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CONTINUOUS BUTTERMAKING -- A PROCESS

CAPABILITY STUDY

A thesis presented in partial fulfilment
of the requirements for the degree
of Master of Technology in
Industrial Management at
Massey University

Dean Thomas John Stockwell

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"If you can measure that of which you
speak, and you can express it by a
number, you know something of your
subject, but if you cannot measure
it, your knowledge is meagre
and unsatisfactory"

Lord Kelvin.

SUMMARY

A process capability study was conducted on a Contimab MC 30 continuous buttermaking machine. The compositional parameters of butter moisture and salt content were considered.

The initial investigation showed that compositional variation with respect to time was significantly greater than variation within the product at any one instant. A significant correlation was found between variations in moisture and salt content and it was considered that variation in both moisture and salt content was strongly influenced by the variable performance of the salt slurry injection system.

The preceeding results suggested examination of the salt slurry injection pressure and linear extrusion speed of the butter ribbon. A complex relationship was seen to exist between these factors and the product composition; possible explanations are considered.

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D.T.J. Stockwell
(November, 1972)

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SECTION IINTRODUCTION

Continuous buttermaking has become an important process in the New Zealand Dairy Industry. From the first experimental trials in 1964 conducted by staff of the New Zealand Dairy Research Institute, continuous manufacture of butter by the Fritz process has now reached a commercial production of over 80,000 tons.

Process control of the buttermaking process plays an important part in determining the economic return on the product. At this stage adequate information is available on the general operating principles of Continuous churns. However, in the absence of change in the operating conditions the product continues to show compositional variation. There is little information available to determine the causes of such variation. The work undertaken during this project was primarily aimed at investigation of this variation. It was conducted as a process capability study.

It is clear that Continuous Buttermaking will continue to be an important process in the New Zealand Dairy Industry for some time, and it is essential that further information regarding the process is made available in order to facilitate improved process control.

An Introduction to Continuous Buttermaking

Continuous manufacturing processes for butter may be divided into two broad groups.

(1) Churning of cream of normal composition (35-45% fat) such as the Senn and Fritz processes. The cream is churned in horizontal cylinders by high speed beaters. The butter granules formed are separated from the buttermilk and this may be accomplished in several ways. The granules are washed and then pass into a working section. Salt, in slurry form, and additional water may be injected into the butter during the working period. The final product is extruded from the worker and may then pass to a packing unit.

(2) Reseparation of the cream to give a high fat content cream. Destabilisation of the emulsion following the second separation may be used to facilitate concentration of the fat. Accurate quantities of other constituents such as salt, water and flavouring are added to the

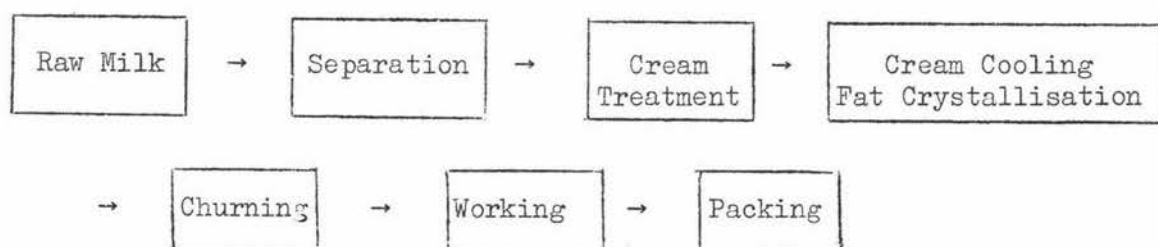
concentrated cream to obtain a standardised mix of that composition desired in the butter. The standardisation may be accomplished either by batch or continuous techniques. The standardised mixture is then cooled, agitated and worked by various methods to obtain a product similar to conventional butter.

The butter texture obtained by recent modified processes of this type is satisfactory in comparison with conventional butter and is an improvement over earlier techniques.

This type of process may also be used to manufacture recombined butter from anhydrous milk fat, skim milk powder (or serum), salt and water. Processes of this type include New Way Process, Alfa, Alfa Laval, Meleshin, Cherry Burrell, Creamery Package and Kraft.

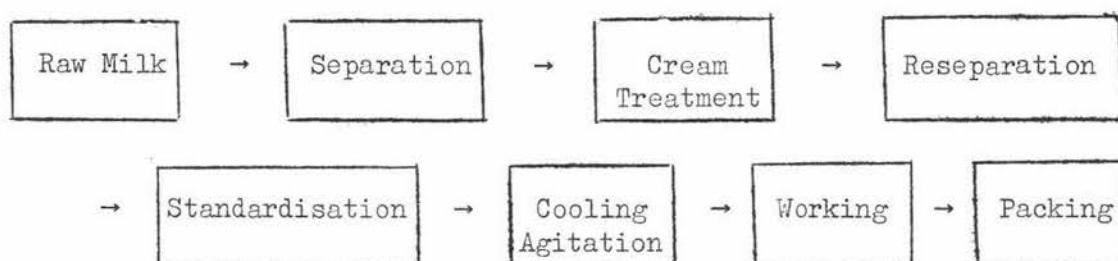
General Process Block Diagrams

(1) Churning cream of normal composition.

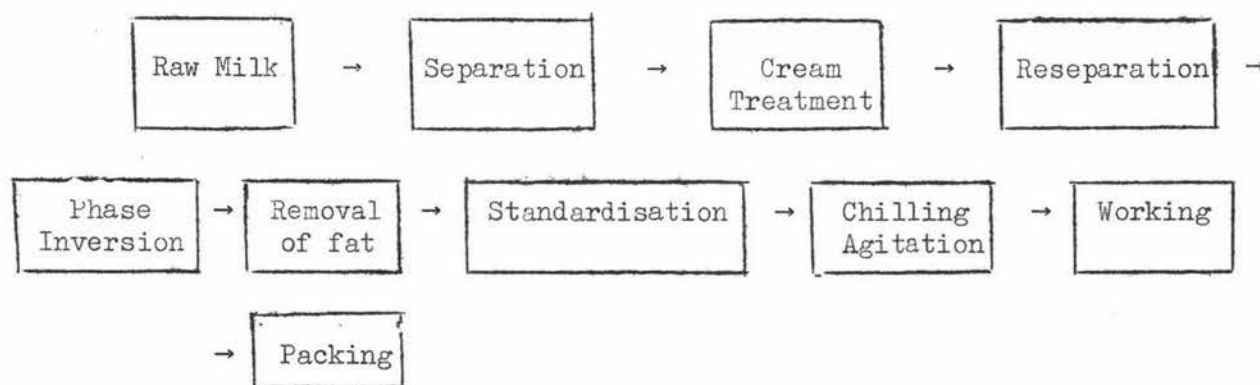


(2) Reseparation Methods.

(a) Manufacture from high-fat cream.



(b) Manufacture using separated milk fat.



Continuous Buttermaking in New Zealand

Continuous Butter manufacture in New Zealand has centred around use of the Fritz process which involves churning cream of 35%-45% fat content. This process was favoured over the 'reseparation' method for several reasons.

- (a) The product was very similar to that of conventional churning.
- (b) It was likely that the different texture of butter manufactured from the reseparation methods would not be acceptable to consumers used to conventional butter.
- (c) Plant costs and layout were less favourable for the reseparation method.

Recent developments, however, have resulted in a change in these factors. A modified reseparation method may now become acceptable when these factors are reviewed.

An Alfa continuous plant was used to manufacture butter in New Zealand in 1947. This was the earliest commercial trial of Continuous butter manufacture. This process was rejected due to difficulty in moisture control and unacceptability of physical characteristics.

A Continab MB5 continuous buttermaking machine was selected for trials by the Dairy Research Institute. It was installed during October 1964 in a factory of the Manawatu Cooperative Dairy Company and operated by staff of the Dairy Research Institute. Later, the machine was purchased by the Manawatu Cooperative Dairy Company and used to produce butter, for patting, to be supplied to the local market. This machine, using the Fritz process, was able to manufacture salted butter. Previous machines had been unable to manufacture salted butter and as all but a small proportion of New Zealand produced butter is salted, these earlier machines were not suitable for New Zealand conditions.

A second Fritz process machine, a Westfalia BUC 1500 was later imported for trial by the New Zealand Cooperative Dairy Company and first operated in the autumn of 1966. After modifications to the working section and salt slurry injection system this continuous churn was in regular operation during the summer of 1966/67.

At the present time the New Zealand dairy industry has more than

twenty continuous butter churns. Three types of machine are in use in New Zealand,

Continab (France)

Silkeborg (Denmark)

Westfalia (Germany)

In each case the Fritz process is the basis for production of butter.

The Project

A considerable amount of information has been compiled during investigations and trials conducted on continuous buttermaking machines in New Zealand. Much of this has been the result of work carried out by staff of the Dairy Research Institute. This information deals with the general operating technique of continuous butter making, covering cream composition and treatment, churn operation and butter packing. These operating instructions provide a guide for manufacture of quality butter throughout the dairying season, during which considerable changes in raw material and other factors may occur. From this information an acceptable product which meets compositional, microbiological and textural requirements may be produced.

It is well known by butter makers, that even with correct control settings, a good quality raw material and reasonably steady conditions the butter produced by the machine has a significantly varying composition. The control of butter quality parameters can be a complex task. Variations in product characteristics may occur for no 'apparent' reason; e.g. when no changes have been made in operating conditions. Such changes may be caused by a large number of factors, many of which the operator is either unaware of, or unable to control.

The object of the project was to obtain information concerning the behaviour of the butter manufacturing system. The important parameters of performance must include those on which the product is graded and which determine the economic return.

The objective characteristics of moisture and salt content are important factors in determining monetary return - as high values for moisture and salt content will result in favourable return, yet exceeding the maximum permissible limit will incur monetary penalties and in

extreme cases rejection of the product. Modification of rejected product to enable acceptance will incur further cost.

The butter churn operator is mainly concerned with moisture and salt levels in his product, as the product quality and his own performance are judged by these factors. Microbiological standards play an important role in butter quality - but these factors are not available for examination as readily as the moisture and salt values.

From the analysed Moisture and Salt results the operator behaves as a 'feedback' link to the machine. He acts to control the machine output by suitable operation of control mechanisms.

The object of the research was to:

- (i) measure and record variation in butter moisture and salt content as a study of process capability
- (ii) assign some causes to the variations where such causes were suggested by the results of the investigations.

It was not the purpose of this work to define exhaustively the assignable causes of variation in this process. If sufficient information could be obtained it might be possible to improve control of butter manufacture. Reduction in compositional variation will enable changes to be made in manufacturing limits and it is likely an increase in monetary return will result.

Throughout the investigation attention was paid more to 'macro-variations' and trends in compositional change. Experimental methods were selected considering several factors. The accuracy required in compositional determination was a major consideration. Highly accurate analytical results requiring a considerable amount of time and attention to detail were not necessary to determine the significant trends and changes occurring in butter composition.

Literature Review

At the present time information regarding the process of continuous buttermaking is generally related to determining process conditions which can result in manufacture of an acceptable product. Since the composition of an acceptable product has relatively wide tolerances, such information deals with 'coarse' control of process variables. Significant changes in product composition may be corrected by appropriate changes in processing conditions and churn operation of this type has been documented for New Zealand conditions.

Dolby, Jebson, Le Heron (1965) (1) of the New Zealand Dairy Research Institute have discussed the operation of a Continab MB 5 continuous churn during a trial of six months. A later report by Dolby (1967) (2) considered operation of a Westfalia BUC 1500 and similarly the emphasis was on achieving control such that a suitable product was manufactured. Anderson (1969) (3) discussed commercial operation of a Silkeborg continuous buttermaker over a period of eight months.

A more detailed review of these investigations and their results, is presented in Section I in a discussion of continuous butter manufacture.

Little or no information has been available regarding patterns and trends in butter composition during manufacture, when the churn has been running under production conditions with infrequent control changes.

Determination of Butter Composition

The composition of butter has an important effect on the economic return achieved for the product. It is in the best interests of the buttermaker to maintain a high overrun yet not exceed legal requirements, or offend the consumer.

Because of this, considerable effort has been made to facilitate control of buttermaking. In particular, research into continuous measurement techniques for evaluation of butter moisture content has

been extensive. It is hoped that accurate continuous measurement of butter moisture content would enable feedback of information to some control system which would act to correct fluctuations in composition by adjustment of process factors.

Two techniques have been investigated extensively.

- (i) continuous measurement of the dielectric constant of butter
- (ii) continuous measurement of microwave absorption.

The quantity of microwave energy absorbed by a material such as butter is related to the moisture content of the material.

Parkash and Armstrong (1969) (4, 5) investigated the dielectric constant for butter and found that several factors contributed to this parameter. In a particular butter, increasing moisture or salt content tended to result in an increased dielectric constant; and in butters worked for the same time it increased almost linearly with moisture content. However, the dielectric constant decreased markedly with increased working time until a steady base value was reached. This base value was considered to be a function of the butter moisture content. For a butter of constant moisture content, the dielectric constant increased almost linearly with salt content.

Thus it is seen, that under production conditions where variation in working time could occur, fluctuations in salt content and also temperature will tend to vary the dielectric constant - as well as the measured parameter - moisture content.

Sone, Taneya, Handa (1970) (6) discussed conditions for measurement of dielectric constant in continuous butter manufacture. Using a frequency range from 300 KHz to 1 MHz it was found to be possible to detect changes of as low as 0.1 % moisture as a related variation in dielectric constant. Temperature correction was considered to be necessary to achieve greater accuracy, as the dielectric loss factor is dependent upon temperature in the frequency range used.

Koenen (1968) (7) describes an instrument developed by Brabender for continuous measurement of dielectric constant of butter. The dielectric constant is then related to a moisture content and a digital or graphical readout is given.

This instrument is claimed to have an accuracy of better than $\pm 0.2\%$ moisture if run under suitable conditions. These conditions include:

- (a) a discrete distribution of moisture droplets, also indicative of adequate working.
- (b) stable inputs of cream composition, flow rate, machine beater and worker speeds.
- (c) constant back pressure in the extruded ribbon, this may be influenced by behaviour of the packing unit.
- (d) constant butter density - a change in air content of 1.0% may give rise to an indicated change of 0.1% moisture.

This instrument may also be used for analysis of salted butter.

Fexa and Rosenbaum (1965) (8) describe a Czechoslovak Akvameter, a moisture measuring device based on measurement of electrical permittivity which is related to dielectric constant. The claimed accuracy was $\pm 0.3\%$ moisture, with a sensitivity of $\pm 0.05\%$ moisture.

Cerna and Vedlich (1965) (9) continued analysis of the performance of the Akvameter. It was found necessary that moisture droplet diameter should be less than 20 microns. Calibration of the instrument was used to compensate for pH, solids-not-fat and air content variation.

Fexa and Rosenbaum (1966) (10) and Fexa (1967) (11) discussed automatic regulation of butter moisture content by use of the Akvameter in conjunction with a Czechoslovak continuous buttermaking machine. A control system is proposed.

It was reported by Dolezalek and Rosenbaum (1970) (12) that in use of the Akvameter MA-2, of 34 observations most results showed close agreement with those obtained by standard moisture tests. Four results differed by $\pm 0.2\%$ moisture, fourteen by $\pm 0.1\%$ moisture and the remainder were in exact agreement.

It was said to be important that manufacturing conditions were stabilised; water dosing was not used as if there was insufficient working after dosing the free moisture resultant in the butter had a deleterious effect on the accuracy of the meter.

The long term accuracy under the variable conditions likely to be found in normal manufacture was not discussed.

The National Research Council of Canada (13) has developed a microwave instrument for measurement of water in butter and an accuracy of two parts in ten thousand in determination of butter moisture is claimed. It is not stated whether this applies to both salted and unsalted butter. However, recent information indicates that work on development of this instrument has not been successful and the project has been terminated.

Slight (1970) (14) describes a similar microwave technique but indicates an accuracy of up to $\pm 0.1\%$ moisture, depending also upon the material and its method of presentation. No specific details are given for analysis of butter.

Conclusions

Two basic types of continuous moisture measuring instruments have been developed. At present neither instrument has been fully tested and accepted for New Zealand conditions.

Variability of raw materials, machine factors and butter compositional factors such as salt and air content reduce the reliability of the instruments. However, if a suitable instrument is developed, it is likely that it will become part of a more complex system designed to control butter moisture content.

Little emphasis has been given to continuous salt estimation, but since this is an important economic factor with respect to overrun it is likely that continuous salt measurement in butter will be a further requirement for any control system utilising error detection in the output, with information feed back to the processing unit.

The Economic Importance of Butter Composition

The monetary return on butter is related to its composition and the overrun achieved. Moisture, salt and curd content determine the overrun and the return per pound of fat may be calculated from the basic price paid per pound of butter and the known compositional values.

$$R = \frac{P}{1 - (M + S + C)}$$

where R - return (cents/lb. fat)

P - price for butter (cents/lb.)

M - Fractional Moisture Content

S - Fractional Salt Content

C - Fractional Curd Content

As the moisture content increases the return per pound fat will also increase, but the moisture content is limited to a maximum of 16.0%. For values above this limit, a penalty is imposed. Assuming the moisture values to approximate to a 'Normal Distribution', it is possible to determine the quantity of product which will fall both inside and outside the tolerance and hence the return on the product.

If it assumed that salt and curd values are constant, then for a selected standard deviation of the moisture values, the return on the product may be calculated for each overall moisture mean value.

Assumptions:

Price/lb. butter = P

= 26.26 cents

Penalty for overmoist butter, a = 2 cents/lb.

Salt Content = 1.6 %

Curd Content = 1.1 %

$$R = \frac{P - aK}{1 - (M + S + C)}$$

where K = fraction of produce exceeding 16.0% moisture, determined from a Normal Distribution of the stated standard deviation.

M = average moisture content of butter.

Sample Calculation

$$\begin{aligned}
 \text{Mean moisture} &= 15.9 \% \\
 \text{Standard deviation of moisture values, } S &= 0.1 \quad (\text{selected value}) \\
 \text{Transformation to unity Normal Distribution, } Z &= \frac{16 - M}{S} = \frac{0.1}{0.1} \\
 &= 1.0 \\
 \text{Area to right of } Z \text{ in Normal Distribution, } K &= 0.156
 \end{aligned}$$

$$\begin{aligned}
 M + S + C &= (15.9 + 1.6 + 1.1) \% \\
 &= 18.6 \% \\
 &= 0.186
 \end{aligned}$$

$$\begin{aligned}
 R &= \frac{P - aK}{1 - (M + S + C)} \quad \text{cents/lb. fat} \\
 &= \frac{26.26 - 2(0.156)}{1 - 0.186} \quad \text{cents/lb. fat}
 \end{aligned}$$

$$\text{Return} = \underline{34.34 \text{ cents/lb. fat}}$$

For a series of selected standard deviations the return was calculated for various mean moisture values.

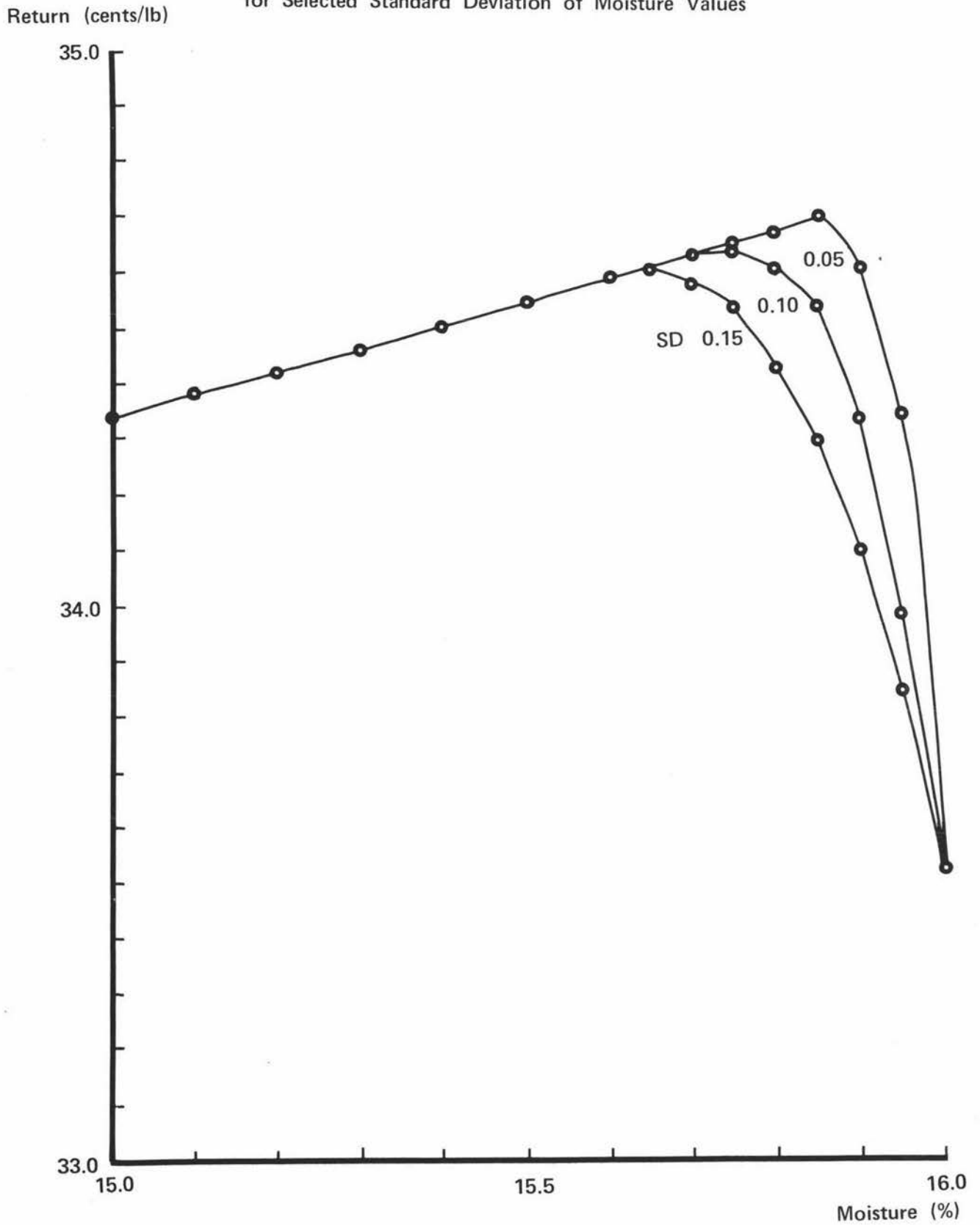
Fig. 1 (page 14) is a graph of the Return (cents/lb. fat) vs. Mean Moisture Content for selected standard deviations of the moisture values.

Discussion

It is seen from this graph that an optimal return may be achieved for each standard deviation of the moisture variable by selecting the correct mean moisture, the greatest return being realised for the lowest standard deviation. The practical situation does not allow such precision, but these calculations can provide a suitable and practical approach to improving monetary return.

A similar graph may be drawn to indicate the varying economic return if other compositional factors such as salt content and curd content are treated in the same manner.

Fig. 1. Graph of Return (cents/lb. fat) vs Mean Moisture Content for Selected Standard Deviation of Moisture Values



THE CONTIMAB CONTINUOUS BUTTERMAKING MACHINE

Churning

A variable speed mono pump supplies cream of fat content 38-42% to the single stage horizontal churning cylinder. The cream enters tangentially to the four bladed beater rotating in the churning cylinder. The beater speed can be varied (by means of a variable-diameter, expanding pulley) from 1000 to nearly 2000 r.p.m.

For churning of low fat cream or of cream having 'hard' fat, increased turbulence in the churn may be achieved by insertion of perforated liners in the churning cylinder. Chilled water may be circulated in a jacket surrounding the primary churn.

The butter granules and buttermilk pass from the churning section into the base of the working section. The working tunnel is inclined to allow drainage of wash water and buttermilk from the various sections.

Working Section

The butter granules float on a pool of buttermilk in the base of the working section. Twin rotating screws carry the butter granules forward to the first operation which is buttermilk drainage.

The buttermilk drains from the working section through a sieve which retains any granules flushed from the worker. The level of buttermilk in the working section is determined by the level of a draining syphon and may be varied in order to alter the moisture content of the butter.

The granules are carried by the screws into the butter drying tunnel where buttermilk drainage occurs. A variable profile pressure plate restricts the butter outflow. Reduction of the exit profile increases the back pressure in this section and assists in buttermilk removal. This pressure plate is able to be used to vary the moisture content of the product.

The butter is extruded in thin bars and passes into the washing section where it is sprayed with chilled water and then is forced through orifice plates after which cruciform beaters act to mix the butter. The wash water drains through a sieve and is taken from the working section.

Salting of the butter is the next operation. A salt-water slurry is held in a well agitated tank. The slurry is injected by a diaphragm pump into the working section through three points located around the working tunnel. The butter, which is in 'spaghetti' form when the salt is injected, undergoes further working and mixing as it passes through orifice plates followed by cruciform beaters. The salt injection volume may be controlled by varying the stroke of the diaphragm pump.

The butter passes through a vacuum chamber and then into the final working section which again consists of orifice plates followed by cruciform beaters. The butter is extruded from the outlet head into the packing unit.

The size of perforation in the orifice plates can affect the amount of working the butter receives. Smaller diameter perforations may be used to increase the amount of working. Similarly, restriction of the outlet head size increases the amount of working the butter receives, as the back pressure in the working section is increased.

Fig. 2 (page 17) shows a general diagram of plant layout.

Fig. 3 (page 18) shows a schematic diagram of a Continab continuous buttermaking machine.

