Studies on rancid milk. Relation of surface tension of rancid milk to its acid coagulation. (Abst.) Jour. Dairy Sci. 22:415-416.

Tarassuk, N. P., and F. R. Smith.
1940. Relation of surface tension of rancid milk to its inhibitory effect on the growth and acid fermentation of Streptococcus lactis. Jour. Dairy Sci. 23:1163-1170.

Thomas, W. R., W. J. Harper, and I. A. Gould.
1954. Free fatty acid content of fresh milk as related to portions of milk drawn. Jour. Dairy Sci. 37: 717-723.

Thomas, E. L., A. J. Nielsen, and J. C. Olson.
1955a. Hydrolytic rancidity in milk - a simplified method for estimating the extent of its development. Am. Milk Review. 17 (1):50-52, 85.

Thomas, E. L., A. J. Nielsen, and J. C. Olson.
1955b. Observations on the extent of lipolysis in raw milk supplies as related to various milk handling procedures. (Abst.) Jour. Dairy Sci. 38:596.

Triebold, H. O.
1949. Quantitative Analysis with Applications to Agricultural and Food Products. 3rd. Ed. D. Van Nostrand Co. Inc. New York. 331 pp.

Trout, G. M.
1932a. Sources of some abnormal flavors in milk. Mich. Agr. Expt. Sta. Quart. Bul. 14:141-142.

Trout, G. M.
1932b. Some flavors of milk and their detection. Proc. 25th Ann. Meeting, Internatl. Assoc. Milk Dealers. Lab. Sect. pp. 80-92.

Trout, G. M.
1933. Physical and chemical effects of homogenization on milk. Proc. 26th Ann. Conv. Internatl. Assoc. Milk Dealers, Lab. Sect. pp. 199-220.

Trout, G. M., C. P. Halloran, and I. Gould.
1935. The effect of homogenization on some of the physical and chemical properties of milk. Mich. Agr. Expt. Sta. Tech. Bul. 145. 34 pp.

Trout, G. M., J. M. Jensen, and E. S. Humbert.
1955. Rancidity development in cream from cold - separated raw milk. Mich. Agr. Expt. Sta. Quart. Bul. 37 (3):393-399.

Weaver, E.
1939. Okla. Agri. Expt. Sta. Tech. Bul. 6. 56 pp. (Original not seen. Cited by Fredeen, J. E. et. al. Jour. Dairy Sci. 34:521-528.)

Date Due