Fig 2

SCHEMATIC DIAGRAM OF PLANT LAYOUT

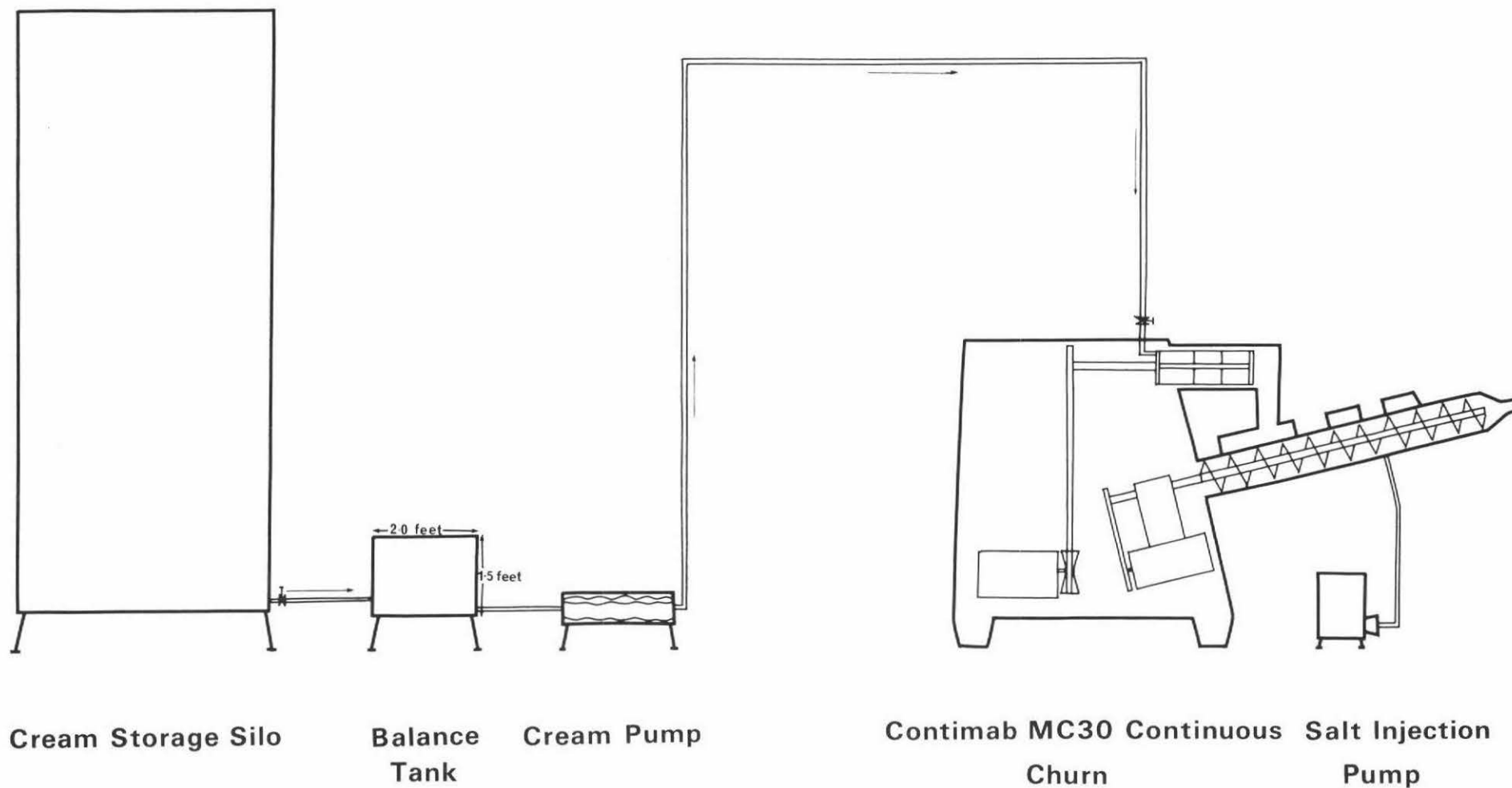
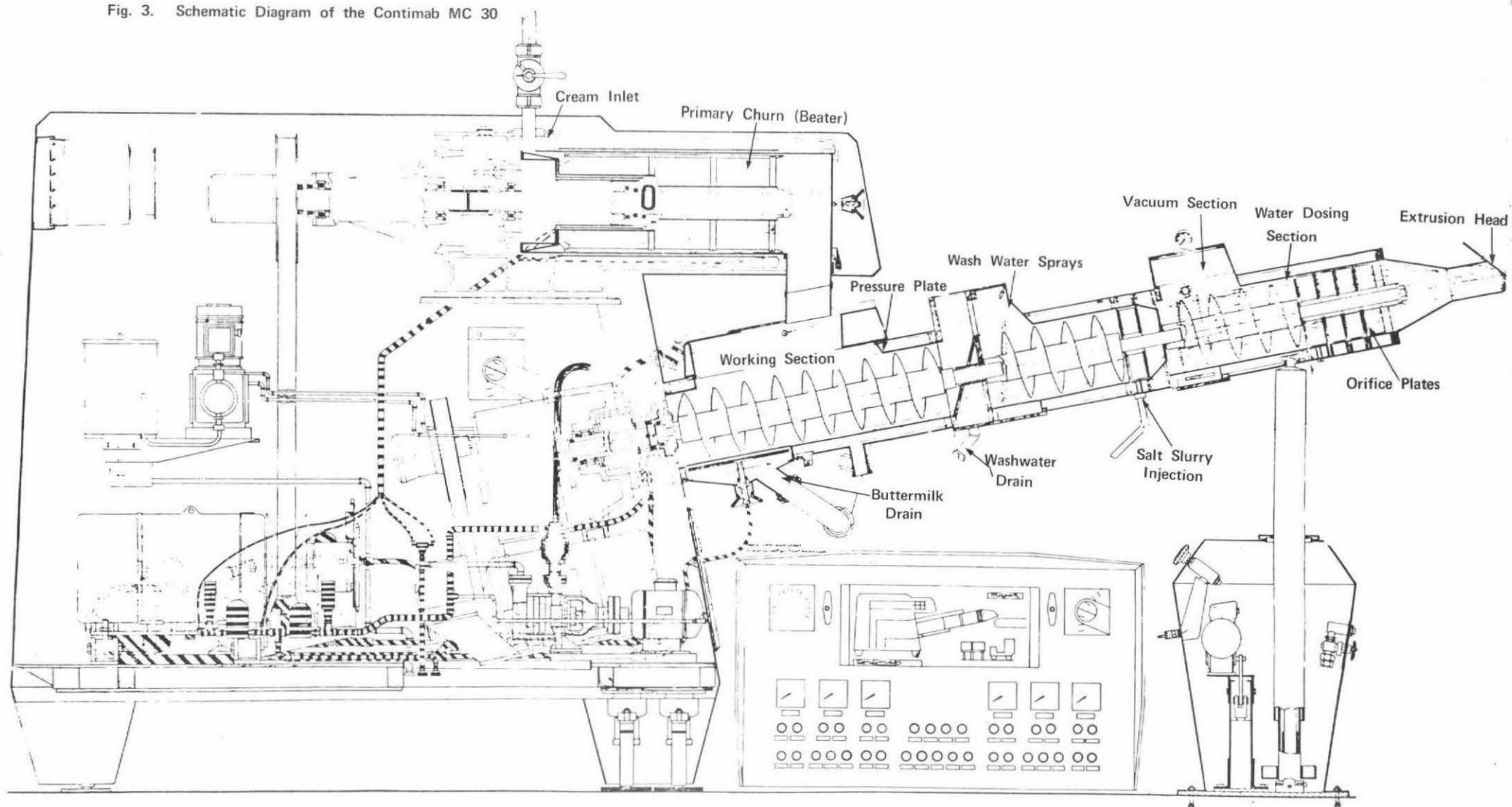


Fig. 3. Schematic Diagram of the Contimab MC 30



Factors Affecting Butter Composition

The following discussion is confined to the operation of the Contimab continuous churn. In some instances quantitative effects are considered and these are given only as a general guide. Interactions of several factors may alter conditions sufficiently so as to change the quantitative effects quite considerably. Similarly, extreme conditions of operation may cause unusual behaviour.

Churning of the Cream

Generally, variation of a cream or machine characteristic which tends to facilitate churning of the cream tends to increase the moisture content of the butter.

Cream Characteristics

(a) Fat Content

The fat content of the cream may be standardised to an optimum value of 40-41% for continuous buttermaking.

High fat cream (45% fat), although assisting granule formation, may be difficult to churn because of its high viscosity. A low fat cream (35%) is difficult to churn because of the high proportion of serum to fat. This hinders fat globule agglomeration.

Variations in fat content may give rise to changes in the moisture content of butter. It has been shown that an increase in cream fat content of 1% may give rise to a butter moisture content increase of 0.6% if no compensation is made by alteration of other factors. (1)

(b) Butterfat Characteristics

The butterfat composition is important in determining the type of cream treatment used prior to butter manufacture. The treatment given is able to influence the churning character of the cream. It also influences the fat properties which provide the textural character of the butter.

A soft fat is one which has low softening temperature. Such a fat may be plastic even at sub-ambient temperatures.

A hard fat is one which has higher softening temperature and it may be hard or solid even at temperatures exceeding ambient. Butter fat is a mixture of glycerides having different softening temperatures. The texture of the product is determined by the composite character of the mixture.

Milk produced in early spring generally has soft butter fat. The hardness of the fat increases during the spring and summer until it reaches a maximum in December. A gradual decrease in hardness occurs during the remainder of the season.

The spring cream having a soft butter fat is shock cooled after pasteurisation-vacreation and is generally churned at lower temperatures near 45-48°F. The summer cream having a harder butter fat requires slow cooling after pasteurisation-vacreation and the churning temperature is higher being in the region 53-55°F.

Fat globule size may also affect churning of the cream. Cream having large fat globules will churn more readily than cream with small fat globules. The globule size may be affected by the type of milk produced by a particular breed of cow and also by cream treatment.

Excessive pumping and agitation tends to break up fat globules, especially when the cream is warm. Correct cream handling may avoid this. The pasteurisation operation may influence fat globule size also. Indirect heating such as in a plate heat exchanger assists in fat globule agglomeration. Direct steam injection has a reverse effect and disruption of the globules may occur. Variations in the conditions during this treatment may result in a variable raw material for processing and this could cause variation in the product.

(c) Cream Acidity

The acidity of the cream can influence its churning ability. A cream having acidity higher than normal tends to churn more readily - and moisture content may rise if compensation is not made.

In the Contimab machine, when cream acidity exceeded 0.13%, difficulty was found in maintaining the moisture level below 16.0%. (1)
For high acid cream, such as this, variation in other controlling

factors is necessary such as lowering of churning temperature or decrease in primary churning by lowering of beater speeds.

Variations in cream acidity will thus tend to give rise to variation in the moisture content of the product. It has been shown that an increase in cream acidity (determined as lactic acid) of 0.01% can give rise to an increase of 0.5% in butter moisture content. (1)

(d) Cream Churning Temperature

This characteristic is important in continuous buttermaking. The churning temperature is to some extent determined by the cream treatment. This is a function of the type of cooling given to the cream as it comes from the treatment unit and also of the temperature cycle maintained during overnight storage in the holding silos. An increase in cream churning temperature generally results in an increase in moisture content of the butter as the cream churns more readily. The converse is also true.

Some measure of control may be exerted during manufacture by using the chill water jacket on the primary churn. Temperature changes of 1-2°F. may be achieved although this change in temperature does not have as great an effect on the butter moisture content as would a similar change in temperature of the bulk cream. It has been shown that an increase of 1°F. in bulk cream temperature can give rise to a butter moisture content increase of 0.5%. (1)

Machine Variables

(a) Primary Churn

The primary churn beater speed is a prime source of control for moisture content of the product. By increasing the beater speed the amount of churning of the cream is increased and the butter moisture content rises.

Experimental work has shown that an increase of 100 r.p.m. in beater speed may result in a butter moisture content increase of up to 0.5%, but the relative effect varies considerably with changing conditions. (1)

Control of beater speed is by a variable-diameter expanding pulley activated through a servo mechanism.

The beater speed ranges from 1000 - 1800 r.p.m. on the Contimab. Excessive speeds for churning of low test cream can result in "thrashing" of the cream and consequent excessive fat losses in the buttermilk due to fat globule break up. Soft spring fat may require beater speeds as low as 1000 r.p.m. At this level, subject to cream flow, the motor may draw a current of only 40 Amps. Harder summer fat may require a beater speed of up to 1800 r.p.m., at which the motor may draw 72 Amps.

The range of beater speeds used is dependent on the type of cream. However, speed variation about this 'base' speed may be used to control moisture.

(b) Cream Flow Rate

The rate of cream flow to the primary churn is another controllable factor. Reduction in cream flow rate over a limited range can allow a greater amount of churning and so causes an increase in moisture content. Likewise an increase in cream flow rate can reduce butter moisture content.

Changes in cream flow rate in order to change butter output generally result in a change in the butter moisture content and so necessitate process adjustments.

(c) Working Section

The working section of the Contimab may be used to control moisture and salt levels in butter.

(i) Speed of worker screws

The important source of fine control is the speed of the worker screws. Increasing the speed of the working screws causes an increased quantity of buttermilk to be carried forward, thus incorporating it into the butter. A decrease in worker speed will achieve a decrease in moisture content. An excessively low worker speed can result in under-working of the butter with consequent poor texture and moisture distribution. The maximum useful worker speed is generally limited by the moisture content which tends to increase with worker speed, and also the

capabilities of the driving mechanism.

The worker speed may range from 30 r.p.m. with spring cream (soft fat) to 60 r.p.m. with summer cream (hard fat).

(ii) Level of buttermilk

The level of buttermilk in the base of the working section may be adjusted by varying the height of the gooseneck syphon which drains the buttermilk. A higher level of buttermilk will tend to increase the quantity of buttermilk carried forward and thus increase the butter moisture content. This is a relatively coarse control and is not generally varied during a run. Better control may be achieved by changing other factors.

(iii) Restriction plates in the working section

Restriction plates within the working section can be altered in order to change the butter moisture content. The restriction at the butter drying section is significant. A reduced area (increase in restriction) will cause the butter moisture content to drop.

The restriction plates also control the amount of working the butter receives, particularly in the latter section after salt slurry injection.

(iv) Dosing pump

A feature of the Contimab MC 30 machine is the 'moisture dosing pump'. This diaphragm pump is used to alter the moisture level in the butter. It is situated prior to the final working section, just after the vacuum chamber and it injects water into the butter. By varying the flow rate of this pump the moisture level may be varied. It is more convenient to alter the setting of this pump than to change another factor which may give rise to other changes in interrelated factors. The dosing pump is thus an 'independent' unit for fine moisture control and may be used to add up to 0.15% moisture into the butter.

(v) Chilled buttermilk recycling

Recycling of chilled buttermilk was used on the Contimab MC 30 studied during the trials. The recycled buttermilk sprayed on to the granules chilled them, thus firming the granules. This may have an

effect on the moisture content but the temperature and flow of buttermilk are generally not used to control moisture content.

(vi) Wash Water

The wash water temperature can also influence moisture content. However, it is not a convenient method of control.

(vii) Salt slurry injection

Salt is incorporated into the butter by injection of a salt/water slurry. The composition of the slurry may be varied, but a slurry of 60 parts salt/40 parts water by weight was used in the machine during experimental trials.

The salt content of the butter may be varied by control of the slurry injection. This is achieved by changing the dosing volume. Because of the water associated with the salt a change in dosing volume in order to vary the salt content will result in a corresponding change in the quantity of water injected into the butter.

(viii) Angle of inclination of the working tunnel

An increase in the angle of inclination of the working tunnel tends to result in improved buttermilk drainage and so reduces the moisture level. This is not normally changed during a run, but the angle may be increased to promote drainage during periods of difficult moisture control e.g. with spring cream having soft butterfat.

Operation of Contimab Continuous Buttermaker

The preceeding discussion has indicated some of the raw material and machine variables which determine the composition of the end product. These factors are interrelated, thus to achieve a change in composition an alteration may be made to one or more of these control factors.

A summary of these control factors and their effect on composition is presented below in Table I.

TABLE I

<u>Factor</u>	<u>Change</u>	<u>Moisture Content</u>	<u>Salt Content</u>
Fat Content of Cream	Increase	Increase	
Acidity of Cream	Increase	Increase	
Cream Temperature	Increase	Increase	
Churn Beater Speed	Increase	Increase	
Cream Flow Rate	Increase	Decrease	
Chill Water Temperature on Primary Churn	Increase	Increase (small)	
Worker Speed	Increase	Increase	
Buttermilk Level	Rise in Syphon Level	Increase	
Worker Angle	Increase	Decrease	
Wash Water Temperature	Temperature Increase	Increase	
Salt Pump Stroke	Increase	Increase	Increase

TABLE II An Indication of Typical Operating Conditions

	<u>Spring Cream</u> (soft fat)	<u>Summer Cream</u> (hard fat)
Fat Content	40.5 %	40.5 %
Churning Temperature	45°F.	52°F.
Beater Speed	1000 r.p.m.	1800 r.p.m.
Amperage	40 Amps	74 Amps
Worker Speed	35 r.p.m.	55 r.p.m.

Note 1 - A list of references used in preparation of this section is presented in Section B of the bibliography.

SECTION IIMETHODS OF ANALYSIS

The factors selected for analysis were chosen primarily because of their direct bearing on the economic return received for the product. Such factors as moisture and salt content which influence the overrun achieved on the product are in this category. Other factors which affect grading of the product may also be included.

In addition, those factors which influence process operation, having an indirect effect on the economic return, have been considered. For example, butter moisture content is dependent upon a number of cream and machine operating factors. Similarly, butter salt content is also determined by several machine operating factors.

The methods used in analysis of the factors were required to satisfy certain conditions.

(1) The method must be comparable to that used in the factory laboratory, as it is by the results obtained from the laboratory that the operator controls the continuous churn. As it is the variation in churn operation being examined, highly accurate analysis of the product is not necessary when the process is controlled to lesser precision.

(2) Similarly, the method should be comparable to that used in grading of the product which influences product remuneration.

(3) The method should be uncomplicated and suitable for examination of many samples.

(4) The accuracy of the method should be sufficient to detect changes and trends in the factor. Highly sensitive techniques are not required.

Sampling Errors

Sampling errors are introduced into results when non-homogeneous products such as butter or cream are sampled. Moisture droplet dispersion, fat globule distribution may be homogeneous under ideal mixing conditions but under practical operating conditions this may not be true.

The extent of non-homogeneity is difficult to assess as the differences involved can become incorporated with experimental errors. Thus differences between duplicate or multiple samples reflect a combination of errors in sampling and experimental technique.

The use of larger samples can reduce sampling errors to some

extent, as localised minor variations will have a less significant influence on the result.

Throughout experimental work samples of more than 8 grams weight have been used. (Further discussion of errors is made with reference to individual tests.)

Determination of Moisture in Butter

The method selected for moisture analysis of butter was basically that method used in the factory 'Moisture Test Room'. It is also generally used by Dairy Board Grading Officers and thus is the basis for monetary return on the produce.

The method is not difficult to use and a satisfactory rate of analyses can be achieved.

Modifications were made to the cooling procedure for dishes after drying when empty, and after heating of the sample. This was done in order to avoid introduction of errors due to weight changes when cooling. Adoption of a standardised procedure assists in elimination of errors.

All weighing measurements were made to a four decimal place, six significant figure accuracy using a Mettler H6 balance. The final results were expressed to two decimal place, four significant figure, accuracy. Duplicate analyses were made from each sample and results were finally expressed as the mean of the duplicate values.

Summary of Procedure for Butter Moisture Determination (26)

Apparatus Moisture beaker
 Moisture tongs
 Flame source, hotplate
 Balance
 Sampling 'trier'

Method (1) Dry beakers in oven overnight (100°C.)
 Remove and cool for a standard time of 1.5 hours on the
 balance room bench.

- (2) Weigh all dishes, set one aside as a standard (zero balance before use).
- (3) Weigh accurately a butter sample of 8-10 grams.
- (4) Preheat sample on hotplate, complete moisture removal by heating over flame till curd becomes a light brown colour.
(Take care to avoid splashing of fat from dish.)
- (5) Cool for standard time 2.5 hours.
- (6) Reweigh (zero balance before use).
- (7) Adjust final weights by difference in weight of standard dish.
- (8) Calculate moisture content.

Analysis of Errors

Sources of error in the experimental method are considered in the following discussion. Assignable errors will be evaluated where possible and their nett effect on the result calculated.

Sources of error.

- (1) Correct use of the balance was important to avoid errors. The balance was zeroed prior to weighing and care taken to avoid draughts.
- (2) Weighing of the dish, dish and sample.
- (3) Underheating of the curd, which can lead to moisture remaining in the sample.
- (4) Overheating of the curd, which can lead to curd decomposition.
- (5) Frothing and spitting can cause fat loss. This may be avoided by careful control when heating the sample.
- (6) Change in atmospheric conditions can lead to variation in the amount of adsorbed moisture on the dishes - this can cause weight change. This source of error was minimised by use of a standard moisture dish which was not used in the test. Weight changes in this dish occurring during the period of analysis were determined and adjustment made to the final weights of experimental dishes.
- (7) Non-homogeneity of sample (as discussed earlier).

Evaluation of Errors in Weighing - A Typical Calculation

The error possible in reading the balance was assumed to be 1 division of the most sensitive scale.

$$\text{Scale reading error} = \pm 0.0001 \text{ gm.}$$

$$\text{Consider a typical dish weight} = 23.0000 \pm 0.0001 \text{ gm.}$$

$$\text{Dish + sample weight} = 31.0000 \pm 0.0001 \text{ gm.}$$

$$\therefore \text{Sample weight} = 8.0000 \pm 0.0002 \text{ gm.}$$

$$= \underline{8.0000 \text{ gm.} \pm 0.003\%}$$

$$\text{Dish + sample weight} = 31.0000 \pm 0.0001 \text{ gm.}$$

$$\text{Final weight} = 29.7600 \pm 0.0001 \text{ gm.}$$

$$\therefore \text{Weight loss} = 1.2400 \pm 0.0002 \text{ gm.}$$

$$= \underline{1.2400 \text{ gm.} \pm 0.02\%}$$

$$\text{Fractional Moisture Content} = \frac{\text{change in sample weight}}{\text{initial sample weight}}$$

$$= \frac{1.2400 \text{ gm.} \pm 0.02\%}{8.0000 \text{ gm.} \pm 0.003\%}$$

$$= \underline{0.1550 \pm 0.02\%}$$

$$= (0.1550 \pm 0.00003)$$

$$\text{Moisture Content} = \underline{(15.50 \pm 0.003) \%}$$

Thus it may be seen that the assignable weighing errors, are only a minor source of error. For a lower sample weight the error will increase.

Since the results are considered with respect to larger variations in composition and trend changes, this source of error is not significant. Compositional results were calculated to three decimal places and rounded to two decimal places.

Determination of Salt in Butter

The Acetone Test for Salt in Butter was the method selected for analysis of samples. It is based on the Mohr titration. Since both butterfat and water are miscible with acetone it provides a medium whereby the salt present in the butter may disperse readily. The salt is then available for titration with silver nitrate using potassium chromate indicator.

For the purposes of this test, the complete sample remaining after moisture determination was analysed by this method. It was hoped that by analysis of a larger sample of 8-10 grams, original weight, without transfer of material, sampling errors could be reduced.

Summary of Procedure for Butter Salt Determination (27,28)

- (1) Warm the sample to melt the butterfat.
- (2) Add 30 ml acetone and stir well.
- (3) Add approximately 100 ml of distilled water.
- (4) If butter is acid, add a small amount of pure CaCO_3 to neutralise the solution. The chromate indicator gives satisfactory results only in neutral and alkaline solution.
- (5) Titrate using AgNO_3 solution of known concentration and 3-4 drops of K_2CrO_4 indicator should be added.

Note 2

- (1) The commercial acetone used was checked and found to be free of chloride.
- (2) Distilled water was used in all analyses.

Analysis of Errors

The end-point in titration of the chloride ion is a possible source of experimental error. This is due to the cloudy nature of the stirred solution caused by the silver chloride precipitate. However, the titration was taken to a consistent end point colour. Because the variation in salt content is more important than the actual value, having a consistent end point colour is the major consideration.

Consider a titration error of ± 0.1 ml. (2 drops)

Minimum titre values were approximately 7 ml.

$$\text{Titration error} = \frac{\pm 0.1 \times 100 \%}{7}$$

$$= \pm 1.5 \% \text{ of the titre value}$$

For a salt content of 1.5% actual error is ± 0.022 expressed as percentage salt.

Titre values were generally in the region of 10 ml. and so this error is reduced.

Analysis of Differences between Duplicate Results

Differences between duplicate results of a single sample may be attributed to two factors.

- (1) An actual difference between the sample compositions occurring because of the non-homogeneity of the substance being analysed.
- (2) A difference which is a result of inherent errors in the method of analysis.

An analysis of differences between duplicate results of the tested samples was carried out. The differences were due to the combined effects of the above factors.

The 'differences' for n samples were used in the calculation of 'mean difference', and 'standard deviation of differences'.

Moisture Content

Number of samples, n = 70
Mean difference = 0.029 % moisture

Range - minimum difference = 0
maximum difference = 0.08 % moisture

Salt Content

Number of samples, n = 70
Mean difference = 0.046 % salt

Range - minimum difference = 0
maximum difference = 0.11 % salt

Differences in excess of these quoted values were considered unacceptable and samples were tested a second time.

Generally the difference between duplicate samples was low and at an acceptable level. In examination of results compositional variations were compared with the possible magnitude of duplicate differences when considering real or significant variations.

Determination of Fat Content of Cream

The method used was the standard Babcock method for fat determination in cream. (29)

(An examination of errors is given in the discussion of experimental results.)

Determination of Titratable Acidity of Cream

The Titratable Acidity of cream was determined as lactic acid by the standard method. (30)

(An examination of errors is given in the discussion of experimental results.)

Calibration of the Varian Strip Chart Recorder

The calibration curve of the Varian recorder is presented in Fig. 4 (page 34).

The calibration was conducted with reference to a Mercury-Glass thermometer.

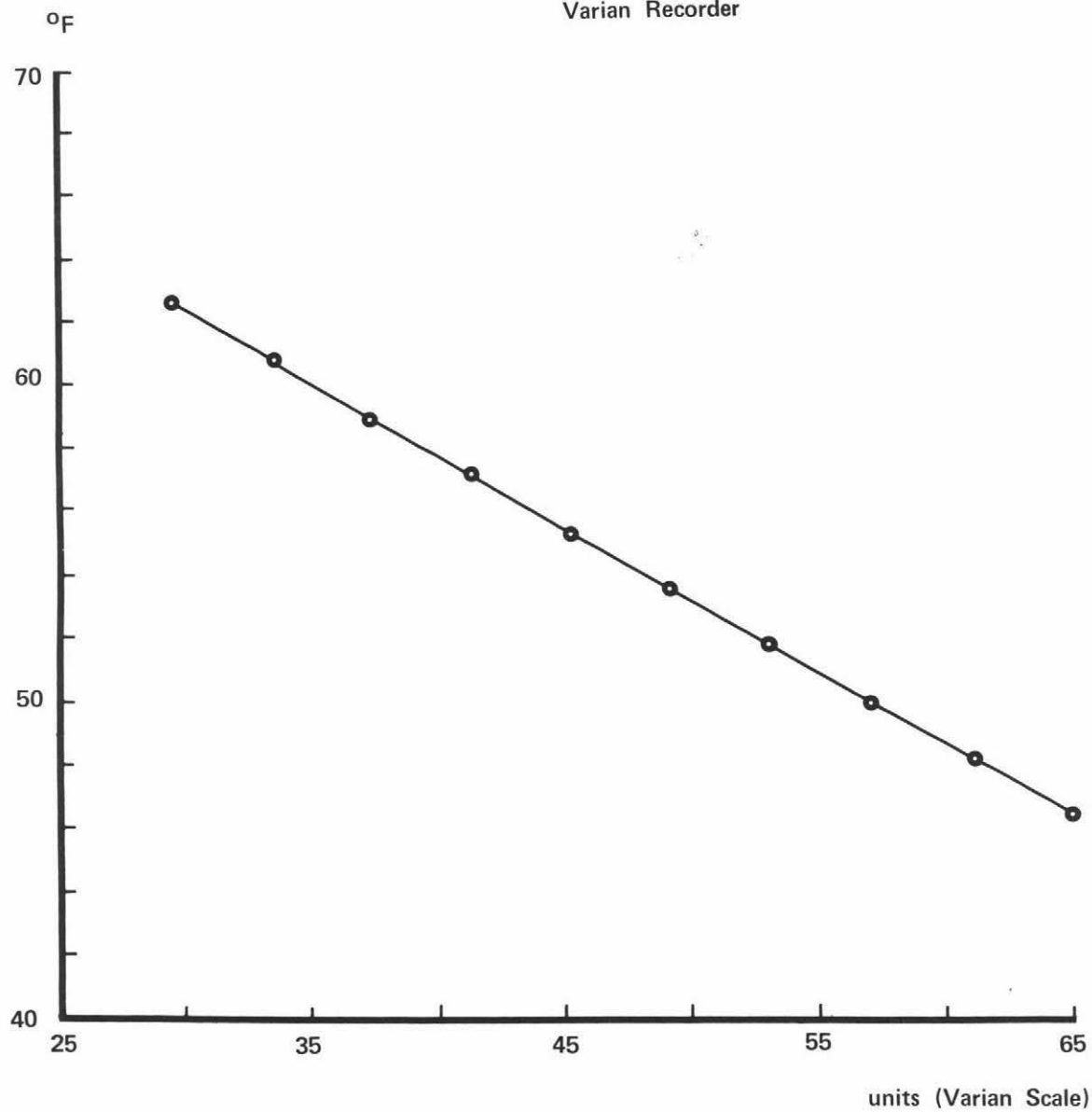
Varian Recorder	- Model G-15-1
Scale	- 1 millivolt
Thermocouple	- Copper-Constantan
Reference temperature	- Ice point
Thermometer	- Mercury-Glass (reading to 0.1°C) (BS593 - A)

The thermometer was fitted with a magnifier to facilitate scale reading. It was used to measure the 'known temperature' of a well stirred

water bath.

The calibration curve approximates closely to a straight line, and it is assumed that over the temperature range investigated, that the measured temperature is directly proportional to the Varian scale reading.

Fig. 4. Graph of Temperature ($^{\circ}\text{F}$) vs Scale Reading for Calibration of Varian Recorder



SECTION IIIEXPERIMENTAL WORKEXPERIMENT I

A study of weight changes during cooling of samples in the gravimetric analysis of moisture content of butter.

The object of this experiment was to determine the magnitude of weight changes occurring during cooling periods. By cooling the dishes to a constant weight or to a level of minimum change in weight, an important source of error may be eliminated or reduced to an acceptable level.

Consider a sample of weight 10.00 grams. The weight loss when moisture is removed will be between 1.5 gm. - 1.6 gm. for a calculated moisture 15% - 16%.

Since a weight change of 1.500 gm. \equiv 15.00% then if we wish to detect changes in the second decimal place of the moisture content value, expressed as a percentage, the weighing accuracy must be in the region of 0.001 gm. \equiv 0.01% moisture.

Thus unless correction is made for warm-weighing the final weight to be used in calculations should be accurate to the third decimal place or better.

For smaller samples of less than 10 grams, for a moisture content value accurate to 0.01%, the weighing accuracy should be taken to the fourth decimal place.

However, the inherent errors involved in the method of moisture removal will impose a limit on the accuracy necessary in experimental weighing.

Weight Changes During Cooling of Empty Dishes

The metal dishes used in moisture determination were dried overnight in a 100°C. oven. After removal from the oven, the dishes were placed on a metal tray, they were then placed in a balance room on a marble aggregate bench and allowed to cool. The dishes were weighed at half hour intervals until changes in weight were minimal.

Little change in weight was recorded after 1.5 hours cooling in a sample of 24 dishes. The magnitude of change was $\leq \pm 0.0004$ gm. between 1.5 hours and 2.0 hours cooling. Thus 1.5 hours was selected as a suitable cooling time for empty dishes after oven drying.

Weight Change During Cooling of Dish + Sample after Moisture Removal

A similar trial was conducted on butter samples undergoing cooling after moisture had been driven off during heating. From a sample of 12 dishes the minimum weight changes occurred after a cooling period of 2.5 hours, although weight changes after 2 hours were reduced to an acceptable level. Magnitude of change after cooling for 2.5 hours was $\leq \pm 0.0005$ gms.

Thus by using a consistent procedure for cooling of moisture dishes during the gravimetric moisture determination of butter, an important source of error has been removed or reduced to a low level which will help to improve the accuracy and repeatability of results.

During cooling of the moisture dish and the dish including butter sample the final weights were not constant and a small error is introduced in the result.

The magnitude of these weight changes may be used in calculation of the possible error.

Cooling of dish - change after 1.5 hours ≤ 0.0004 gm.

Cooling of dish + sample - change after 2.5 hours ≤ 0.0005 gm.

Thus possible error introduced ≤ 0.001 gm.

This could give rise to a discrepancy of up to 0.01% in the estimation of butter moisture content. (Refer to earlier calculation page 35).

Thus considering the possible errors assignable to weighing procedure (page 29) and cooling procedure, a total assignable error has been estimated.

Weighing procedure error ± 0.003 % moisture

Cooling procedure error ± 0.010 % moisture

Total assignable error ± 0.013 % moisture

Note 3

A summary of numerical results for this experiment is presented in Appendix I.

EXPERIMENT II

The initial investigation aimed at determining the variations in moisture and salt content in the product from the Contimab MC 30 when this machine was running under regular production conditions.

For the first experimental run slices were cut from the extruded ribbon immediately before entering the hopper of the packing unit. The sample slices were wrapped in a moisture proof film in order to minimise moisture transfer between the butter surface and the atmosphere during storage. In addition this protected the surface from water splashes and other contamination. The slices were 2.5 - 3.5 inches thick, this enabled a core sample of approximately 10 grams to be removed as a single plug using a 'trier'. Sample slices were removed at specific time intervals: 0, 1, 2, 3, 4, 5, 10, 15, 20, 25, 50, 75, 100, 125 minutes.

Duplicate samples were taken from the slice at nine specific positions making eighteen samples in total. This was done for each of the fourteen slices. Moisture and salt analyses were carried out for each sample. (Fig. 5 (page 45) indicates the sampling pattern used.)

These results were analysed in two ways:

- (i) Each slice was considered separately - standard deviation and mean values were found for moisture and salt content in the eighteen samples.
- (ii) Like positions in the series of slices were considered. Thus for each specific location (1 to 9), the mean and standard deviation were calculated for the moisture and salt values of the time sequenced series.

Table III (page 38) gives the results for moisture and salt content for the 14 'slice' samples taken at the specified times. The results show a wide variation in the mean values for each slice, indicating a large variation with time. The standard deviation for each slice is relatively low in most cases, indicating a comparatively even composition across the slice at any one time.

Table IV (page 39) gives results of moisture and salt content for each of the nine 'like locations' in the series of slices. The mean values for each location showed a remarkably low range. These values are close to the grand mean of all results, indicating that no area in the slice is being consistently starved or enriched with moisture or salt.

TABLE IIIRESULTS FOR INDIVIDUAL SLICESTRIAL (28/9/71)

TIME (minutes)	MOISTURE CONTENT		SALT CONTENT	
	Mean (%)	Standard Deviation	Mean (%)	Standard Deviation
0	15.53	0.05	1.42	0.10
1	15.70	0.08	1.56	0.06
2	15.75	0.05	1.45	0.04
3	15.66	0.11	1.53	0.03
4	15.46	0.05	1.32	0.03
5	15.65	0.04	1.46	0.06
10	15.68	0.04	1.47	0.02
15	15.62	0.04	1.42	0.02
20	15.46	0.04	1.46	0.03
25	15.62	0.04	1.45	0.02
50	15.72	0.05	1.52	0.04
75	15.86	0.04	1.41	0.03
100	15.90	0.05	1.37	0.05
125	15.38	0.10	1.30	0.03

TABLE IVRESULTS FOR LIKE LOCATIONSTRIAL (28/9/71)

LOCATION	MOISTURE CONTENT		SALT CONTENT	
	Mean (%)	Standard Deviation	Mean (%)	Standard Deviation
1	15.63	0.17	1.45	0.08
2	15.65	0.15	1.45	0.09
3	15.65	0.14	1.44	0.08
4	15.63	0.17	1.43	0.09
5	15.65	0.13	1.44	0.10
6	15.66	0.17	1.44	0.08
7	15.63	0.16	1.43	0.07
8	15.66	0.15	1.44	0.07
9	15.62	0.16	1.44	0.09

OVERALL RESULTS

Moisture Mean (%) 15.64
 Standard Deviation 0.15

Salt Mean (%) 1.44
 Standard Deviation 0.08

The higher standard deviation for salt and moisture content compared with the 'slice' values is a reflection of change in the composition of each location over the time sequence. This again indicates that the compositional variation over time is more significant than variation across the ribbon at any one instant.

A second experimental run was conducted; 11 consecutive samples were taken at 1 minute intervals. The results were treated in the same manner as those in the first trial and similar patterns emerged.

The 'slice' means showed considerable variation indicating a compositional variation with time. The mean values for moisture and salt content for 'like locations' were close to the grand overall mean values, as in the previous trial. But whereas in the previous run the variation with time was much greater than that across the slice as shown by comparison of the standard deviations, this was not borne out in the second run.

It appears that the second run was of more regular composition with respect to time, but slightly less homogeneous across the slice at any one instant.

Table VI (page 41) gives results of moisture and salt content for the eleven 'slice' samples taken at specified times.

Table VII (page 42) gives results of moisture and salt content for 'like locations' for the slice samples taken during this trial.

TABLE VIRESULTS FOR INDIVIDUAL SLICESTRIAL (28/10/71)

TIME (minutes)	MOISTURE CONTENT		SALT CONTENT	
	Mean (%)	Standard Deviation	Mean (%)	Standard Deviation
0	15.53	0.05	1.50	0.07
1	15.63	0.07	1.52	0.08
2	15.61	0.03	1.52	0.07
3	15.58	0.04	1.55	0.02
4	15.58	0.06	1.44	0.13
5	15.56	0.09	1.53	0.06
6	15.61	0.10	1.51	0.08
7	15.62	0.04	1.50	0.05
8	15.63	0.06	1.42	0.15
9	15.52	0.03	1.38	0.06
10	15.58	0.06	1.50	0.11

TABLE VIIRESULTS FOR LIKE LOCATIONSTRIAL (28/10/71)

LOCATION	MOISTURE CONTENT		SALT CONTENT	
	Mean (%)	Standard Deviation	Mean (%)	Standard Deviation
1	15.59	0.06	1.47	0.08
2	15.61	0.08	1.49	0.09
3	15.59	0.08	1.48	0.10
4	15.58	0.06	1.46	0.08
5	15.58	0.08	1.51	0.10
6	15.57	0.05	1.48	0.14
7	15.58	0.06	1.48	0.09
8	15.59	0.06	1.52	0.07
9	15.59	0.09	1.49	0.12

OVERALL RESULTS

Moisture Mean (%) 15.59
 Standard Deviation 0.07

Salt Mean (%) 1.49
 Standard Deviation 0.10

Analysis of Variance

An analysis of variance was conducted on the two experimental runs. The factors under observation were:

- 1) Position - Variations in moisture and salt content influenced by the location or cross sectional position at which the sample was taken.
- 2) Time - Variations in moisture and salt content influenced by the time at which samples were taken.

From these results it was found that for variation in moisture content, a significant portion of the variation could be attributed to a first order factor interaction of Position-Time. This indicates that variation is due to a combination of both Position and Time and may not be fully explained by consideration of each factor separately.

For salt content variation a zero order factor was found to be significant, this was Time. No first order interaction was present.

It is likely that for moisture variation a zero order factor is also significant, although this may not be readily examined if a higher order (first order) interaction has been shown to be statistically significant.

From the previous discussion of Tables III - VII, it may be seen that variation with time is important. The variance analysis also showed a high variance value for Time.

Thus it may be concluded that compositional variation is influenced significantly by Time, and also by the interaction of both Position and Time.

Because of the difficulty in analysis of the interacting factors of Position and Time, it was decided that variation in composition should initially be examined with respect to the base factor - Time.

Note 4

A summary of the Analysis of Variance is presented in Appendix II.

EXPERIMENT III

Continuous Block Sample

The previous results showed a product which was varying considerably with time. By taking a complete section from the extruded ribbon a continuous sample was obtained. It was then possible to determine the composition of this section of ribbon at various positions. By determining the speed of ribbon travel, the distance travelled could be related to elapsed time. From these results it was possible to determine the rapidity with which the product composition could change. Variation in composition within this sample is not caused by intervention of the operator, as the time over which the sample was taken was a period of less than 30 seconds. This is in contrast with the previous work, which was sampling over a long time period, during which operator changes may have been made.

Fig. 6 (page 45) shows a schematic diagram of the continuous block with the respective moisture content for each 'slice' expressed as a percentage. The elapsed time is indicated on the lower scale.

Samples 1 - 4 were 'slice' samples removed in the normal manner. Duplicate samples were taken at nine locations as before. 'Slice' samples were also removed from the mid-point and end of the continuous block.

Samples 5 - 13 were taken at one inch intervals - in this treatment the leading face was scraped in order to remove a representative sample. Duplicate analyses were conducted. This sampling method differs from previous techniques. The use of core sampling provided results representative of the whole 'slice' thickness, whereas the latter is a sample representative only of the particular face exposed.

From the earlier discussion of errors and analysis of differences between duplicate results, it was seen that variations in excess of 0.03 % moisture (the mean of differences between duplicates) could indicate a real change in composition. Certainly variations greater than the maximum difference of 0.08 % moisture could be considered significant.

From these results it is seen that compositional changes may occur rapidly. Over a period of only 5 seconds a change in moisture content

Fig. 5. Locational Sampling Scheme used in Slice Analysis

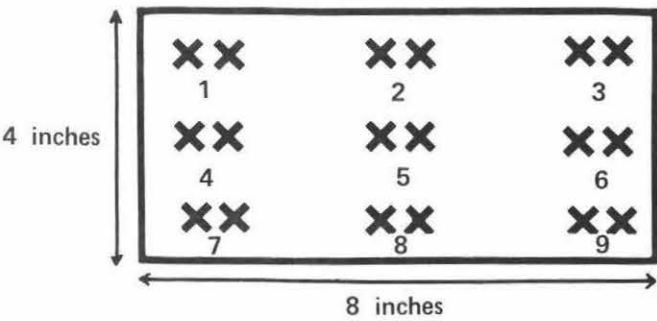
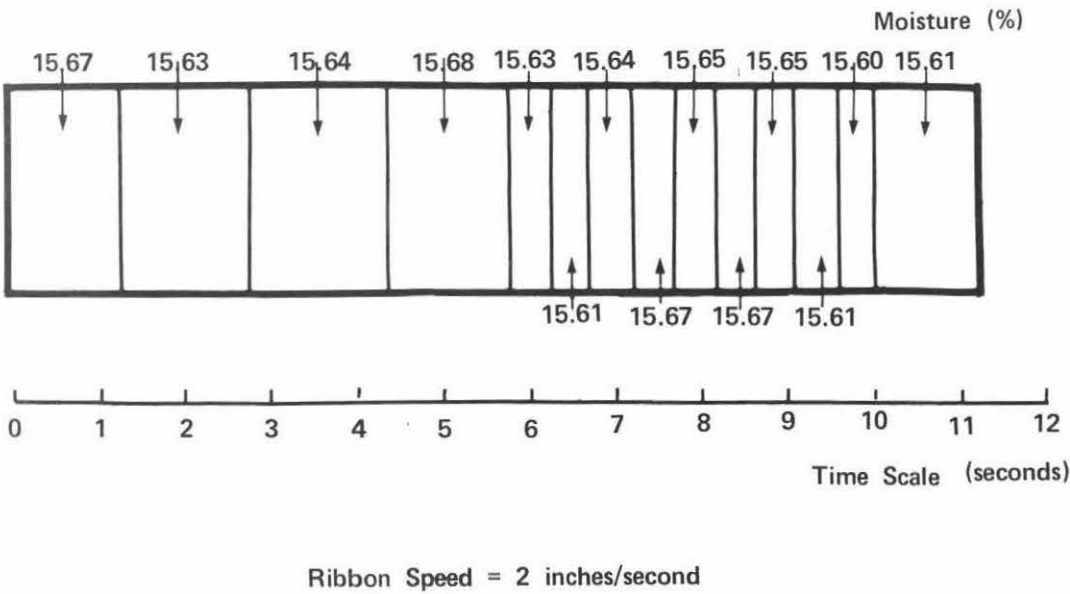


Fig. 6. Continuous Block Sample Results



of 0.05 % has occurred. Moreover, changes of up to 0.02 % moisture can occur almost instantaneously, but these are of doubtful significance.

The 'slice' composition shows considerable variation. The moisture content may vary up to 0.25% and the salt content 0.35%. Such a large variation may not be attributed to experimental sources and must reflect non-homogeneity of the butter. Compositional changes in a single slice sample are virtually instantaneous, and thus may not be caused by time dependent variation of process conditions.

Variation in composition across the slice may be considered a function of the mixing capability of the machine. Under ideal conditions complete mixing should produce a butter of homogeneous composition with respect to a cross section. Because these conditions can not be met, variation does occur across a slice.

However, the variation in machine input factors will also give rise to compositional variation. If it is considered ideal mixing occurs and slice composition is homogeneous, then variation in these machine inputs will result in compositional variation with respect to time.

Analysis of small sections of the ribbon will determine the value of these short time or 'micro' variations but changing of machine variables may occur over relatively longer time periods. The effect of one change may take some time to reach its full value, or it may reach it instantly. For these changes composition will vary - either in a gradual change or a rapid step change respectively.

Thus it is desirable to investigate the 'macro' changes occurring due to changing conditions, as well as the 'micro' variation. For this type of investigation the sampling intervals were selected to observe trends - or changes over an extended time period. A time of one minute was selected as the interval between samples.

The non-homogeneity of a slice is a lesser variation in comparison with long term trend changes. Because of this, a single sample was removed from the ribbon. It was considered that the composition of this sample, assessed from duplicate analyses, provided a suitable estimate of the cross-sectional or slice composition at that sampling point.

The generally low standard deviation across a slice supports this assumption and it has been shown that over several slices the mean composition, at any of the nine locations examined, is close to the overall composition of all samples. Thus by sampling at a single point (plug sample) variations in homogeneity may give rise to a small error but it is not a consistent error which could necessitate compensation.

EXPERIMENT IV

Compositional Changes Occurring in Butter over an Extended Time Period

Since it has been shown that product variation with time is more significant than variation within the product, (or across the slice) at any one time, this trial sought to investigate changes in composition with respect to time.

A single plug sample was removed from the ribbon - and this was considered a representative sample of the product at that specific time. The plug was removed using a large 'trier', length of plug = 2.5" and diameter = 1.5". The plug was placed in a screw top plastic cylindrical container. By using a moisture impervious container samples were able to be stored for some time before analysis.

The sample plug was taken from the middle of the ribbon at the upper surface. Sixty samples were taken at one minute intervals, and a duplicate analysis was carried out on each plug sample.

Analysis of Results

The duplicate results for moisture and salt content were averaged and then treated in the following ways:

- (1) Mean and standard deviation values were calculated
- (2) Graphs of Moisture Content (%) and Salt Content (%) vs. Time were constructed
- (3) Cumulative sums were determined.* The base value or reference value used was the overall mean value for the trial. Graphs were plotted for Moisture and Salt Cumulative Sums.
- (4) Graphs of Moisture Content (%) vs. Salt Content (%) were drawn in some cases. These Scatter Diagrams are useful in detecting the type of relationship occurring between two variables.

*Note 5

Cumulative Sum Techniques, and Correlation (including scatter diagrams) are discussed briefly in Appendix III.

Trial A (24/11/71)

Sixty samples were taken at intervals of one minute. The samples were analysed to determine moisture and salt content.

Figs. 7a, 7b (page 50) show the results presented in graphs of Moisture and Salt Content vs. Time.

Figs. 8a, 8b (page 51) show the Moisture and Salt Cusum Charts.

Discussion of Results

(1) The graphs of Moisture Content and Salt Content vs. Time show strong relationship between the pattern of moisture and salt variation. It may be seen that moisture and salt values both rise and fall in a similar manner, and the magnitude of the changes are comparable.

The correlation coefficient was determined between the two sets of data - Moisture and Salt.

Number of samples, $n = 60$

Moisture-Salt Correlation Coefficient ' r ' = 0.54

Significance level = 0.001

It is seen that the relationship between moisture and salt content is highly significant.

(2) The cusum charts however, provide some additional information. The salt cusum has an initial region of negative slope, indicating the salt content was below the overall trial mean value. The salt content however, increases slowly and in the central section of the trial is close to the overall mean as the graph shows a steady cusum value and has zero gradient. The final section shows a relatively large change in the mean value as the graph tends to rise. The changes in slope at times of 12 and 36 minutes are prominent and may be significant.

The moisture cusum however, does not show such clear trends. Changes tend to occur more rapidly but are not sustained. Thus although the moisture and salt values correlate well there appears to be an independent gradual increase in the salt content over the sampling period.

At the time of this run, other machine factors had not been

Fig. 7a. Graph of Moisture Content (%) vs Time (minutes) (24/11/71)

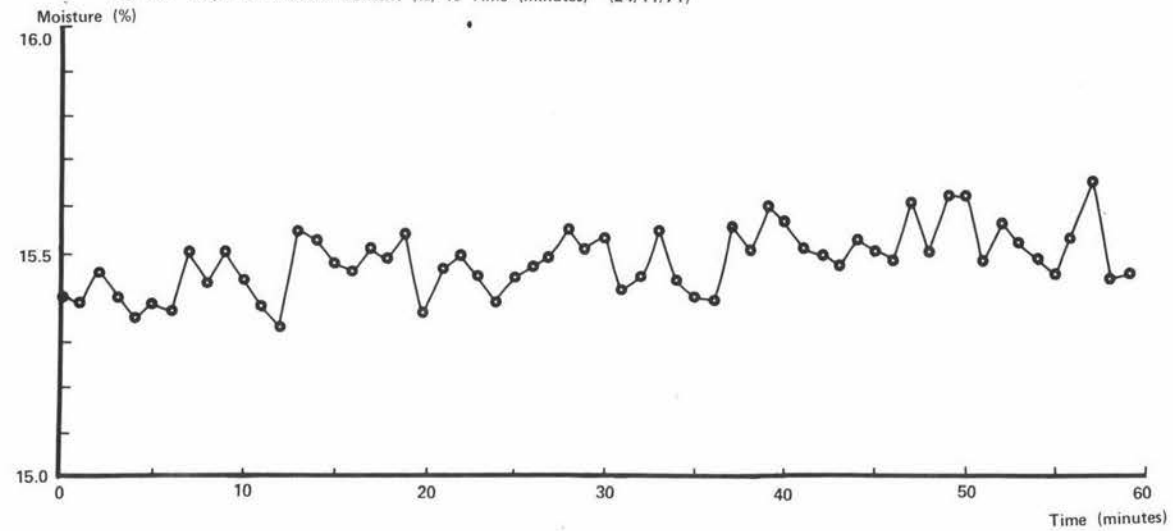


Fig. 7b. Graph of Salt Content (%) vs Time (minutes) (24/11/71)

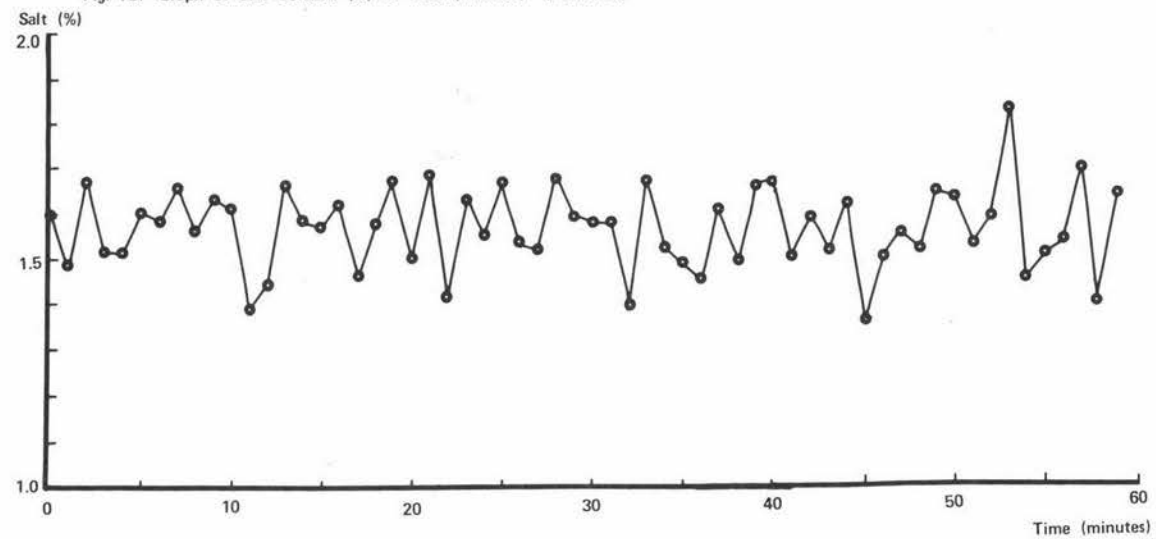


Fig. 8a. Moisture Cusum Chart (24/11/71)

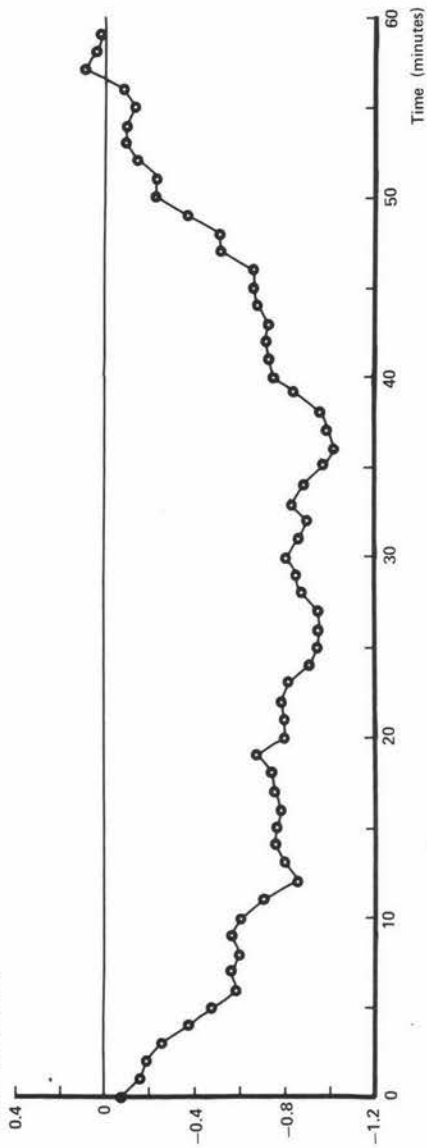
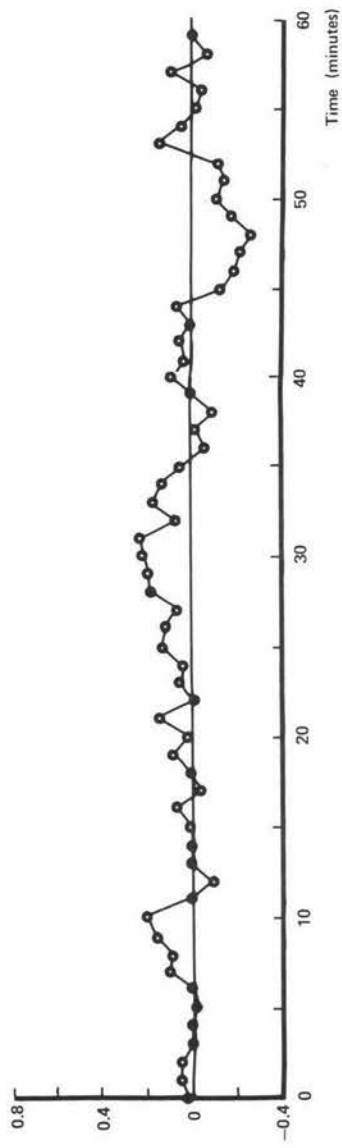


Fig. 8b. Salt Cusum Chart (24/11/71)



considered. Later work tends to indicate that this trend change could be the result of variation in the salt injection system or possibly some trend change in another machine variable.

It is considered that the moisture content is being influenced by the injection of the salt slurry. The slurry, being in this case 60 parts salt/40 parts water, carries similar quantities of salt and water into the product. Thus any variation in the dosing volume is reflected as a 'like' variation in salt content and by association the variation is reflected in the moisture content.

Salt injection is not the sole source of variation in the complex mechanism of butter manufacture, but to gauge the effect of it, if the correlation coefficient 'r' is squared then the result indicates the relative influence that the salt slurry injection is having on the variation in moisture content of the butter.

$$\text{For 'r' = 0.54 } r^2 = 0.29 \text{ or } 29\%$$

Thus in this case 29% of the variation in moisture content is caused by variations in the salt slurry injection system.

Several trials investigating this relationship have found a wide range of correlation coefficients between moisture and salt content. It is evident that the dependence or relationship between moisture-salt variations and slurry injection is quite varied. Results show extremely strong relationship for some sections of a run and yet very little relationship at others. Table VIII (page 53) shows the results obtained from a number of trials, taken at different times during the season.

A wide range of values for 'r' is seen. This implies a changing relationship between moisture and salt values and this is probably due to the influence of external factors.

The correlation between moisture and salt is shown to be significant in ten of the thirteen trials conducted. In two of the non-significant trials sample sizes were lower than usual. It has been shown that during a trial some sections can show little or no relationship between moisture and salt content whereas the remainder may be highly related.

Two further trials are discussed with reference to compositional behaviour patterns.

TABLE VIII

SUMMARY OF RESULTS FOR THE CORRELATION COEFFICIENT
BETWEEN BUTTER MOISTURE CONTENT AND SALT CONTENT

Date	Sample Size (n)	Time Period Considered (minutes)	r	Significance Level	Moisture		Salt	
					Mean (%)	Standard Deviation	Mean (%)	Standard Deviation
24/11/71	60	0-59	0.54	0.001	15.48	0.09	1.56	0.09
7/12/71	60	0-59	0.70	0.001	15.63	0.16	1.54	0.14
21/12/71	40	0-39	0.56	0.001	15.41	0.16	1.52	0.10
7/2/72	40	0-39	0.58	0.001	15.69	0.15	1.56	0.09
7/2/72	22	14-35	0.86	0.001	15.61	0.14	1.49	0.14
3/3/72	40	0-39	0.35	0.05	15.51	0.07	1.51	0.06
11/3/72	40	0-39	0.27	0.1	15.51	0.14	1.28	0.09
11/3/72	27	12-38	0.56	0.01	15.51	0.13	1.28	0.09
28/3/72	15	0-14	0.29	not significant	15.42	0.10	1.56	0.11
6/4/72	40	0-39	0.22	not significant	15.41	0.19	1.64	0.10
6/4/72	18	0-17	0.64	0.001	15.22	0.07	1.66	0.11
6/4/72	22	18-39	0.78	0.001	15.56	0.11	1.63	0.09
3/5/72	25	0-24	0.28	not significant	15.29	0.07	1.40	0.06
16/5/72	40	0-39	0.49	0.001	15.38	0.12	1.59	0.06
16/5/72	37	2-38	0.69	0.001	15.39	0.12	1.59	0.06
22/5/72	40	0-39	0.31	0.05	15.39	0.11	1.35	0.08
26/5/72	40	0-39	0.08	not significant	15.36	0.10	1.19	0.06

Trial B (11/3/72)

Forty samples were taken at intervals of one minute and the samples were analysed in the usual manner.

Figs. 9a, 9b (page 55) show the results presented in graphs of Moisture and Salt Content vs. Time.

Figs. 10a, 10b (page 56) show the Moisture and Salt Cusum Charts.

Discussion of Results

(1) Comparison of the moisture and salt graphs for Trial B (Figs. 9a, 9b) show the variable relationship which can occur between moisture and salt content.

The portion of the graph from 12 minutes to 38 minutes was extremely well correlated ($r = 0.56$, significant at 0.001 level). The values from 5 minutes to 11 minutes show a very consistent salt level in the butter whereas variation continues to occur in the moisture content, and so the relationship between moisture and salt is poor.

It is not possible to establish a definite reason for this low salt content. Non-homogeneity of the salt slurry could be a contributing factor. If a lesser amount of salt was present in the slurry then the dosing volume would carry a smaller quantity of salt into the butter and the relative quantity of water incorporated into the product would increase.

Changes in salt slurry composition may be caused by

- (i) Low level in the tank
- (ii) A new charge of slurry may be of different composition.

A further example of low salt content is seen in Trial H (26/5/72). (See Table VIII (page 53)). The salt content of 1.19% is lower than usual, and the standard deviation of 0.06 indicates a low variation in salt content. For this trial the correlation coefficient is very low ($r = 0.08$). Thus it is possible that the salt content has a limiting level below which the injection doses have little effect on the variation in moisture content, but above this minimum level the relationship is present.

Fig. 9a. Graph of Moisture Content (%) vs Time (minutes) (11/3/72)

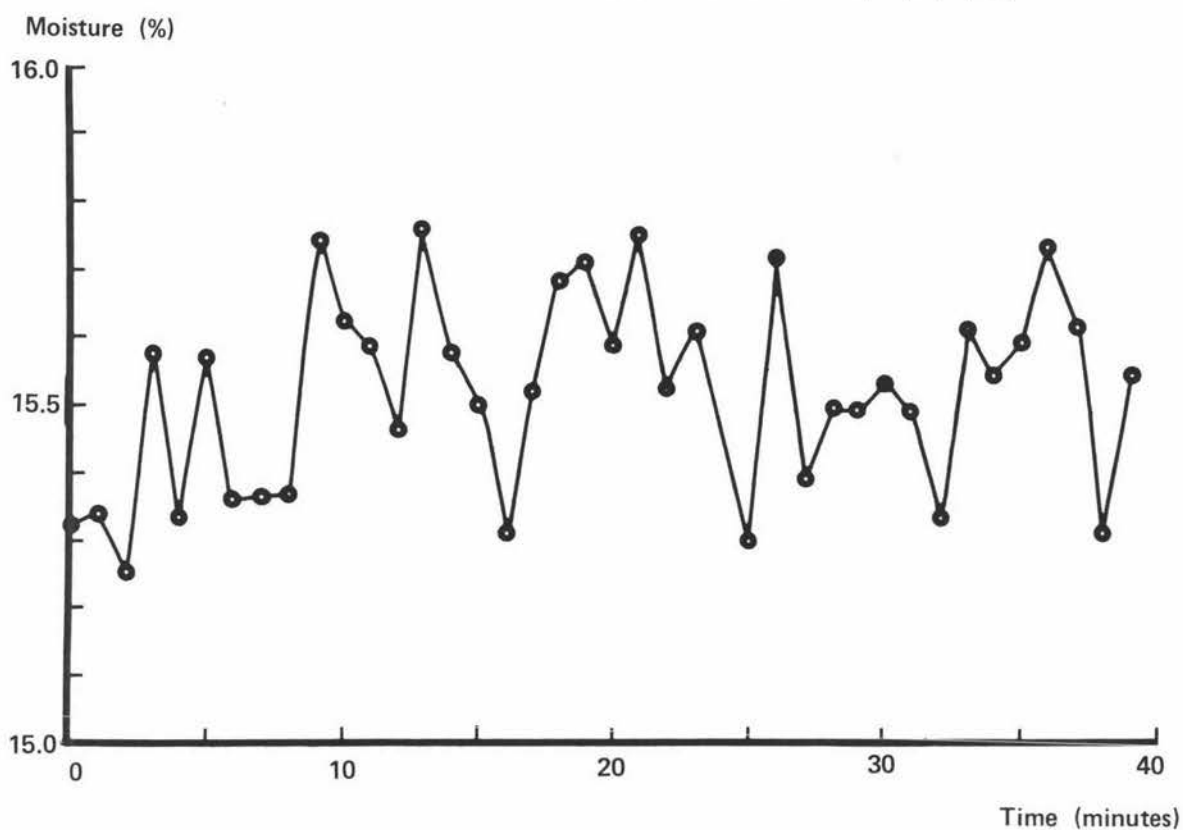


Fig. 9b. Graph of Salt Content (%) vs Time (minutes) (11/3/72)

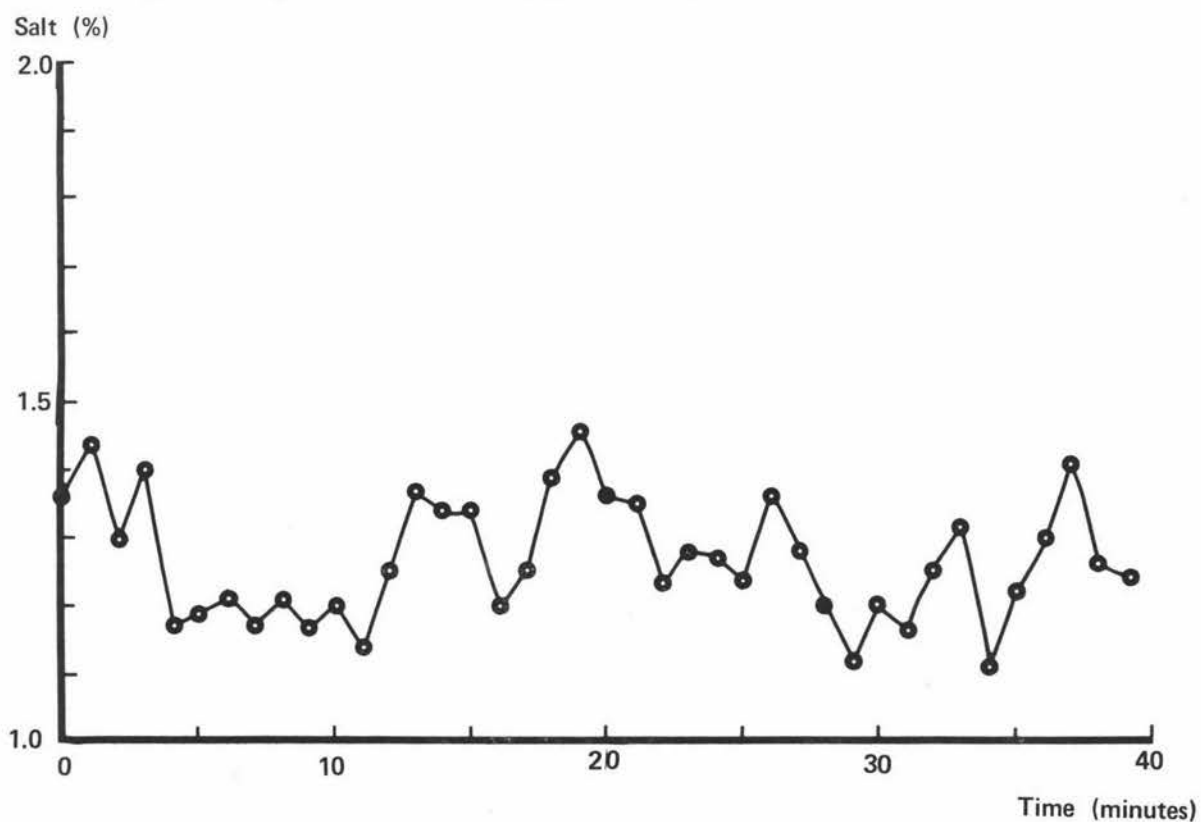


Fig. 10a. Moisture Cusum Chart (11/3/72)

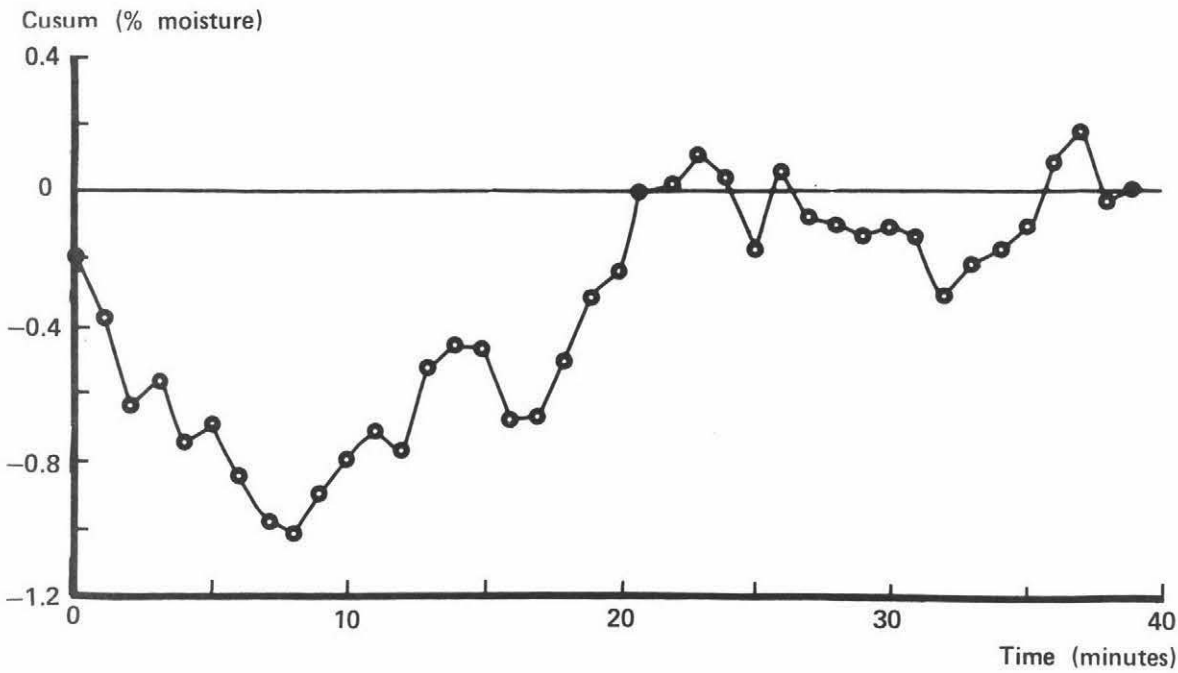
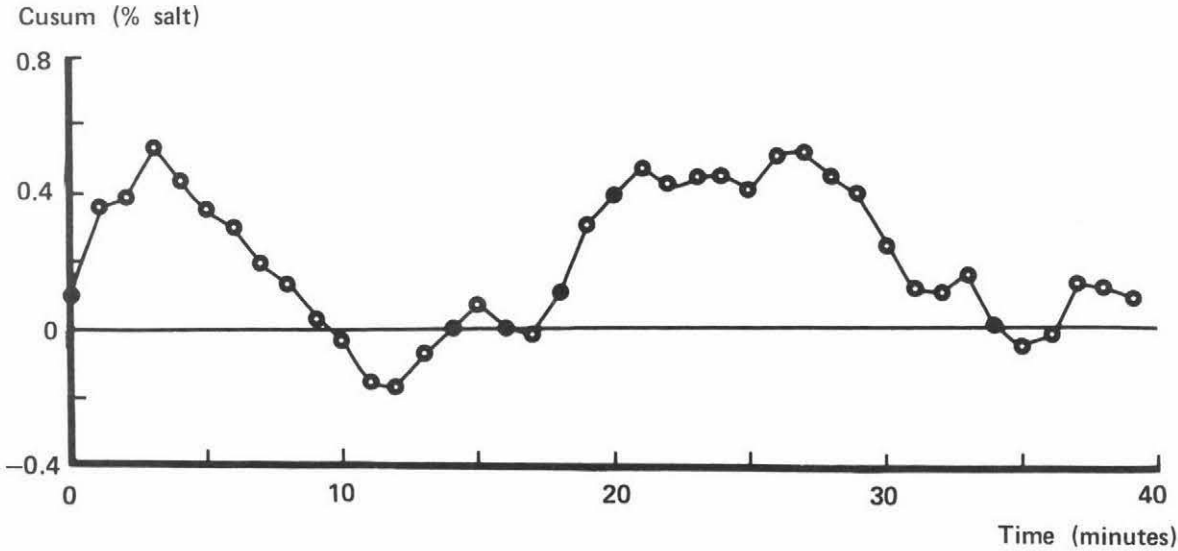


Fig. 10b. Salt Cusum Chart (11/3/72)



The quantity of slurry injected at any one time could be greater than that which can be effectively handled by the subsequent working and mixing process. Use of more than one injection section along the working section or earlier injection could contribute to a less variable product.

(2) Cusum charts for moisture and salt content reveal similar information to that discussed on the previous page. The sections of graph 12 minutes to 38 minutes are virtually identical in their pattern. This again indicates strong correlation between moisture and salt content, with minimal external disturbances upsetting this relationship.

Trial C (6/4/72)

Forty samples were taken at one minute intervals and analysed in the normal manner.

Figs. 11a, 11b (page 58) show the results presented in graphs of Moisture and Salt Content vs. Time.

Fig. 12 (page 59) shows a graph of Moisture Content vs. Salt Content for the trial.

Figs. 13a, 13b (page 60) show the Moisture and Salt Cusum Charts.

Discussion of Results

(1) The results of this trial are of particular interest because of the marked change in moisture values which has occurred at the time of 18 minutes. The moisture-salt correlation if calculated for the whole run is not significant, but on separation of the two portions of the graph, the correlation for each section is highly significant.

This is an important example of a 'step change' in the processing conditions. In this trial, the step change resulted from changes in process control settings. An increase in the cream flow rate was made and at the same time the primary churn speed was increased. The increase in churn speed more than compensated for the increase in flow rate and resulted in a rise in the moisture content of the product. This was independent of the salt content.

Fig. 11a. Graph of Moisture Content (%) vs Time (minutes) (6/4/72)

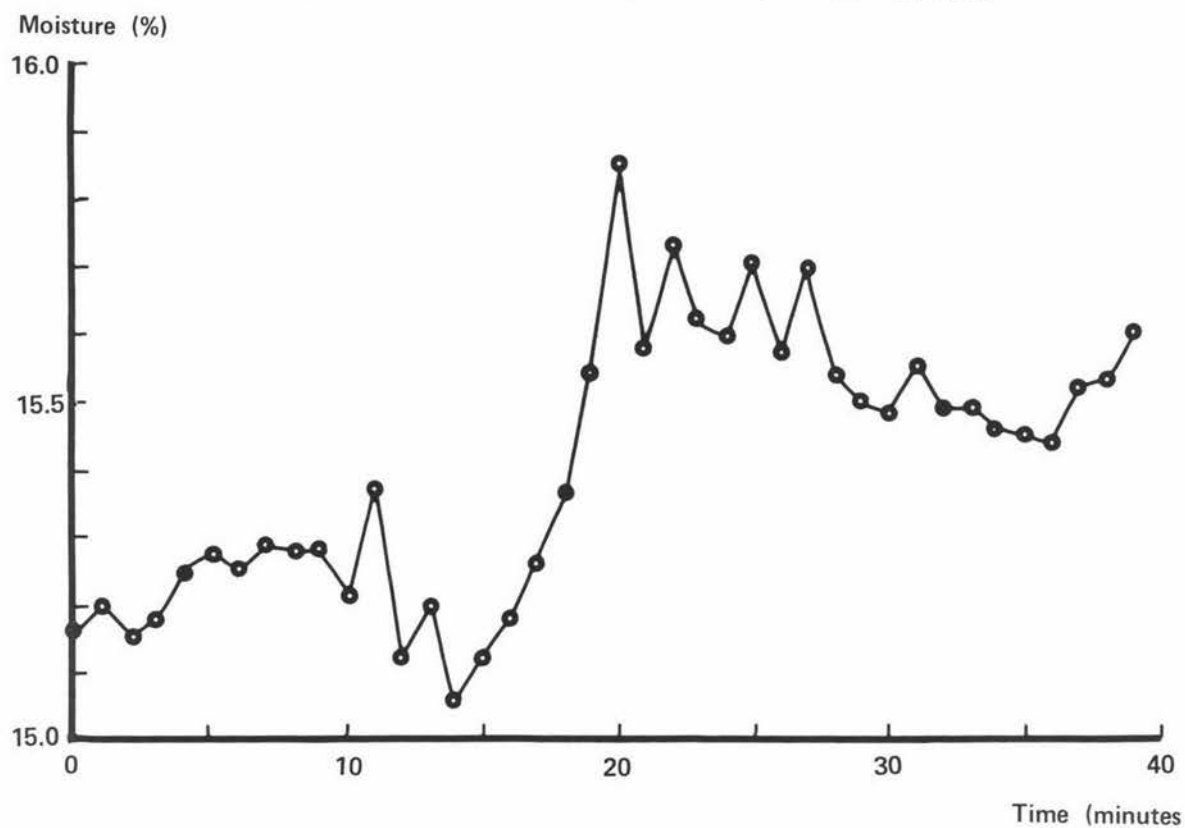


Fig. 11b. Graph of Salt Content (%) vs Time (minutes) (6/4/72)

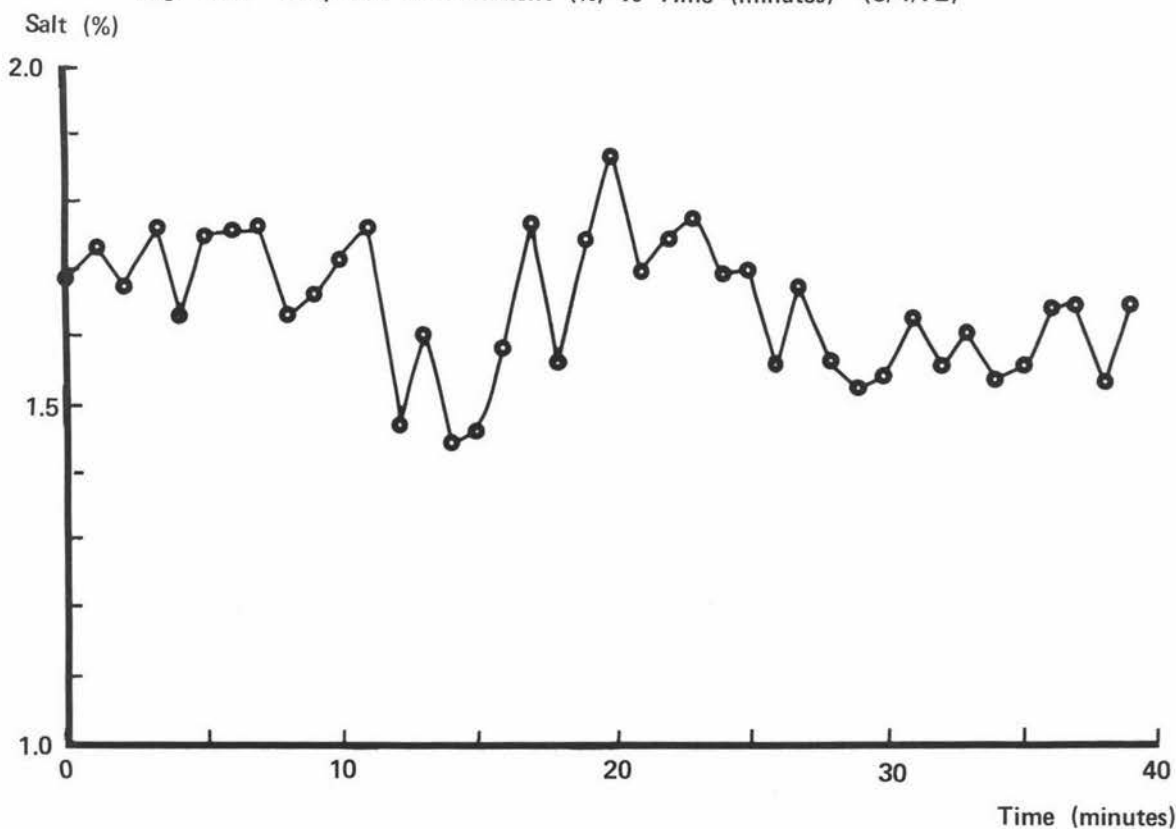


Fig. 12. Graph of Moisture Content (%) vs Salt Content (%) (6/4/72)

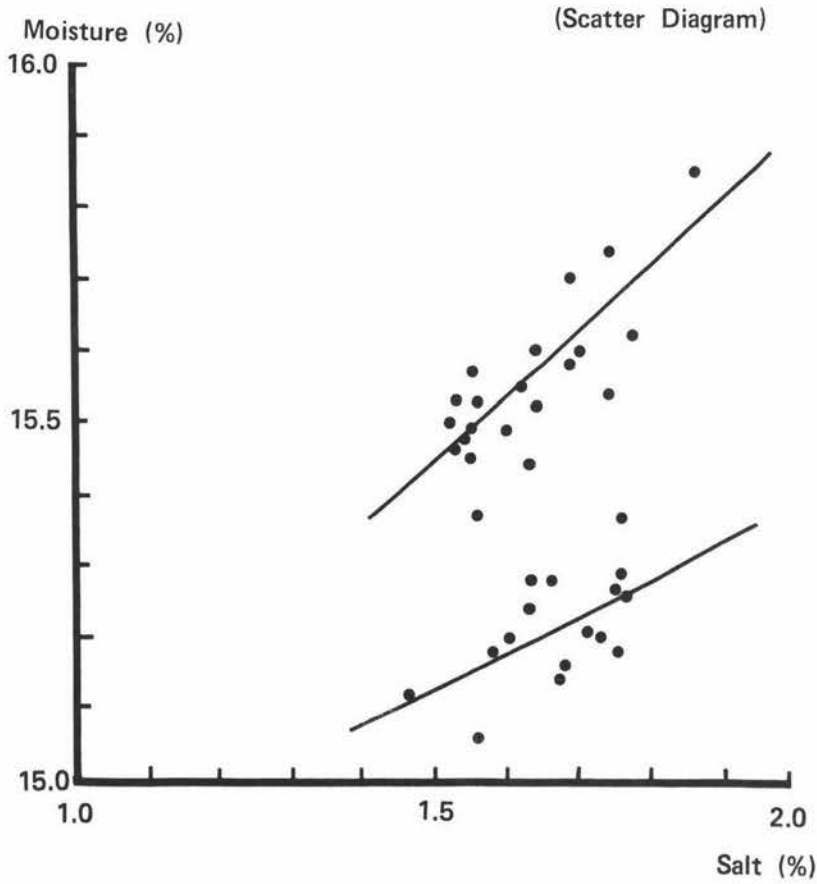


Fig. 13a. Moisture Cusum Chart (6/4/72)

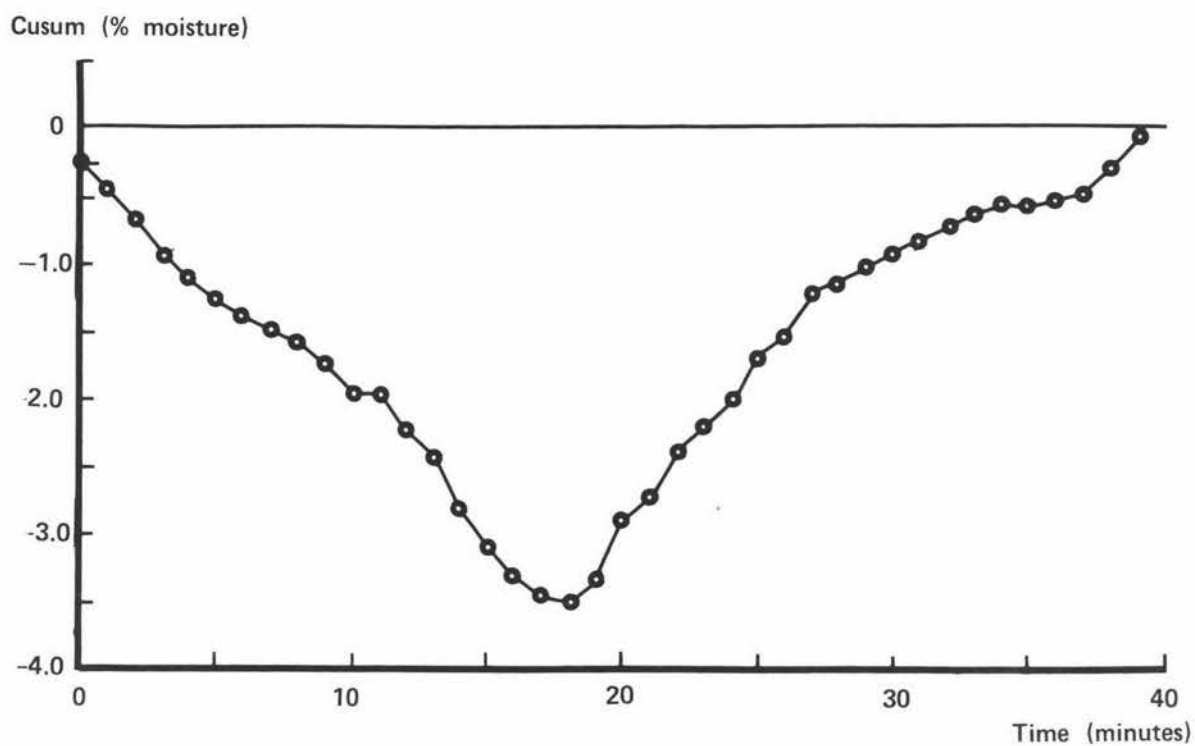
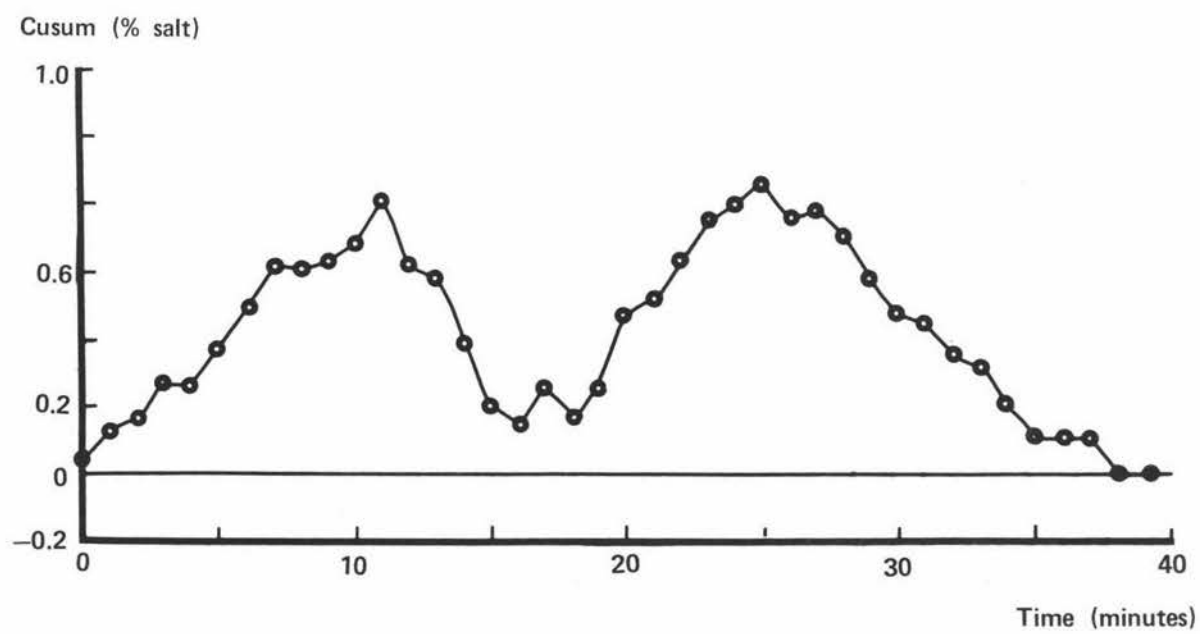


Fig. 13b. Salt Cusum Chart (6/4/72)



(2) A graph of Moisture Content vs. Salt Content was drawn. Two distinct portions exist and two separate regression lines may be drawn through the plotted points. This distinction reflects the two moisture levels.

(3) The cusum chart of Trial C also shows this very distinct change in mean moisture value at 18 minutes. In this moisture chart it is clearly seen that a significant change in slope has occurred at 18 minutes. Subsequent to this change the chart tends to flatten out after 28 minutes indicating a slight decrease in the process mean.

The salt cusum chart shows a more variable pattern, having several short term changes in mean value.

However, it is important to see that although the main factor affecting moisture content at this time is an overriding effect, the lesser variation in salt content is still reflected in the moisture cusum chart.

At 13 - 14 minutes, the salt level drops quite markedly, at this point also a slight change in slope is seen in the moisture cusum, a sympathetic change.

Similarly, the moisture and salt cusum charts show a change in mean at 18 minutes, but the magnitude of the moisture change precludes salt injection from being the sole causative factor. However, the salt mean changes again at 28 minutes and this is reflected as a slight change in slope also in the moisture cusum.

The Comparative Magnitude of Moisture and Salt Variation

The relative magnitude of changes in the moisture content and salt content is important in examination of the relationship between these two variables.

The salt slurry used during the experimental runs was composed of 60 part salt/40 parts water by weight. Thus assuming close association of the salt and water in the slurry a known ratio of salt and water is incorporated into the product. A variation in salt content should also be seen as a proportionate variation in moisture content if other factors do not interfere.

Likewise the standard deviation would be of similar order for both salt and moisture content as their ranges of variation would be comparable.

Inspection of results for Trial D (7/12/71) supports these facts. (See Table VIII (page 53)).

Figs. 14a, 14b (page 63) show the results presented in graphs of Moisture and Salt Content vs. Time.

Fig. 15 (page 64) shows a graph of Moisture Content vs. Salt Content for this trial.

Figs. 16a, 16b (page 65) show the Moisture and Salt Cusum Charts.

Proportional variation of Moisture and Salt values does occur, and the standard deviation of these factors is also similar indicating variations of approximately equal magnitude.

Moisture Mean	15.63 %	Salt Mean	1.54 %
Standard Deviation	0.16	Standard Deviation	0.14
Correlation Coefficient 'r' = 0.70 n = 60			

If, for example, there was complete interdependence between moisture and salt content the correlation coefficient would approach a value of 1.0 and the proportionate variation would apply in all changes of salt content and its dependent variable, moisture content.

Fig. 14a. Graph of Moisture Content (%) vs Time (minutes) (7/12/71)

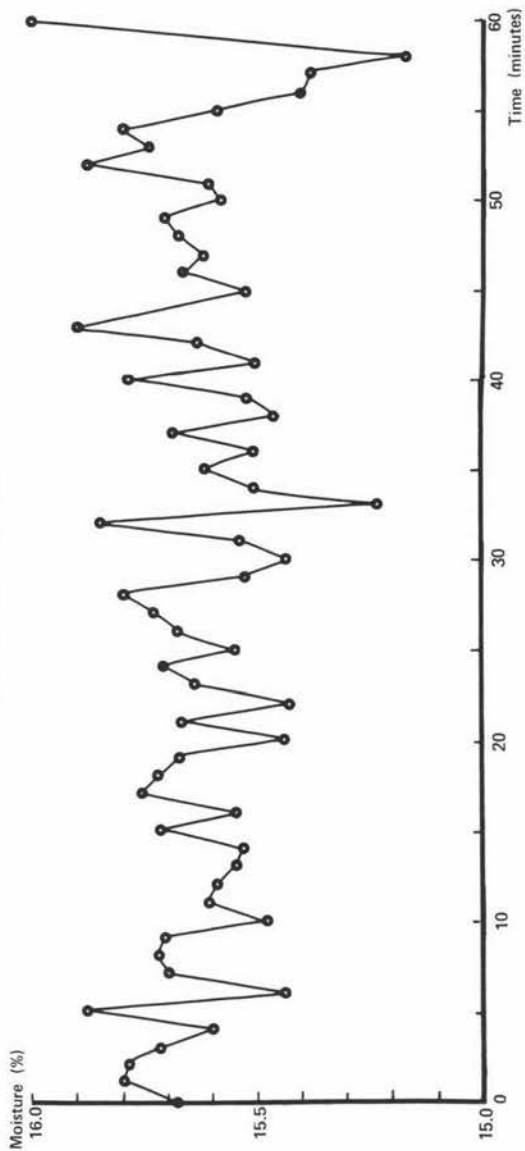


Fig. 14b. Graph of Salt Content (%) vs Time (minutes) (7/12/71)

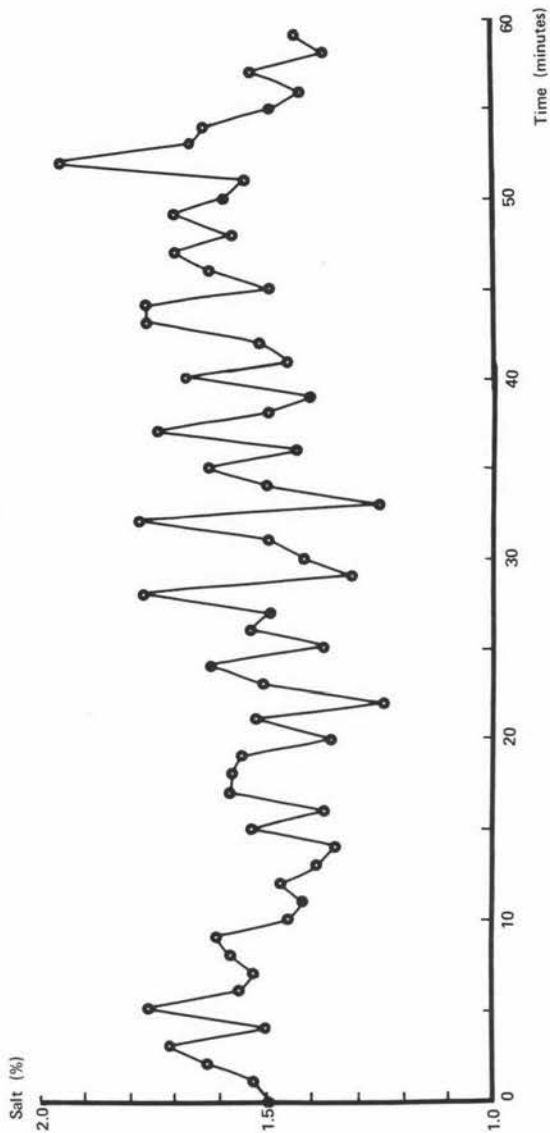


Fig. 15. Graph of Moisture Content (%) vs Salt Content (%) (7/12/71)

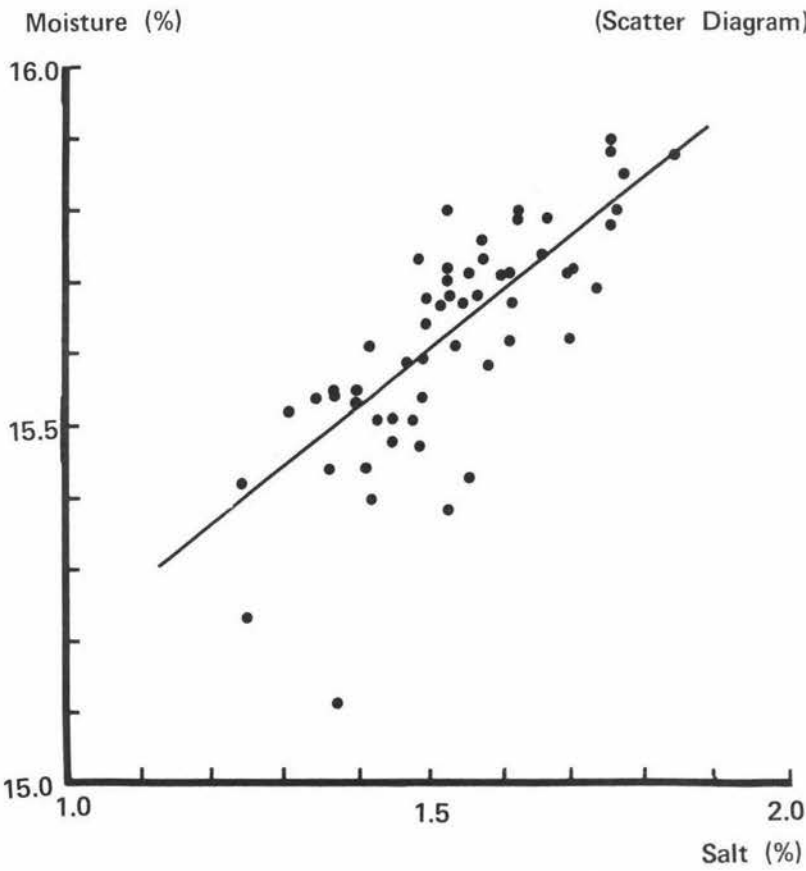


Fig. 16a. Moisture Cusum Chart (7/12/71)

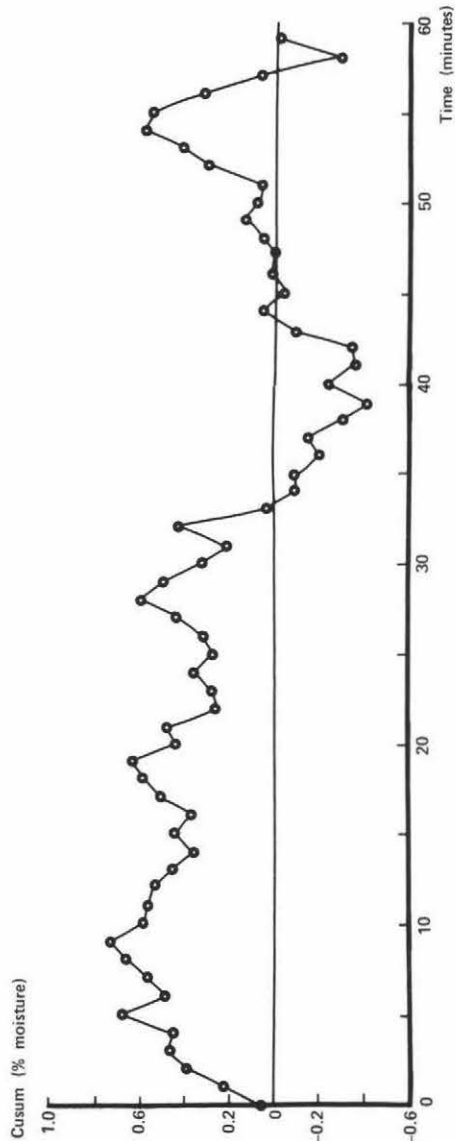
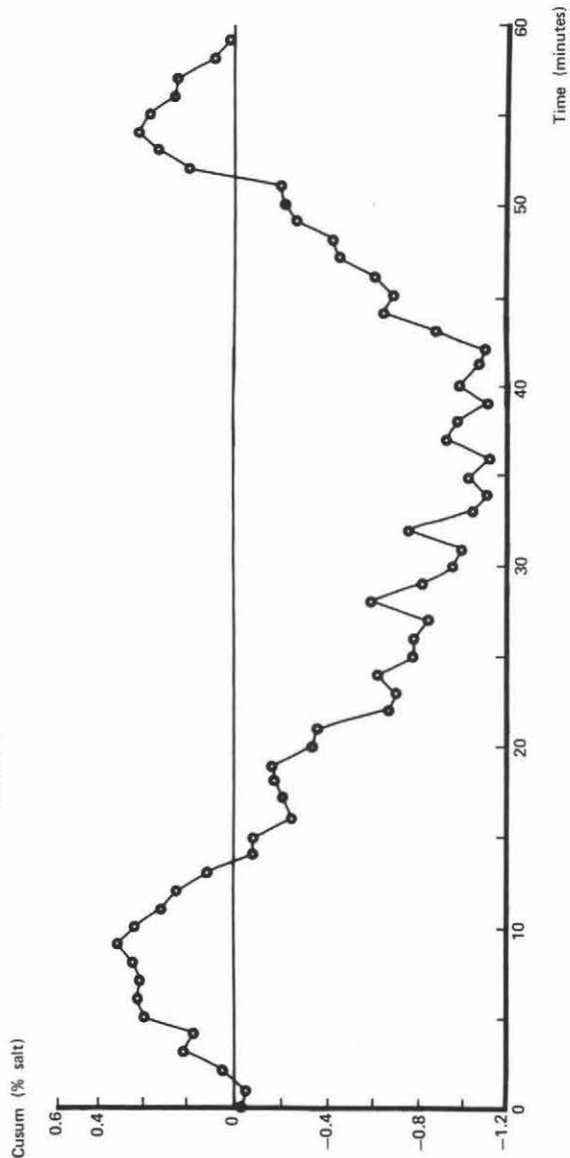


Fig. 16b. Salt Cusum Chart (7/12/71)



The influence of overriding external factors weakens this relationship, the correlation coefficient is seen to lessen and expected proportionality is not present.

The graph of Moisture vs. Salt content also indicated a strong relationship. If a line is drawn through the cluster of points such that it approximates to the general trend it is seen that the slope of this line approaches 38° (a gradient of 0.80). The regression line calculated for this data was described by the equation

$$M = 0.79 S + 14.41 \quad \text{where } M = \text{butter moisture content (\%)} \\ S = \text{butter salt content (\%)}$$

0.79 - gradient of the line

14.41 - intercept on the y axis

For an ideal situation of total dependence of moisture on salt the gradient of this line should correspond to the ratio of water : salt in the slurry. For the slurry in use - having 60 parts salt : 40 parts water, by weight, the gradient should be $(40/60) = (2/3)$. This would result in a Moisture - Salt relationship such that

$$M = \frac{2}{3} S + C \quad \text{where } M = \text{butter moisture content (\%)} \\ S = \text{butter salt content (\%)}$$

C - a constant

In the practical situation the preciseness of this relationship does not exist, the interdependence is more varied, and the gradient of the scatter diagram deviates from the $\frac{2}{3}$ predicted. However, over the considerable number of samples selected, the comparative magnitude of variation, as seen in both the Scatter Diagram and the graphs of Moisture and Salt vs. Time; does in fact agree closely with theoretical predictions.

The cusum charts for moisture and salt show marked similarity. Trends and variations are in phase and in the same direction and do indeed have comparable magnitude.

Other trials runs may not show such strong relationship and this is likely to result from influences of other factors. With such external influences minimised, it is probable that the type of behaviour shown in these results would exist at all times.

It appears at this stage that reduction in the variability of the product can be achieved by improving the salt injection system.

EXPERIMENT V

An examination of salt injection pump performance.

Tests were conducted on a salt pump of similar design taken from the smaller MB 5 model. Results from the tests showed that:

The dosing volume of the pump varied with pressure required to pump the fluid. The pressure may be considered as two components

- (a) delivery pressure - at which the slurry is injected into the churn,
- (b) suction pressure - influenced by the level of slurry in the holding tank.

As the delivery was increased, or the level in the tank fell, the dosing volume dropped markedly. Now, as the machine operator is able to exert control on the slurry level in the tank, the main factor to be considered is the pressure within the working section - that which the pump must act against to deliver the dosing pulse. Thus the variation in the working section pressure will affect the dosing and so will also affect moisture and salt content of the product.

Note 6 Numerical results for this test are presented in Appendix IV.

An important corollary of the pump performance is that the Contimab machine incorporates a water dosing unit for fine control of moisture. Being the same type of diaphragm pump it is likely that this feature also gives rise to similar variations in its output under varying operating conditions. This could then accentuate or reinforce variation produced at the salt injection stage.

The factors which will affect the delivery pressure are determined by those within the working section:

- (i) volume of product in the worker - which is a product flow characteristic
- (ii) action of the screws within the worker, and the type of flow which the butter exhibits in the region of the slurry ingress.

It is possible that fluctuations in flow will result in fluctuations in pressure within the worker. An increased flow of cream will result in increased product in the worker. If this produces a greater pressure in the worker, then the slurry injected will be of a lower volume. This lower volume of slurry is then distributed throughout the increased weight of butter and must result in a lower moisture and salt content. It is a reinforced effect, a higher weight of butter receiving a lower dose of slurry.

The Frequency Distribution of Moisture and Salt Values

From approximately 200 samples analysed a frequency distribution was calculated for moisture and salt values. The distribution of these values showed similarity to the 'Normal Distribution'. Because of the capability of the operator to alter the process mean values of the butter composition, this is not a true normal distribution as a deterministic element is present. It is likely, however, that should a machine be run for some time without variation of the control factors, the compositional values would approximate to a normal distribution.

Table IX (page 69) gives the frequency distribution of the 194 results, which were taken from four trials.

Fig. 17 (page 70) gives a graphical presentation of these results in a histogram.

Calculation showed that the values did approximate to a normal distribution.

Note 7 Details of the calculation are presented in Appendix V.

TABLE IX

Data for the frequency distribution of Moisture and Salt values
taken from four trials. (25/11/71, 7/12/71, 21/12/71, 7/2/72)

Moisture Class	Frequency	Salt Class	Frequency
15.00 - 15.05	0	1.00 - 1.05	0
15.05 - 15.10	0	1.05 - 1.10	0
15.10 - 15.15	0	1.10 - 1.15	0
15.15 - 15.20	2	1.15 - 1.20	0
15.20 - 15.25	5	1.20 - 1.25	1
15.25 - 15.30	5	1.25 - 1.30	1
15.30 - 15.35	8	1.30 - 1.35	3
15.35 - 15.40	15	1.35 - 1.40	12
15.40 - 15.45	19	1.40 - 1.45	16
15.45 - 15.50	22	1.45 - 1.50	33
15.50 - 15.55	29	1.50 - 1.55	37
15.55 - 15.60	12	1.55 - 1.60	28
15.60 - 15.65	16	1.60 - 1.65	26
15.65 - 15.70	12	1.65 - 1.70	24
15.70 - 15.75	22	1.70 - 1.75	5
15.75 - 15.80	11	1.75 - 1.80	6
15.80 - 15.85	5	1.80 - 1.85	1
15.85 - 15.90	9	1.85 - 1.90	0
15.90 - 15.95	0	1.90 - 1.95	1
15.95 - 16.00	0	1.95 - 2.00	0
16.00 - 16.05	2	2.00 - 2.05	0
	194		194

Grand Mean = 15.58

Standard Deviation = 0.17

N = 194

Grand Mean = 1.57

Standard Deviation = 0.11

N = 194

Fig. 17a. Frequency Distribution Histogram for Moisture Values

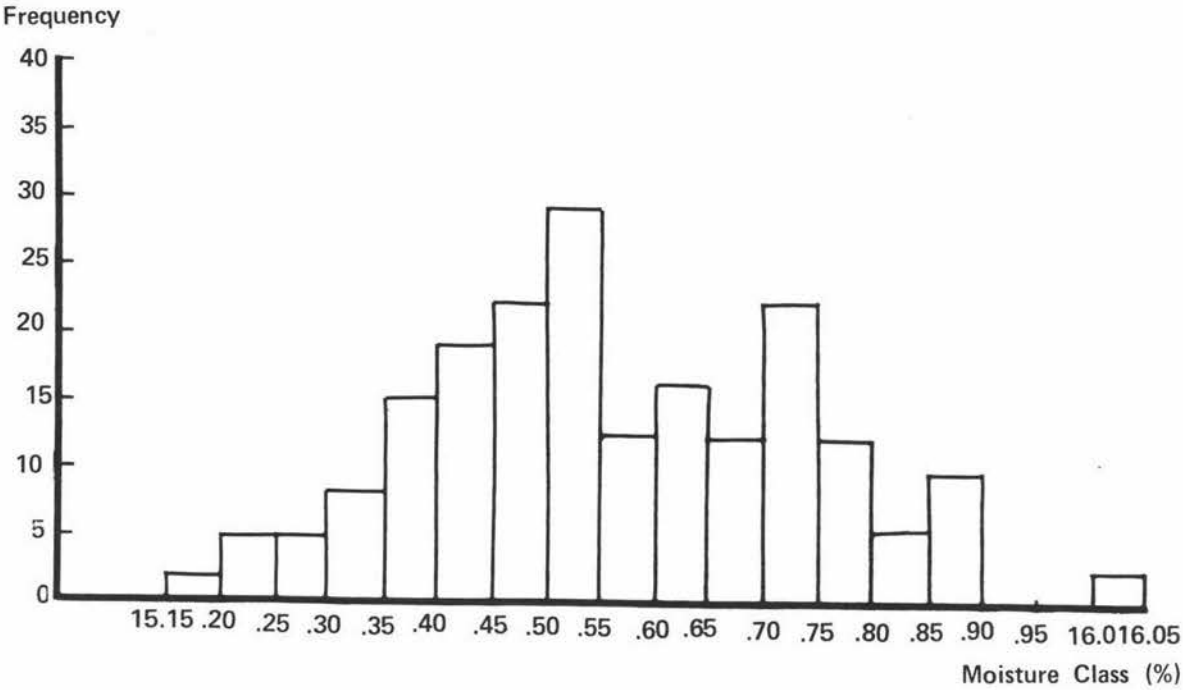
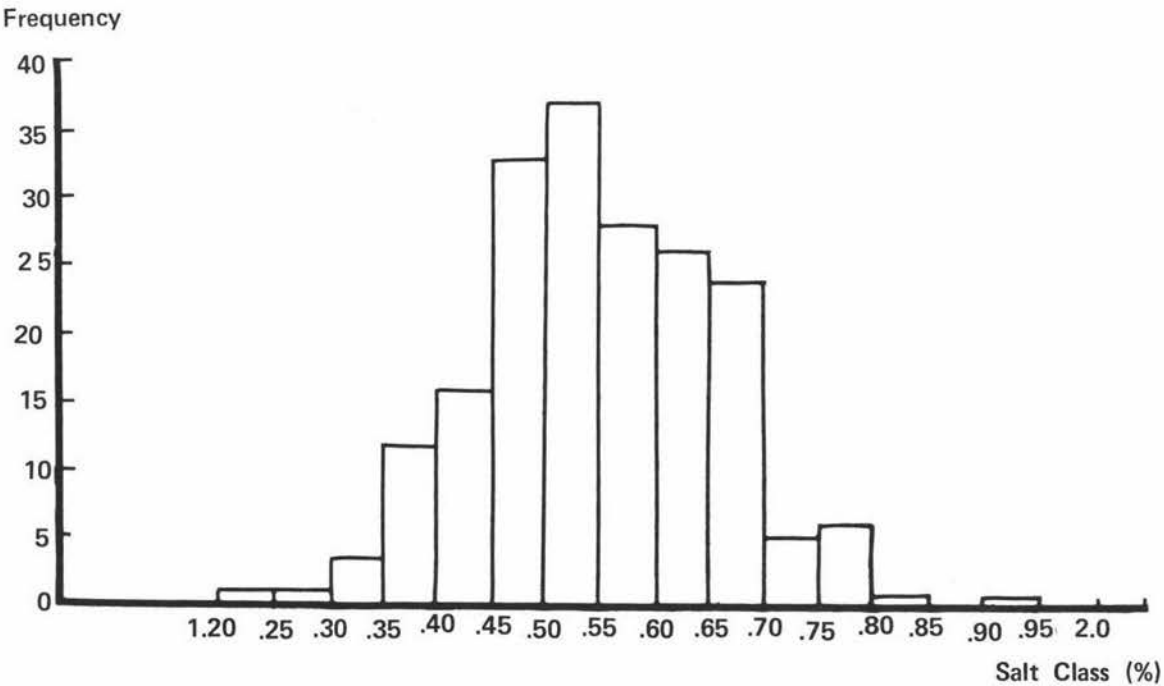


Fig. 17b. Frequency Distribution Histogram for Salt Values



Conclusions

Thus it is known that in the MC 30 machine:

(1) Variation in product composition is significant over time although the product at any one instant is of relatively even composition.

(2) The salt pump injection system has been shown to cause up to 74 % of the variation in moisture content. The remainder is a result of other factors.

(3) Installation of a positive displacement pump, one having a constant delivered volume which is independent of delivery pressure could cut down a portion of this variation. However, changes in volume flow will still influence the moisture and salt content - as the constant volume of slurry will be incorporated into a varying quantity of product.

The results also imply that present testing frequencies do not provide a good indication of process changes, as large variations in moisture and salt content can occur rapidly. The use of duplicate samples would reduce error and the application of statistical techniques such as control charts would assist in better process control.

SECTION IV AN INVESTIGATION OF SELECTED PROCESS VARIABLES

A definite relationship has been established between moisture and salt content. Variations in performance of the salt slurry injection system are considered to influence the moisture content. However, only a portion of the compositional variation can be attributed to this source, and so further investigatory work was initiated with the aim of assessing other possible sources of process variation.

The factors investigated were those considered to be a possible major source of variation in product composition. Owing to the complex nature of continuous butter manufacture a great many base factors and interacting factors of higher order could be sources of compositional variation. Because of the restricted time available for this investigation only a limited number of factors could be considered.

By comparing the patterns of variation of the selected variables, with those of the butter composition parameters it will be possible to determine if relationships do occur. From this information the type and strength of such a relationship may be determined.

A. Compositional Factors

Raw material or process factors which could influence butter moisture or salt content were studied. The possible range of values of the selected factors needed to be such that a real variation could be caused in the butter composition if the factor value was not steady.

The factors investigated were

- (1) Fat content of the cream
- (2) Temperature of the cream
- (3) Titratable acidity of the cream
- (4) Product flow rate
- (5) Pressure within the working section

These factors were investigated and then patterns of variation were compared with the characteristic moisture and salt variation. If a particular factor was seen to behave in a consistent manner with little variation, while over the same time period the moisture-salt variation was still present at its typical level, this factor was not considered

to be a prime source of product variation.

Cream Characteristics

Cream characteristics play an important role in continuous churning. The effects of variation in cream temperature, fat content and titratable acidity have been discussed in Section I and their quantitative influence has also been included.

In examining cream factors, it is important to determine if any sustained change in their value has occurred. Minor fluctuations of short duration are likely to have little effect on butter composition because of the system's 'capacitance' which will tend to exert a 'damping' effect. A change of duration e.g. greater than 30 seconds may begin to have an important effect on churning. A sustained step change in the level of a cream factor will cause a change in the process and this will be reflected in the product composition. Similarly, cycling of these variables will result in cycling of the product composition factors, if the cycle has sufficient amplitude and time period. The causes of variation in cream characteristics may be rather complex, some basic causes will be discussed briefly.

Cream Temperature

Variations in cream temperature may be initiated at a number of points in the process. Defective or faulty operations may themselves initiate temperature variations or sustain those variations already present.

Faulty cooling after cream vacreation may give rise to temperature change. However, these variations are not likely to be sustained unless subsequent operations during cream holding are faulty.

Temperature variation may be caused during the holding period in the vat prior to churning. Inoperative, or inadequate agitation may allow stratification of the cream. The subsequent cooling operation to compensate for the latent heat of crystallisation may not be evenly applied. In addition, regions near the cooling surface may drop in temperature more rapidly and this cream will increase in viscosity resulting in reduced heat transfer to the bulk of the cream. If this

occurs uneven cooling is also likely to result. Not only may the final cream temperature be variable if uneven cooling occurs, but the nature of the fat may vary due to differing treatment applied to that fat. This is also likely to contribute to variable churning properties.

Cream Fat Content

A major cause of variation in cream fat content is the stratification which results from faulty agitation. In addition regions close to the cooling surface may also have compositional differences if compared with the bulk cream. Adequate cream agitation should minimise this source of variation.

Titratable Acidity

Variations in titratable acidity of the cream may be the result of defective operation of the neutralising unit if automatic control is used. Batch neutralisation can give rise to variation in acidity of the cream, but in both cases adequate agitation should preclude variation.

Trial D (7/2/72)Temperature of the CreamProcedure

The cream temperature was measured at the balance tank prior to the mono-pump. A Copper-Constantan thermocouple was inserted through a section of stainless steel tubing which was placed down the side of the balance tank into the centre of the pipe opening which led to the cream pump.

An ice junction was used as the reference temperature and the output voltage was recorded on a Varian Continuous Chart Recorder, Model G-15-1.

Scale range - 1 mv

Chart speed - 1"/2.5 minutes

The cream temperature was recorded over a period of 5 hours 25 minutes, commencing at startup of production and running during processing of the first vat and also during the first 30 minutes of use of the second vat. During a selected portion of the temperature measurement run 40 samples of cream and butter were taken at one minute intervals.

Results

Fig. 18 (page 76) shows the graph of Scale Response of Temperature vs. Time for cream flowing through the balance tank during the period in which cream and butter samples were taken.

It has been shown in the Calibration of the Varian Recorder that the Response (Scale reading) is directly proportional to the temperature. Thus the graph (Fig. 18) is in effect a graph of Temperature vs. Time.

From the time-temperature relationship it is seen that during the period in which butter and cream samples were taken the cream temperature was constant.

Scale reading = 48.5 ± 0.5 units

Temperature = $54^{\circ}\text{F} \pm 0.3^{\circ}\text{F}$

Thus variation occurring in the product parameters of moisture and salt content may not be attributed to variation in cream temperature for this run.

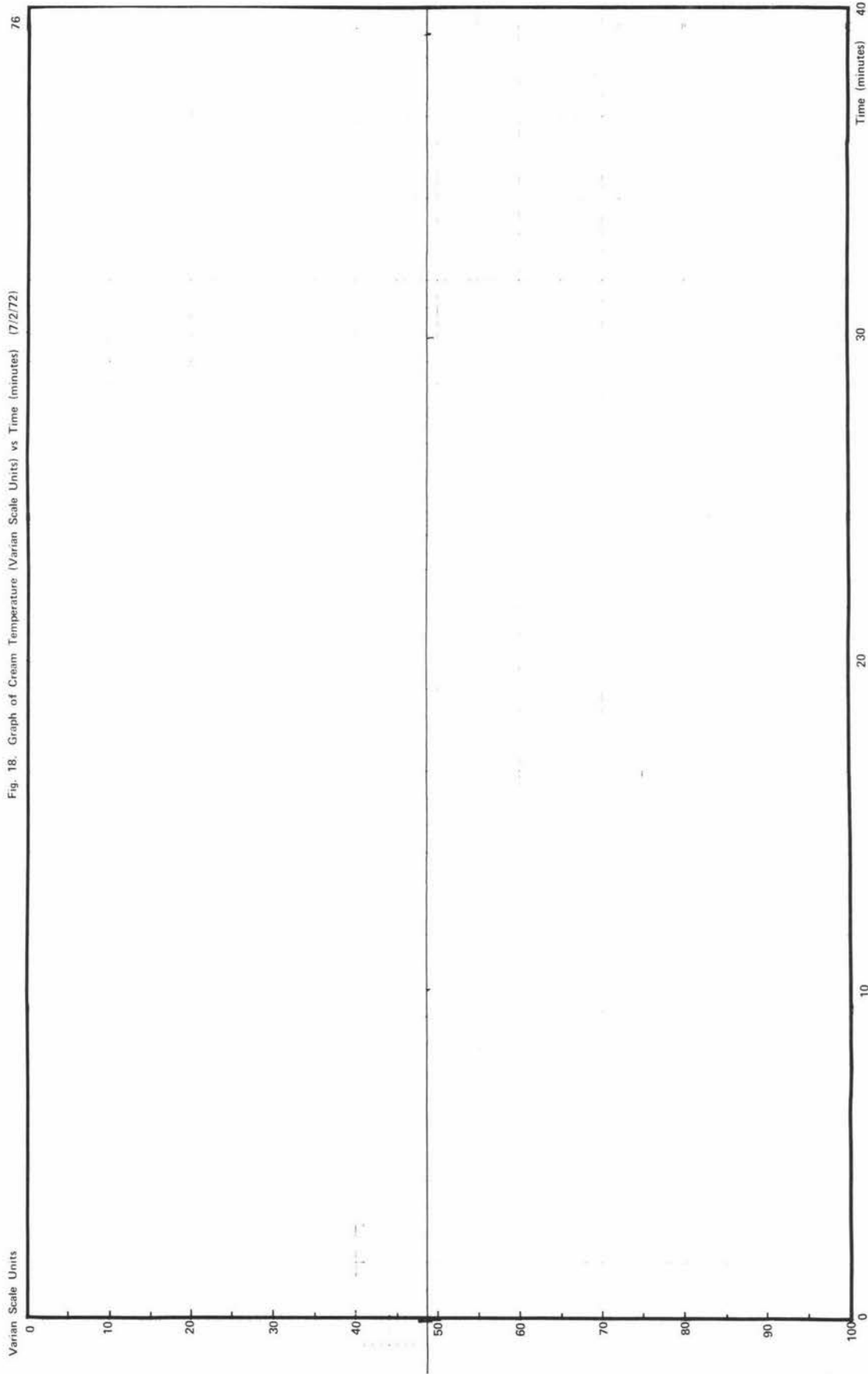


Fig. 18. Graph of Cream Temperature (Varian Scale Units) vs Time (minutes) (7/2/72)

Fig. 19a. Graph of Moisture Content (%) vs Time (minutes) (7/2/72)

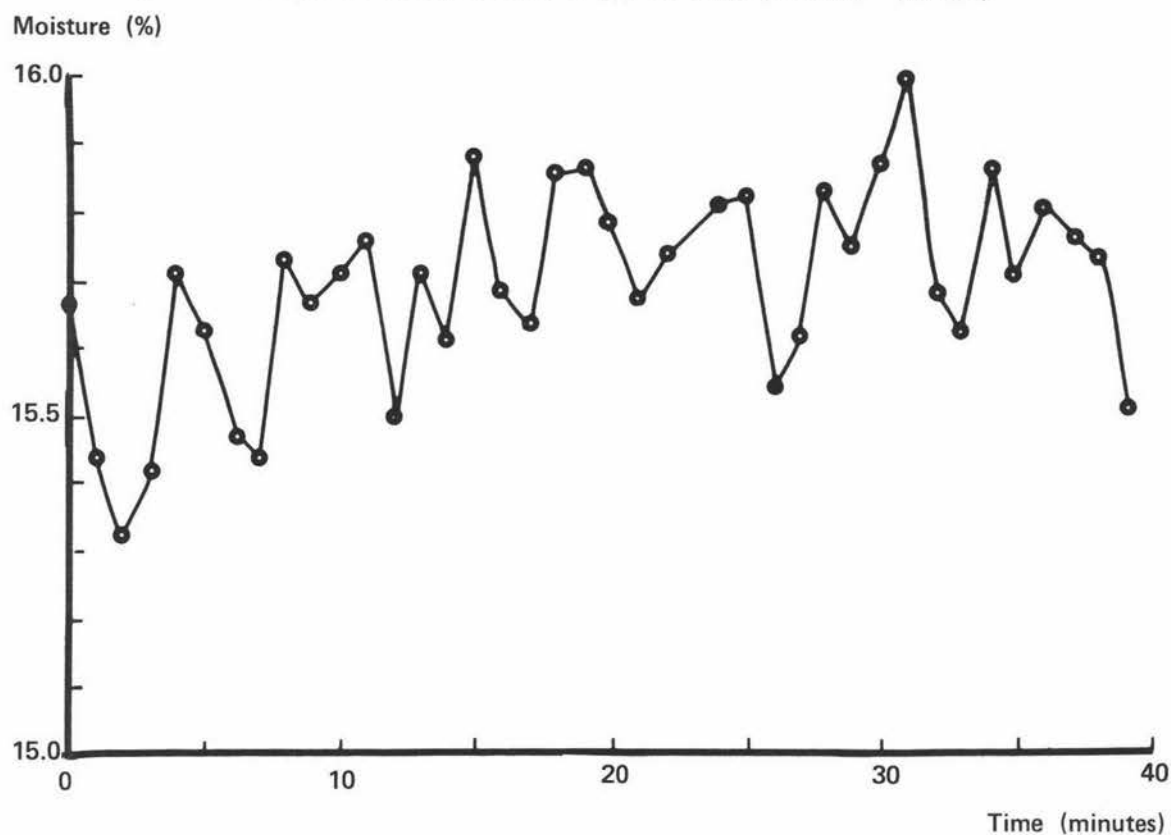
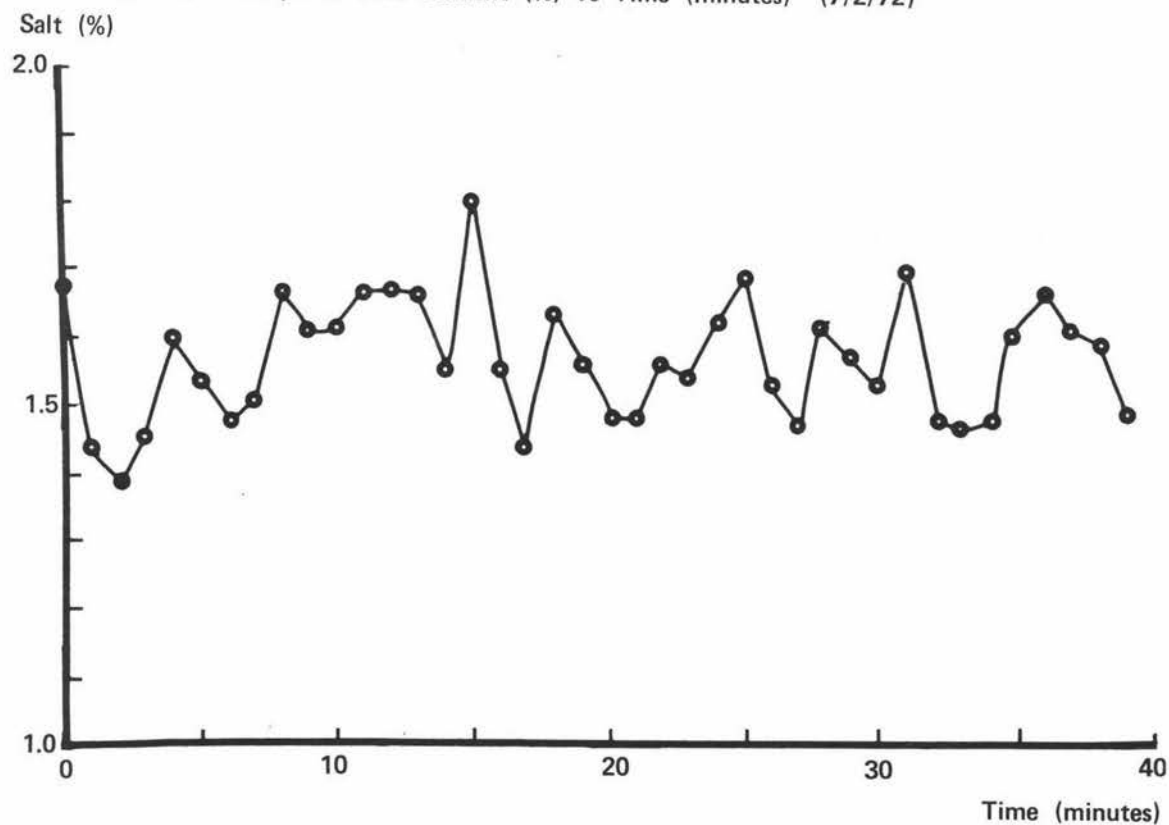


Fig. 19b. Graph of Salt Content (%) vs Time (minutes) (7/2/72)



Figs. 19a, 19b (page 77) show the results presented as graphs of Moisture and Salt Content vs. Time. These samples were taken during the stated period in the cream temperature time trial.

It is seen that the characteristic variation of moisture and salt content still occurred. A significant correlation ' r ' = 0.58 was calculated for the data.

Moisture Mean	= 15.69 %	Salt Mean	= 1.56 %
Standard Deviation	= 0.15	Standard Deviation	= 0.09

Although cream temperature can give rise to variation in product composition, as shown previously, the characteristic moisture and salt variation has still occurred even when cream temperature is stable. Thus it would seem that cream temperature is not one of the major variables being sought which gives rise to the characteristic process variation.

Description of Cream Temperature Graph

The time-temperature graph during the run shows little fluctuation in cream temperature. Some variation is seen as a direct result of flow alterations, vat changes and similar operator intervention. These variations are of short duration and small magnitude. Thus they will tend to have only a minimal influence on the process.

Generally cream temperature is seen to be stable and would not appear to be a major source of process variation.

Trial E (7/2/72)Fat Content of the CreamProcedure

The cream was sampled at the balance tank prior to the cream pump (Fig. 2 (page 17)). This position was chosen because of the relative ease in obtaining samples. Sampling at any other position could have required modification to the pipe layout. In addition, consideration of the mixing occurring in the balance tank and cream pump showed that sampling prior to the balance tank would not provide cream representative of that flowing to the continuous churn.

The cream was removed at one minute intervals from the balance tank and put into screw top bottles. The samples were refrigerated until analysed. The Babcock cream testing procedure was used and duplicate fat analyses were carried out on each cream sample. The sample volume taken was 150 mls. By using a relatively large volume it is hoped that errors due to sampling of non-homogeneous substances are minimised. The mean value of the duplicate Babcock results was calculated.

It is known that the moisture content of butter can be altered if a significant change in the fat content occurs. To determine if a relationship existed between variations in the fat content of cream and the moisture content of the butter a correlation coefficient was calculated for the two time series of results. However, because of the capacitance of the system, a time delay will be experienced between the times of sampling the cream, and the butter which is manufactured from that cream. The time delay may be considered as the sum of four components:

- (i) Time taken between sampling of cream and the exit of that cream from the balance tank.
- (ii) Time taken for the cream to pass to the mono-pump and then into the primary churn.
- (iii) The time elapsed between entry of the cream to the churn and its extrusion as the product.
- (iv) The time taken for transport of the butter down the chute to the sampling location.

Calculation of the Time Delay

Conditions assumed:

$$\begin{aligned}
 \text{Churn Capacity} &= 9000 \text{ lb/hr butter} \\
 \text{Cre Cream} &= 40 \% \text{ fat} \\
 \text{Butter Composition} &- 15.8 \% \text{ Moisture} \\
 &- 1.5 \% \text{ Salt} \\
 &- 1.2 \% \text{ Curd}
 \end{aligned}$$

$$\begin{aligned}
 \text{Approximate quantity of butter} \\
 \text{in churn (capacity)} &= 350 \text{ lb} \\
 \text{Specific Gravity Cream (40\% fat)} &= 0.995 \quad (31) \\
 &\approx 1.0
 \end{aligned}$$

(i) Residence time in balance tank

Fig. 2 (page 17) shows a diagram of the balance tank and the dimensions are included.

$$\begin{aligned}
 \text{Diameter of balance tank} &= 2 \text{ feet} \\
 \text{Height of balance tank} &= 1.5 \text{ feet} \\
 \text{Volume of balance tank} &= \frac{\pi D^2 h}{4} \\
 &= \frac{\pi \cdot 2^2 \cdot (1.5)}{4} \text{ ft}^3 \\
 &= 4.7 \text{ ft}^3
 \end{aligned}$$

$$\text{Cream Capacity} = 295 \text{ lb}$$

Now cream 40 % fat100 lb cream \rightarrow 40 lb butter fat

$$\begin{aligned}
 \text{Added Moisture} + \text{Salt} + \text{Curd} &= 18.5 \% \text{ of the total butter} \\
 \rightarrow 40 \text{ lb butter fat} &= 81.5 \% \text{ of the total butter}
 \end{aligned}$$

Thus butter produced from

$$\begin{aligned}
 100 \text{ lb cream} &= 40 \times \frac{100}{81.5} \text{ lb} \\
 &= 49 \text{ lb}
 \end{aligned}$$

Thus 1 unit of butter requires 2 units of cream by weight

$$\begin{aligned}
 \text{Now butter flow} &= 9000 \text{ lb/hr} \\
 &= 9000 \frac{\text{lb}}{\text{hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} \\
 &= 150 \text{ lb/minute}
 \end{aligned}$$

Thus cream required to produce

$$\begin{aligned}
 \text{this butter} &= 150 \text{ lb/hr butter} \times \frac{2 \text{ units cream}}{1 \text{ unit butter}} \\
 &= 300 \text{ lb/minute}
 \end{aligned}$$

Thus capacity of balance tank = 300 lb
 Flow of cream through balance tank = 300 lb/minute
 Thus average cream residence time = 1 minute

(ii) Residence time in pipe line between balance tank and churn

$$\begin{aligned}
 \text{Length of pipe} &= 33 \text{ feet} \\
 \text{Diameter of pipe} &= 2 \text{ inches} \\
 \text{Area of pipe} &= \frac{\pi 2^2}{4} \text{ square inches} \\
 &= \left(\frac{\pi 2^2}{4} \right) \text{ inches}^2 \times \left(\frac{1 \text{ ft}^2}{144 \text{ in}^2} \right) \\
 &= \left(\frac{3.14}{144} \right) \text{ ft}^2 \\
 \text{Flow through pipe} &= 300 \text{ lb/min} \\
 \text{Cream specific weight} &= \left(62.4 \frac{\text{lb}}{\text{ft}^3} \right) \times 0.995 \\
 &= \left(300 \frac{\text{lb}}{\text{min}} \right) \times \left(\frac{1}{(62.4 \times 0.995) \text{ lb}} \text{ ft}^3 \right) \\
 &= 4.8 \text{ ft}^3/\text{min} \\
 \text{Since velocity of flow} &= \frac{\text{Flow rate}}{\text{Area of flow}} \\
 \text{The velocity in pipe} &= \left(4.8 \frac{\text{ft}^3}{\text{min}} \right) \times \left(\frac{1 \text{ min}}{60 \text{ sec}} \right) \times \left(\frac{144}{3.14} \frac{1}{\text{ft}^2} \right) \\
 &= 3.7 \text{ ft/sec} \\
 \text{Length of pipe} &= 33 \text{ ft} \\
 \text{Residence time in pipe} &= (33 \text{ ft}) \times \left(\frac{1 \text{ sec}}{3.7 \text{ ft}} \right) \\
 &= \underline{9 \text{ seconds}} \quad \quad \quad (\text{ii})
 \end{aligned}$$

(iii) Residence time in churn

The assumption is made that the butter exhibits plug flow in the churn.

Primary Churn

It is not possible to calculate the residence time for this section, as the proportion of the primary churn which is filled is unknown. An estimate was made from a trial, of the time taken to travel through the line from the balance tank and through the primary churn.

Estimated time = 12 seconds

With a full line this time may be increased:

Time allowed = 15 seconds (inclusive of (ii))

Working section

It was estimated that the working section contained 150-180 lb of butter.

Now as butter production = 150 lb/min

Then the working section residence time is approximately 1 minute.

(iv) Time taken to travel down the chute to position of sampling

Length of chute travelled = 9 feet

Speed of butter = 2 inches/sec

→ Time of travel = 54 seconds

Thus total time delay between sampling of cream and sampling of the related butter:-

Time - Cream balance tank = 1 minute

Pipe line and primary churn = 0.25 minutes

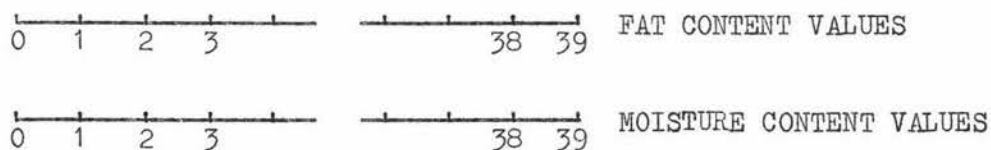
Working section = 1 minute

Chute travel = 1 minute

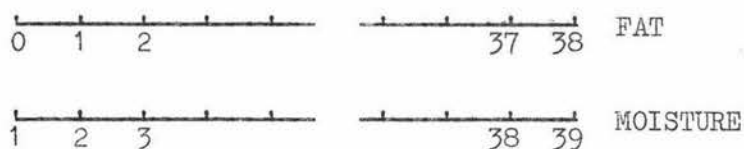
Total time = 3.25 minutes

Calculation of the Correlation Coefficient

Consider if no time delay existed between the series of fat values and the series of moisture values. The correlation coefficient would be calculated from these two time series.



If a time delay of 1 minute existed then as the moisture content is the variable which lags, we would then compare the second moisture value with the first fat value, since the butter moisture value would be dependent on the cream sample taken one minute earlier. Similarly, the 2, 3, 4, ... 38 minute values for fat content are compared with the 3, 4, 5, ... 39 minute values for moisture.



The moisture series is in effect displaced by 1 time unit relative to the fat series. The direction of displacement is such that it compensates for the time delay occurring in the system.

This displacement procedure may be continued to any desired level. It should be noted that as each displacement is effected, the sample size for calculation of the correlation coefficient is reduced by one. It is important that the true sample size be considered in determination of statistical significance. If a relationship does exist between the two variables then a significant correlation coefficient will be found. A maximum value of the correlation coefficient should occur at the displacement level where the two series have been matched correctly - that is when the system time delay has been fully compensated. If the time delay is not an integral number of minutes then it is possible that more than one significant correlation coefficient may occur, at either side of the true value.

By determining a series of correlation coefficients for successive displacement values of the two series it is possible to:

- (1) determine the extent of relationship between moisture content variation and cream fat content variation - if such a relationship exists
- (2) determine the average time delay occurring between the sampling of the cream and butter. In this way the residence time in the churn can be found from data obtained during operation of the machine.

Procedure

40 samples of cream and butter were taken at one minute intervals and these were analysed for the relevant factors. A correlation analysis was carried out on the butter moisture and cream fat values, a displacement analysis was used.

Fig. 20a (page 85) shows the graph of Fat Content vs. Time for the trial.

Table X (page 86) shows the results from the Correlation analysis.

Discussion of Results

It was shown in the previous discussion that in general, an increase in cream fat content causes an increase in the moisture content of butter, and thus a positive correlation coefficient is expected if a relationship exists between these two variables.

From the tabulated results (Table X), three values are statistically significant - at 1, 9, 16 minutes displacement. The 9 minute displacement value is significant to the 0.01 level of confidence, but the correlation coefficient is negative, and this is contrary to the expected result. The coefficients at 1, 16 minutes are positive, which conforms with the theoretical result but they are less significant, a confidence level of 0.10. However, none of these results is in the region of the predicted delay time, although this may be due to incorrect assumptions in the calculation of the delay time.

Table XI (page 87), gives a summary of significant results obtained during three experimental runs. The methods of sampling and analysis were identical for each trial.

Results from another trial (6/4/72), are presented as a whole, then as two separate sections. (This is similar to their treatment when moisture/salt relationships were being considered and is due to the distinct moisture levels occurring during the run.)

The results presented in Table XI do not show a definite trend or relationship between moisture and fat values. The displacement values

Fig. 20a. Graph of Cream Fat Content (%) vs Time (minutes) (7/2/72)

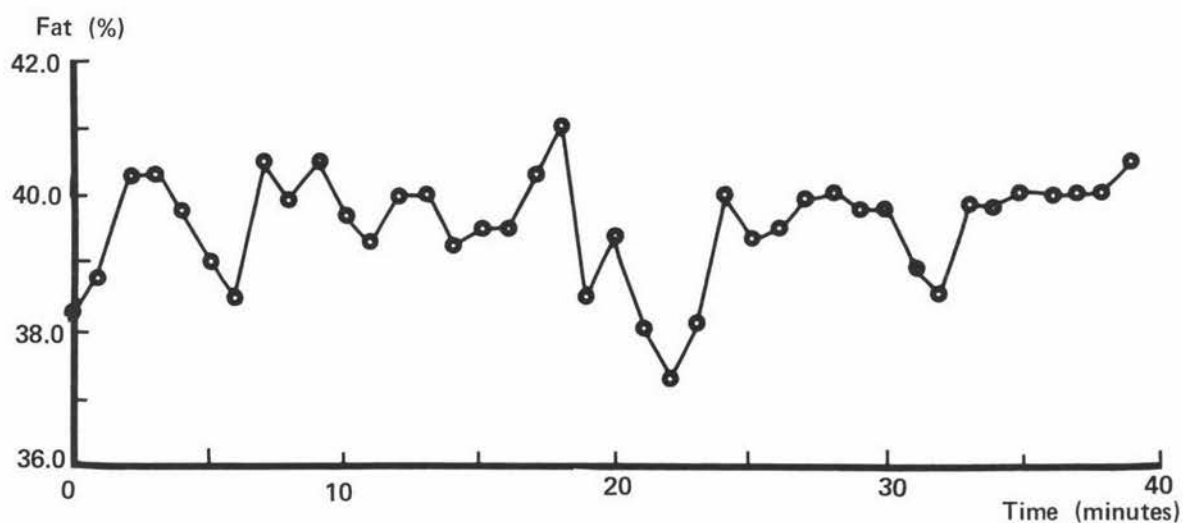


Fig. 20b. Graph of Cream Acidity (% Lactic Acid) vs Time (minutes) (6/4/72)

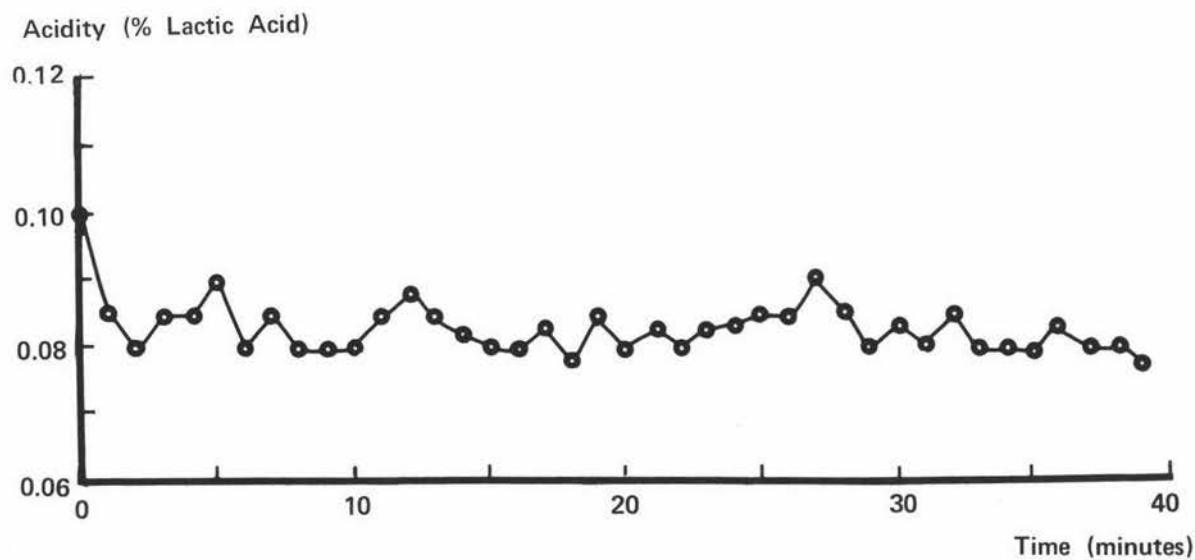


TABLE X

RESULTS OF THE CORRELATION COEFFICIENT BETWEEN
VALUES OF CREAM FAT CONTENT (%) AND BUTTER MOISTURE CONTENT (%)
FOR SUCCESSIVE VALUES OF SERIES DISPLACEMENT

Trial (7/2/72)

Butter Moisture Content Mean (%) 15.69

Standard Deviation 0.15

Cream Fat Content Mean (%) 39.5

Standard Deviation 0.8

DISPLACEMENT VALUE	CORRELATION COEFFICIENT	SAMPLE SIZE	LEVEL OF SIGNIFICANCE
0	-0.149	40	0.10
1	0.261	39	
2	0.119	38	
3	-0.072	37	
4	-0.042	36	
5	-0.071	35	
6	0.210	34	
7	0.253	33	0.01
8	-0.159	32	
9	-0.484	31	
10	-0.093	30	
11	0.132	29	
12	0.083	28	
13	0.123	27	
14	-0.098	26	
15	-0.189	25	
16	0.365	24	
17	0.237	23	
18	0.069	22	
19	-0.201	21	
20	0.114	20	

TABLE XI

SUMMARY OF RESULTS FOR THE CORRELATION COEFFICIENT
BETWEEN BUTTER MOISTURE CONTENT AND CREAM FAT CONTENT

Date	Sample Size (n)	Displacement Value	r	Significance Level	Moisture Mean (%)	Moisture Standard Deviation	Fat Mean (%)	Fat Standard Deviation
7/2/72	40	1	0.26	0.10	15.69	0.15	39.5	0.81
		9	-0.48	0.01				
		16	0.36	0.10				
3/3/72	40	0	-0.36	0.05	15.50	0.07	39.5	0.56
		1	-0.36	0.05				
		4	-0.47	0.01				
6/4/72	40	8	0.29	0.10	15.40	0.20	39.6	0.44
		9	0.31	0.10				
		18 (0-17)	0.41	0.10				

TABLE XIII

SUMMARY OF RESULTS FOR THE CORRELATION COEFFICIENT
BETWEEN BUTTER MOISTURE CONTENT AND CREAM ACIDITY

Date	Sample Size (n)	Displacement Value	r	Significance Level	Moisture Mean (%)	Moisture Standard Deviation	Acidity Mean (%)	Acidity Standard Deviation
6/4/72	40	29	-0.57	0.05	15.40	0.20	0.082	0.003
	18 (0-17)	12	0.62	0.10	15.21	0.07	0.083	0.003
	22 (18-39)	7	-0.48	0.05	15.58	0.11	0.082	0.003
		9	-0.70	0.02				
		12	0.80	0.01				
		14	0.54	0.10				

(Cream Acidity is expressed as % lactic acid.)

TABLE XII

FREQUENCY DISTRIBUTION FOR DIFFERENCES BETWEEN
DUPLICATE ANALYSES FOR CREAM FAT CONTENT

DIFFERENCE (% FAT) BETWEEN DUPLICATES	FREQUENCY
0	26
0.1	0
0.2	5
0.3	4
0.4	0
0.5	25
0.6	0
0.7	2
0.8	0
0.9	0
1.0	12
1.5	3
2.0	<u>2</u>
	<u>79</u>

Sample size $n = 79$

Mean Difference = 0.5%

Standard Deviation of Differences = 0.56

TABLE XIV

FREQUENCY DISTRIBUTION FOR DIFFERENCES BETWEEN
DUPLICATE ANALYSES FOR CREAM ACIDITY

DIFFERENCES (% LACTIC ACID) BETWEEN DUPLICATES	FREQUENCY
0	22
0.005	11
0.01	<u>7</u>
	<u>40</u>

Sample size $n = 40$

Mean Difference = 0.003

Standard Deviation of Differences = 0.004

concerning any inter-relationship.

The analytical errors have become significant because of the relatively small changes in cream fat content. Experimental methods of sampling, analysis and especially reading of the result, do not allow a sufficiently accurate answer to be obtained using the Babcock test. If the variation in fat content was considerably greater than the differences between duplicate results then the analytical errors would be less important.

Conclusion

(1) It has not been shown that variation in cream fat content contributes to the characteristic variation in moisture or salt content of butter. Analytical errors could contribute significantly to the 'apparent' variation in fat content and thus an incorrect pattern of fat values obtained.

(2) Use of more accurate testing methods could reduce analytical error to an acceptable level. The relationship between cream fat content and moisture content could then be reassessed.

(3) Sampling errors could become significant if more accurate analytical techniques are used. It would be important to ensure that bulk samples were homogeneous prior to removal of samples for analysis.

Trial C - Cream Acidity (6/4/72)Procedure

The titratable acidity was determined for 40 cream samples taken at one minute intervals, using the method discussed previously. A correlation analysis was carried out between the two series of values - cream acidity and butter moisture. The displacement technique was used.

Fig. 11a (page 58) shows the results presented as a graph of Moisture vs. Time for the trial.

Fig. 20b (page 85) shows the results presented as a graph of Titratable Acidity, calculated as lactic acid, vs. Time for the trial.

Table XIII (page 87) presents a summary of significant results obtained in the correlation analysis.

Due to a significant process change the results are presented in three sections in a similar manner to the moisture results for this trial.

The summary of results for correlation between moisture content and titratable acidity shows certain characteristics which may be likened to those of the moisture-fat content analysis.

(i) The time displacement shows no particular recurring or cyclic value for significance in correlation.

(ii) Both positive and negative correlation coefficients occur. An increase in acidity tends to cause an increase in moisture content and thus it was expected that a positive correlation would occur between the moisture and acidity results.

(iii) A maximum correlation coefficient is not seen as evidence of correct series displacement. In addition, the significant values do not occur at the same level of time delay as those significant values in the moisture-fat analysis. This would have been expected had a correct time displacement occurred.

Discussion of Errors

The importance of analytical errors in the determination of cream acidity is similar to that concerning cream fat content analysis.

If the 'actual' variation in acidity is not high then the experimental error becomes significant and it can contribute to the 'apparent' variation in the acidity values.

The differences between duplicate results were also analysed for this trial. Table XIV (page 89) presents the frequency distribution of differences between duplicate acidity analyses.

Number of samples, n = 40

Mean difference, μ = 0.003 (% lactic acid)

Standard deviation of

differences, s = 0.004

This compares with the acidity determined as the mean of duplicate analyses.

Number of samples = 40

Overall mean acidity = 0.082 (% lactic acid)

Standard deviation = 0.003

From the tabulated results, the differences of up to 0.01 % lactic acid may contribute a major portion of the variation in the results. The mean difference is large in comparison with the standard deviation of acidity values, and this was seen also in the cream fat content results.

Conclusion

(1) It has not been shown that variation in the titratable acidity of cream contributes to the characteristic variation in moisture or salt content of butter.

(2) Analytical errors could contribute to 'apparent variation' in titratable acidity value and thus an incorrect series of the values obtained. This is a result of the low variation in the titratable acidity series. The possible experimental error is large when compared with the magnitude of variation.

(3) Reassessment of the butter moisture - cream acidity relationship could be practical if the experimental errors could be reduced. Consideration should be given to obtaining homogeneous samples as variations in composition could become important if experimental accuracy was improved.

B. Churn Variables

Two process variables were investigated under normal running conditions

- (1) Linear extrusion speed of the butter ribbon,
- (2) Pressure exerted by the dosing pump in injecting the salt slurry into the working section.

These factors have been previously discussed with reference to variation in salt injection. Fluctuations in pressure have been shown to affect the salt slurry pump performance. It was considered that flow variations could influence pressure conditions within the working section and thus the pressure that the pump must overcome in order to inject the slurry dose. (ref. page 67)

1. Linear Extrusion Speed

The linear extrusion speed of the ribbon is a 'flow' parameter. It reflects the volume of output, as the cross-sectional area of the ribbon is constant and is determined by the size of the extrusion head orifice. An increase in the cream flow rate should result in a corresponding increase in extrusion speed which should be directly proportional unless density changes occur. Major density changes are not likely to occur as the Contimab machine incorporates a vacuum working section. However, slight fluctuations in linear speed may be a reflection of events in the working section rather than the cream flow rate.

2. Slurry Injection Pressure

Both cream flow rate which is related to the quantity of product in the worker, and flow behaviour in the working section could affect the flow characteristics in the region of slurry ingress. This is likely to influence the pressure at this point and so the performance of the slurry pump. Thus these factors may be sources of variation in pump performance and thus in the salt and moisture content.

Measurement of these two factors together with the butter moisture and salt values would enable comparison of behavioural patterns to determine interrelationships.

Measurement Techniques

Linear Extrusion Speed

A toothed wheel was rotated by the butter ribbon flowing from the extrusion head of the churn. The spindle of the wheel was connected through a gear train to a tachometer. The pulse rate of the tachometer is proportional to the rate of revolution of the wheel and thus is related to the ribbon speed. The pulse output was summed for an accurate time interval by an electronic timer-counter and the result displayed digitally. Thus the summed result taken over a constant time interval indicated the relative ribbon speed. A series of readings was taken over a suitable time period. Because only the speed trends and variations were under consideration calculation to determine the actual ribbon speed was not necessary but it may be determined in the following manner.

$$\text{Tooth wheel diameter} = 7\frac{5}{8} \text{ inches}$$

$$\begin{aligned} \text{Circumference of wheel} &= \pi \cdot 7\frac{5}{8} \text{ inches} \\ &= 24 \text{ inches} \end{aligned}$$

1 revolution of tachometer produces 112 pulses

1 revolution of toothed wheel produces, through gearing, 25 revolutions of tachometer.

$$\begin{aligned} \text{Thus 1 revolution of wheel} &= 25 \times 112 \text{ pulses} \\ &= 2800 \text{ pulses} \end{aligned}$$

$$\text{Thus 2800 pulses} = 24 \text{ inches run}$$

$$1 \text{ pulse} = \frac{24}{2800} \text{ inches run}$$

This conversion factor may be used to determine the ribbon speed.

Sample calculation

$$\begin{aligned} \text{Speed mean} &= 257 \text{ pulses/second} \\ \text{Ribbon speed} &= 257 \times \frac{24}{2800} \text{ inches/second} \\ &= 2.2 \text{ inches/second} \\ &= 11 \text{ feet/minute} \end{aligned}$$

Apparatus

Advance Timer-Counter Model SC3

Frequency of speed readings = 26/minute

Summation interval = 1 second

Salt Dosing Pump Pulse Pressure

A diaphragm joint was placed in the slurry injection line. Movement of the diaphragm as a result of applied pressure was transmitted by a fluid link to a Bourdon tube. A link rod was attached to the moving end of the Bourdon tube. The link was then connected to an inductive displacement transducer and the output was derived through use of a displacement converter amplifier. The output from the amplifier was displayed on an oscilloscope and a permanent record of each pulse made by filming the stationary oscilloscope trace.

Bourdon tube 0 -- 120 psi

Displacement Transducer Philips PR-9314A/10 (displacement ± 10 mm)

Amplifier converter -- Philips PR-9309 Nominal Output ± 1 v.

Oscilloscope -- Telequipment S52

Camera -- 35mm with motor driven spools

Frequency of pulse -- 40 pulses/minute

The height of the trace was measured on the film using a Lupe Magnifier (5X) fitted with a millimeter scale. The pulse heights were read manually. Under normal conditions pressures ranged up to 60 psig.

Photographs of the apparatus used are presented in Figs. 21a, 21b (page 96).

Procedure

Continuous readings of ribbon extrusion speed, and slurry dosing pulse pressure were taken over a period of 40 minutes. Samples of butter were taken at 1 minute intervals over the same period. Results for each variable were graphed

- (i) Variable values vs. time
- (ii) Cusum chart

Control changes made by the machine operator were recorded. A time delay will exist between the actual time of change and the time at which the change is seen in the product composition, and it should be considered in interpretation of results.

The data obtained was highly variable and many short time fluctuations were seen. To remove this short duration 'noise' from the graphs the data was modified and the mean value of eight consecutive values was determined. This modified value was considered as the data value and the graphs of Variable Value vs. Time and the Cusum chart were derived from it. This applies to both ribbon speed and slurry pump pressure results.

Fig. 21a Apparatus for Measurement of Ribbon Speed.

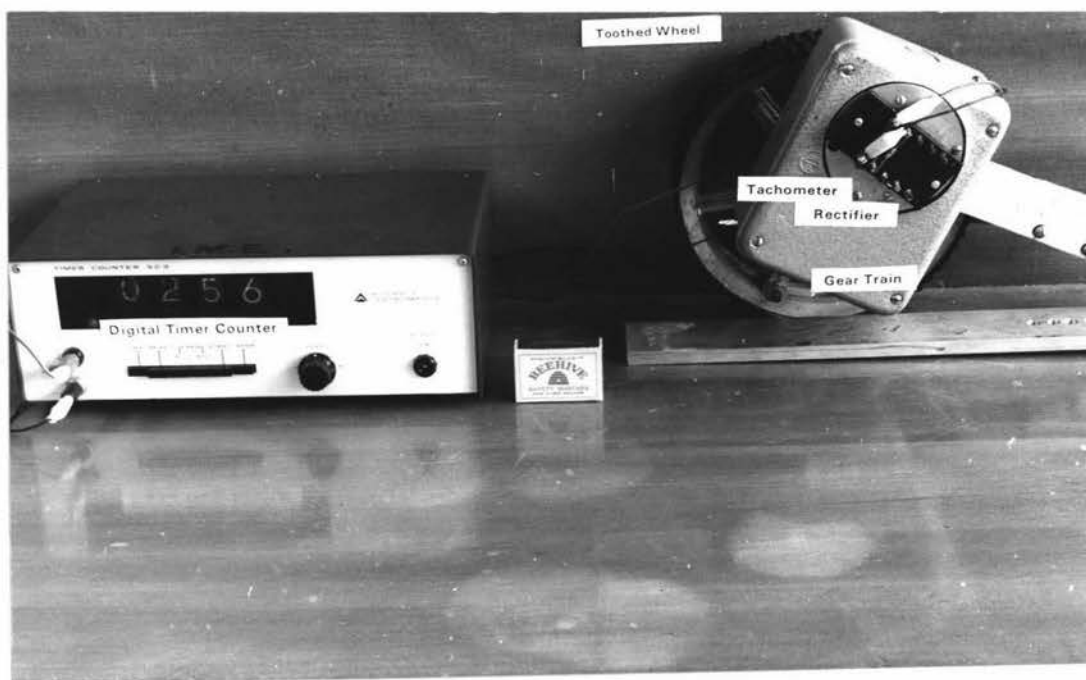
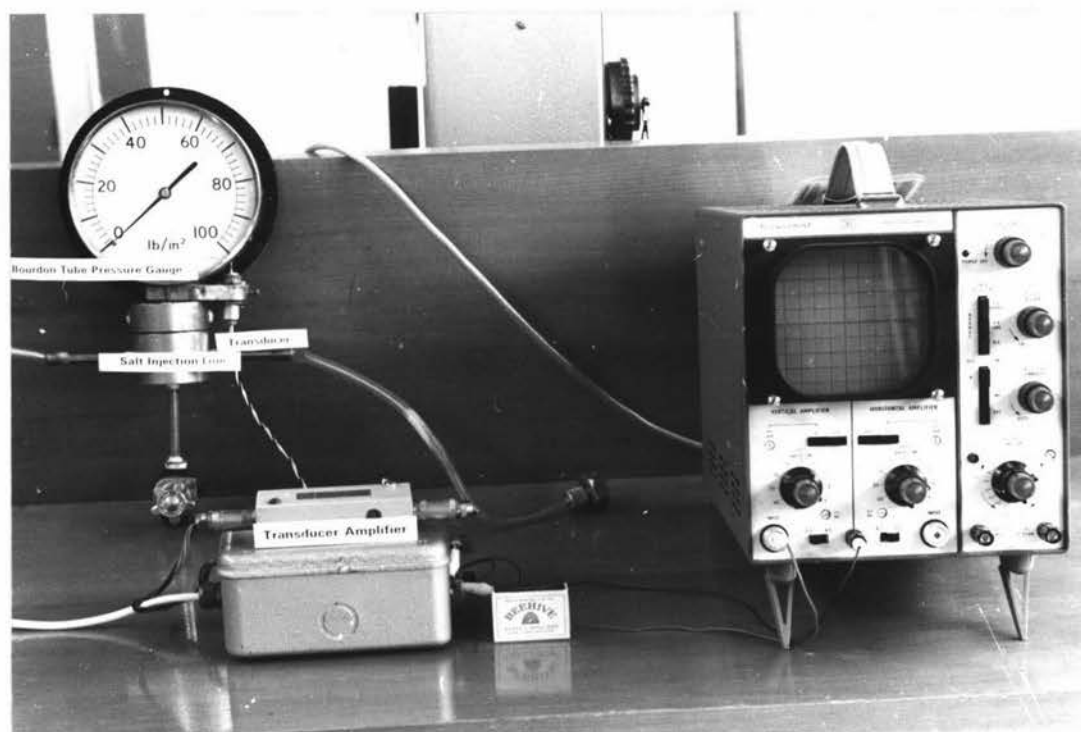


Fig. 21b Apparatus for Measurement of Salt Slurry Injection Pressure.



Discussion of Results

Trial C (6/4/72)

Results were obtained for ribbon speed and butter composition.

Churn operating conditions

Variable Time (min.)	Cream Pump Setting	Salt Pump Setting	Worker (rpm)	Churn Speed
0	3.25	25	28.5	increase
18	3.5	31		
28		29	29.5	

	Mean	Standard Deviation
Moisture (%)	15.41	0.10
Salt (%)	1.56	0.11
Ribbon speed (ft/min)	12.0	0.3

Moisture-Salt Correlation

Time 0-17 minutes (n = 18) 'r' = 0.64 significant at 0.01 level

Time 18-39 minutes (n = 22) 'r' = 0.78 significant at 0.001 level

Figs. 11a, 11b (page 58) show the results presented as graphs of Moisture and Salt Content vs. Time.

Figs. 13a, 13b (page 60) show the Moisture and Salt Cusum charts.

Fig. 22 (page 98) shows a graph of Ribbon Speed vs. Time.

Fig. 23 (page 99) shows the Ribbon Speed Cusum Chart.

The Moisture and Salt characteristics of this run have been discussed earlier and particular reference was made to the significant change in moisture mean. The ribbon speed cusum chart shows a similar change in mean at a time of approximately 18 minutes. This is indicated by a marked change in slope.

Fig. 22. Graph of Ribbon Speed (pulses/second) vs Time (minutes) (6/4/72)

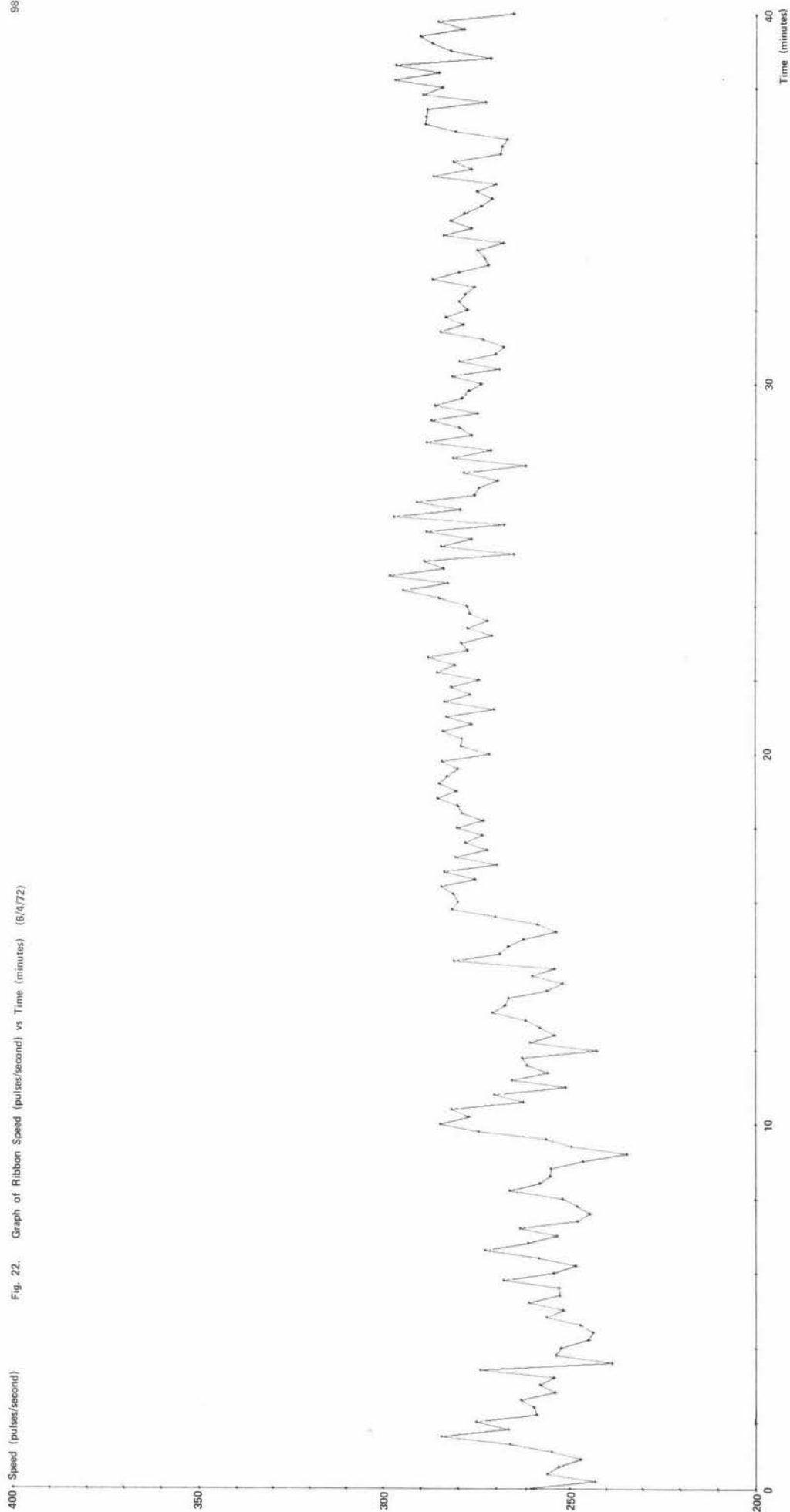
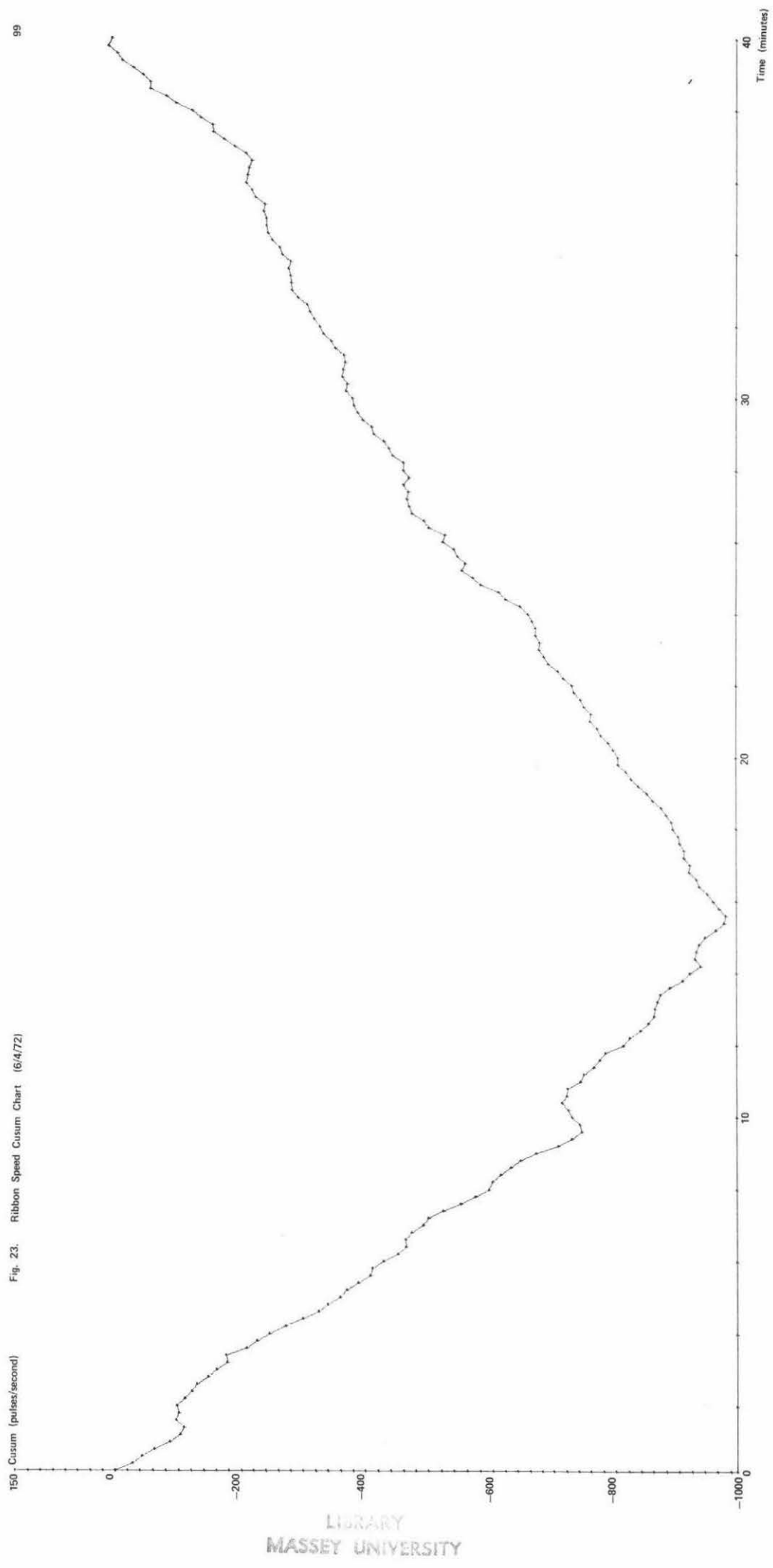


Fig. 23. Ribbon Speed Cusum Chart (6/4/72)



From the churn operating data it is seen that at this time the cream pump flow rate was increased by nearly 8% and thus the volume flow was increased proportionately. Calculation showed that the mean ribbon speed increased by a similar amount.

Cream pump speed (i)	3.25
(ii)	<u>3.5</u>
Difference	<u>.25</u>
	= 7.7 % based on original value

Ribbon speed (i)	259 pulses/unit time
(ii)	<u>280</u> pulses/unit time
Difference	<u>21</u> pulses/unit time
	= 8.1 % based on original value

At the same time, the primary churn speed and the salt pump setting were altered in order to maintain the butter composition. A nett increase in moisture content resulted and a slight nett decrease in salt content occurred.

It is thus seen that the step change in cream flow was reflected accurately by the ribbon speed measurement. The increase in mean moisture content of 0.44% would probably account for the slightly greater increase in ribbon speed.

Trial F (16/5/72)

Results were obtained for ribbon speed, slurry pump pressure and butter composition.

Churn operating conditions

Variable Time (min.)	Cream Pump Setting	Salt Pump Setting	Worker (rpm)	Churn Speed
0	3.0	35	29	
4			31	
12			29	
15		32		
No further change				

	Mean	Standard Deviation
Moisture (%)	15.38	0.12
Salt (%)	1.59	0.06
Ribbon speed (ft/min)	11.0	0.3
Pump pressure (units)	85	5

Moisture-Salt Correlation 'r' = 0.49 significant at 0.001 level
n = 40

Figs. 24a, 24b (page 102) show the results presented as graphs of Moisture and Salt Content vs. Time.

Figs. 25a, 25b (page 103) show the Moisture and Salt Cusum Charts.

Fig. 26 (page 104) shows the graph of Ribbon Speed vs. Time.

Fig. 27 (page 105) shows the graph of Salt Pump Pressure vs. Time.

Fig. 28 (page 106) shows the Ribbon Speed Cusum Chart.

Fig. 29 (page 107) shows the Salt Pump Pressure Cusum Chart.

Fig. 24a. Graph of Moisture Content (%) vs Time (minutes) (16/5/72)

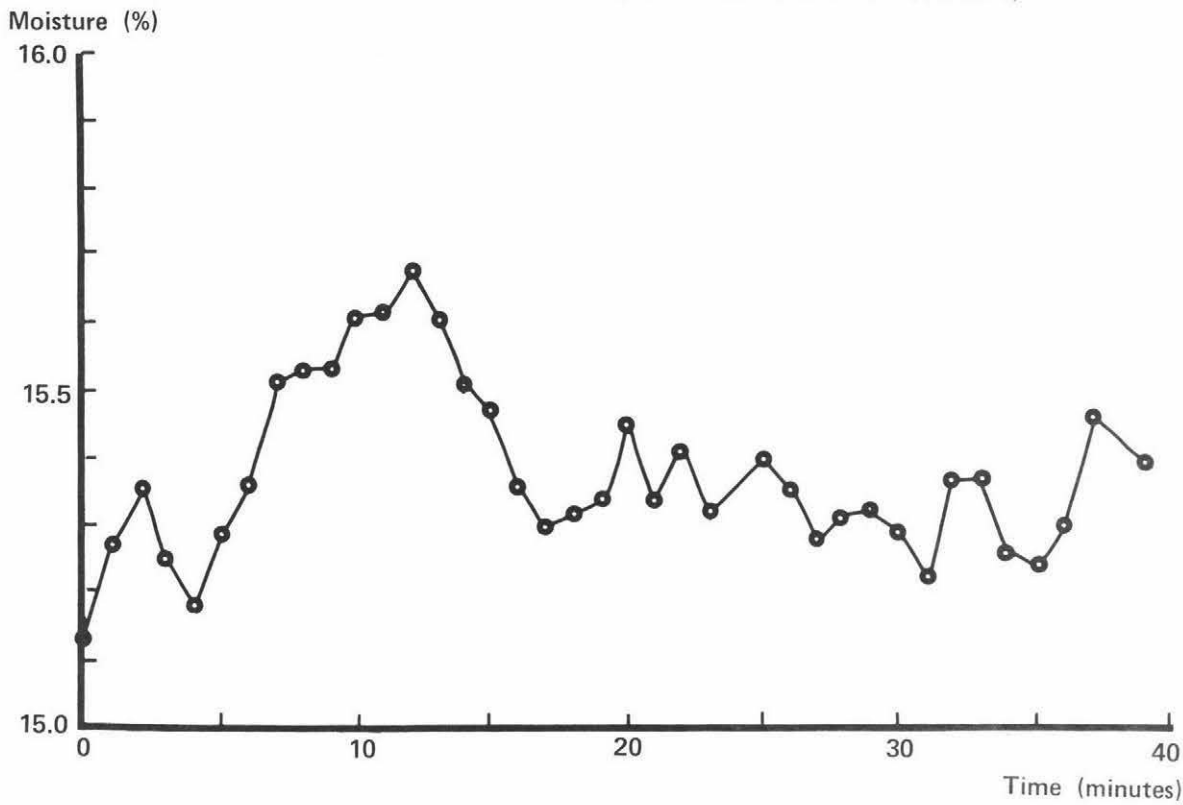


Fig. 24b. Graph of Salt Content (%) vs Time (minutes) (16/5/72)

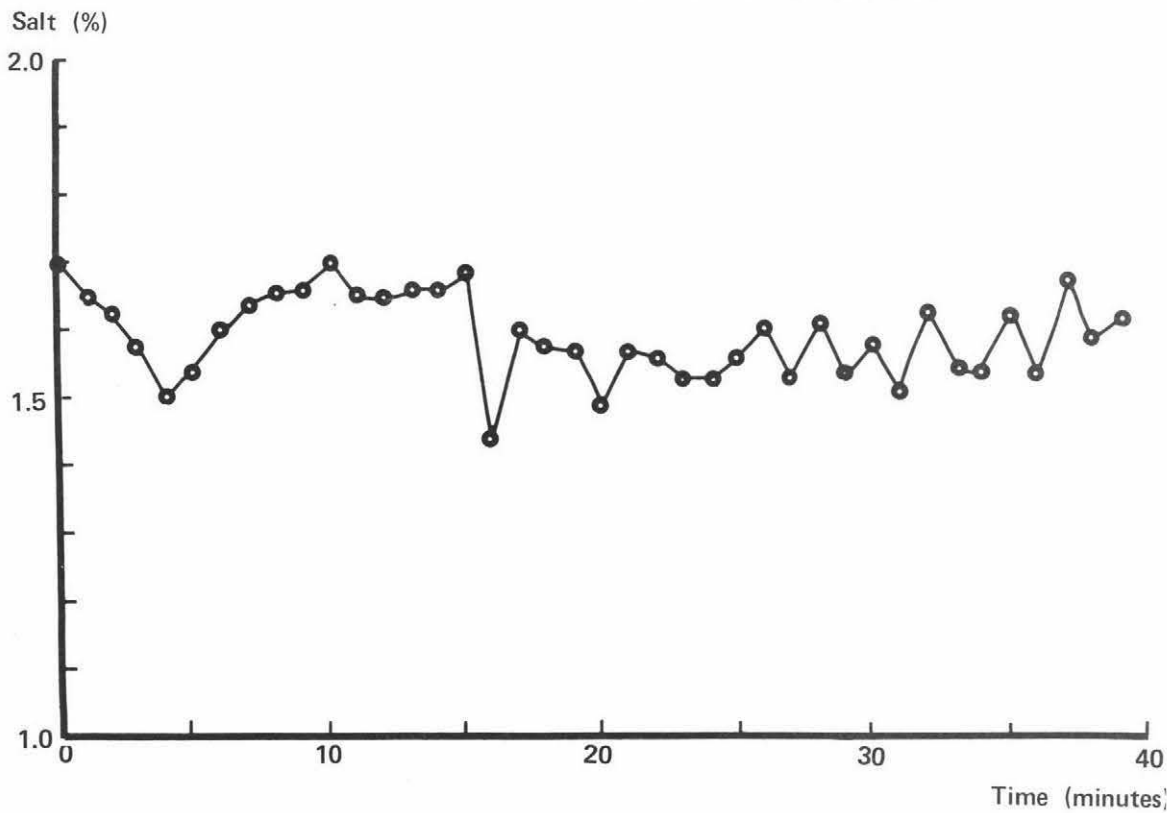


Fig. 25a. Moisture Cusum Chart (16/5/72)

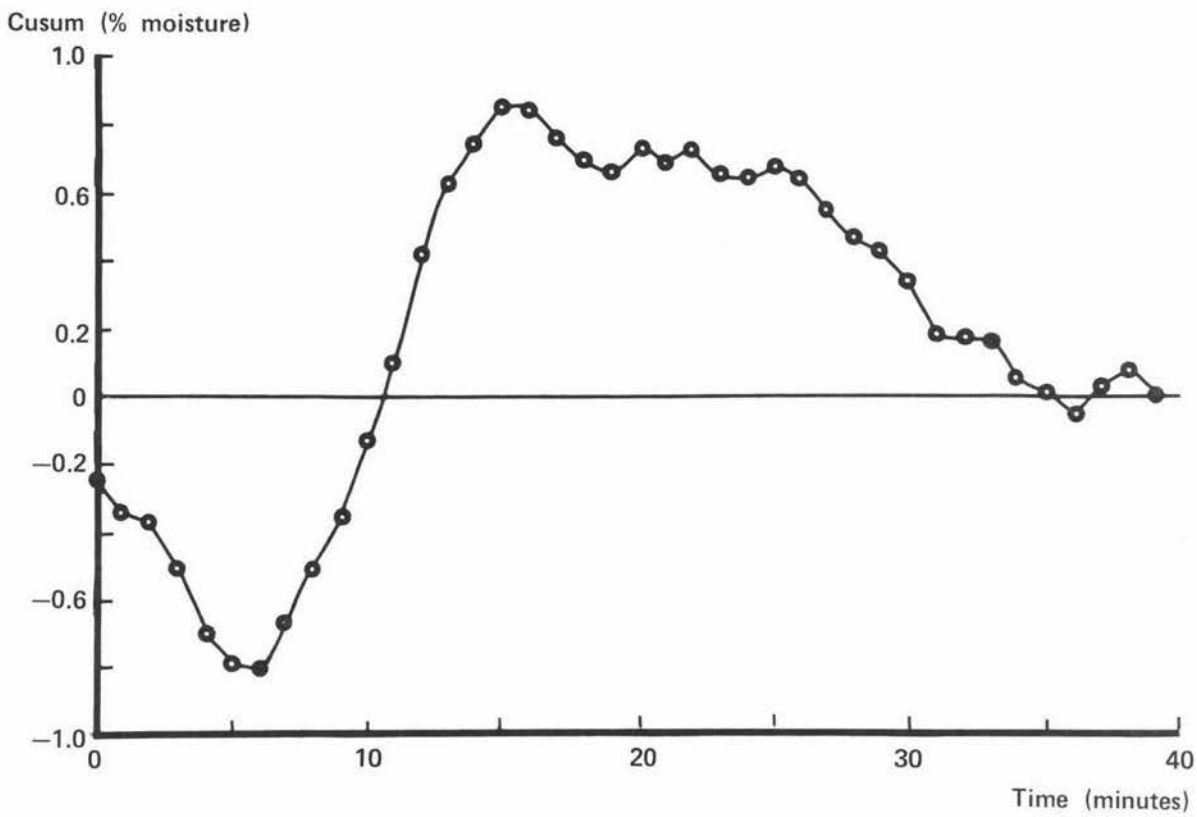


Fig. 25b. Salt Cusum Chart (16/5/72)

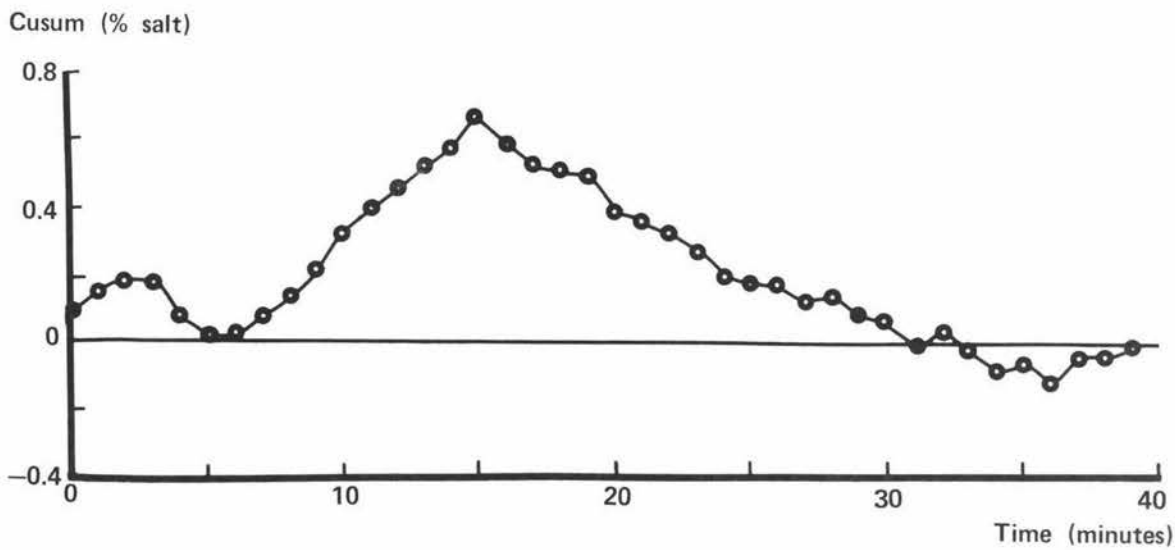


Fig. 26. Graph of Ribbon Speed (pulses/second) vs Time (minutes) (16/5/72)

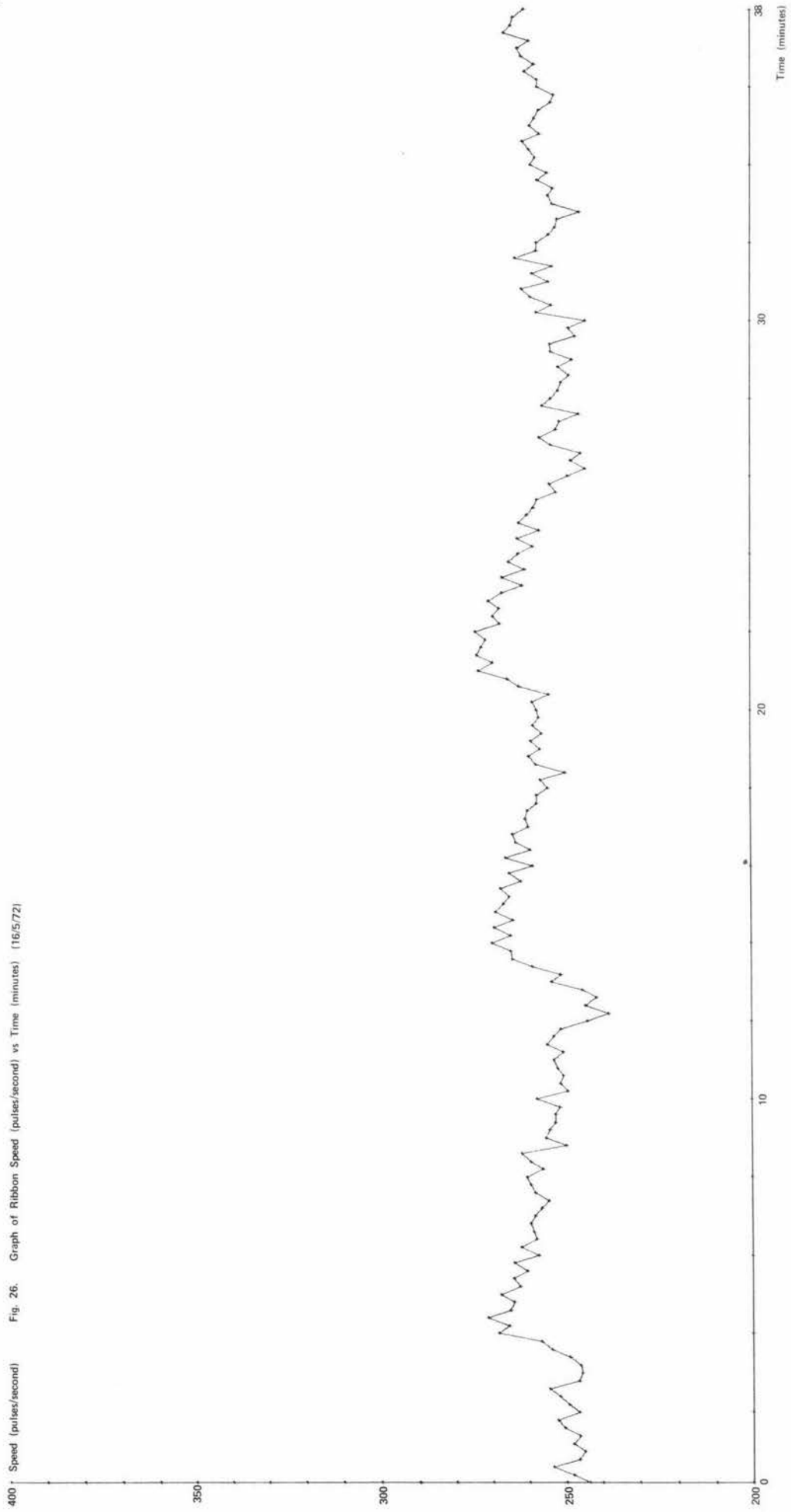


Fig. 27. Graph of Salt Pump Pressure (pressure units) vs Time (minutes) (16/5/72)

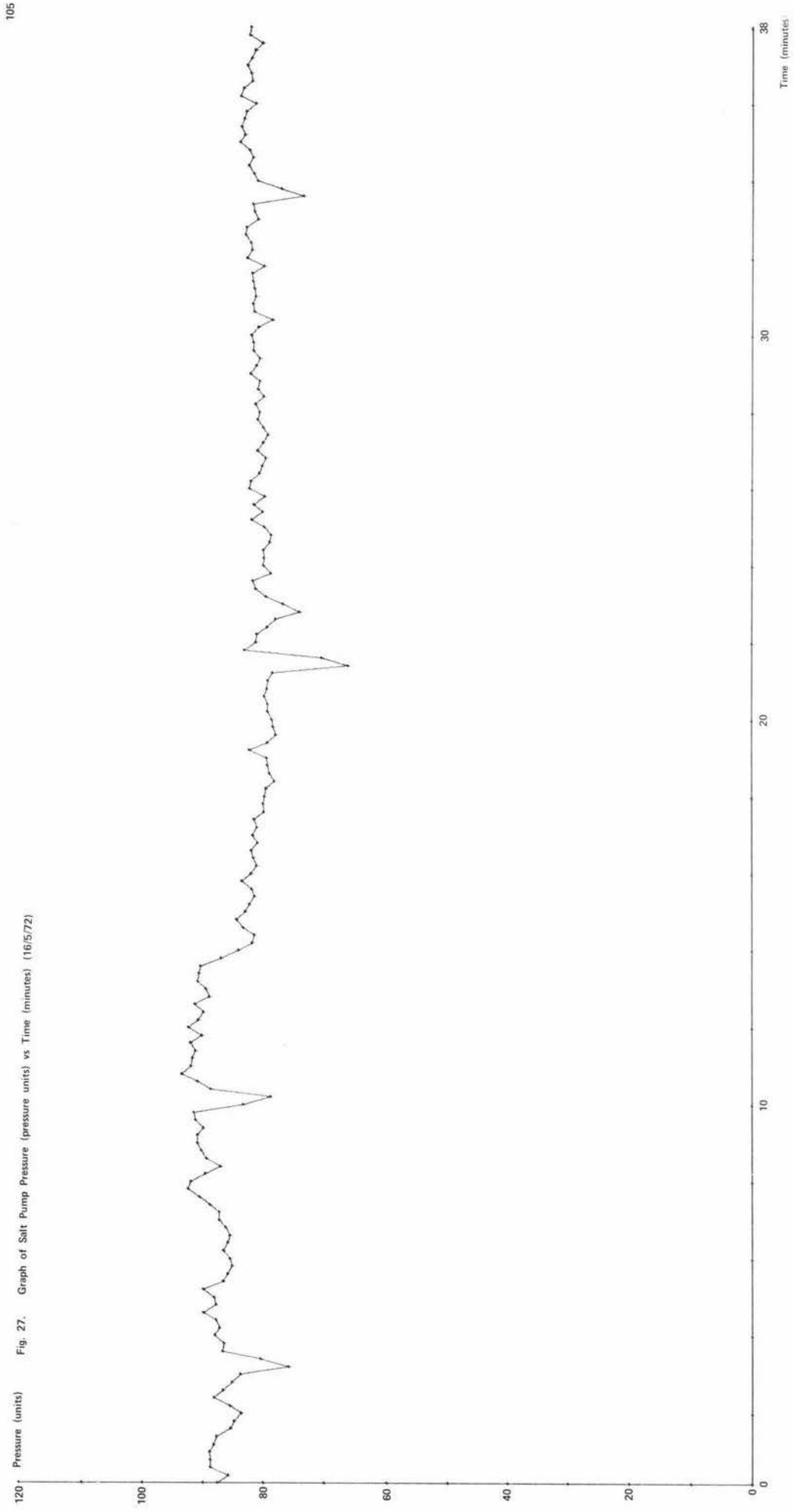


Fig. 28. Ribbon Speed Cusum Chart (16/5/72)

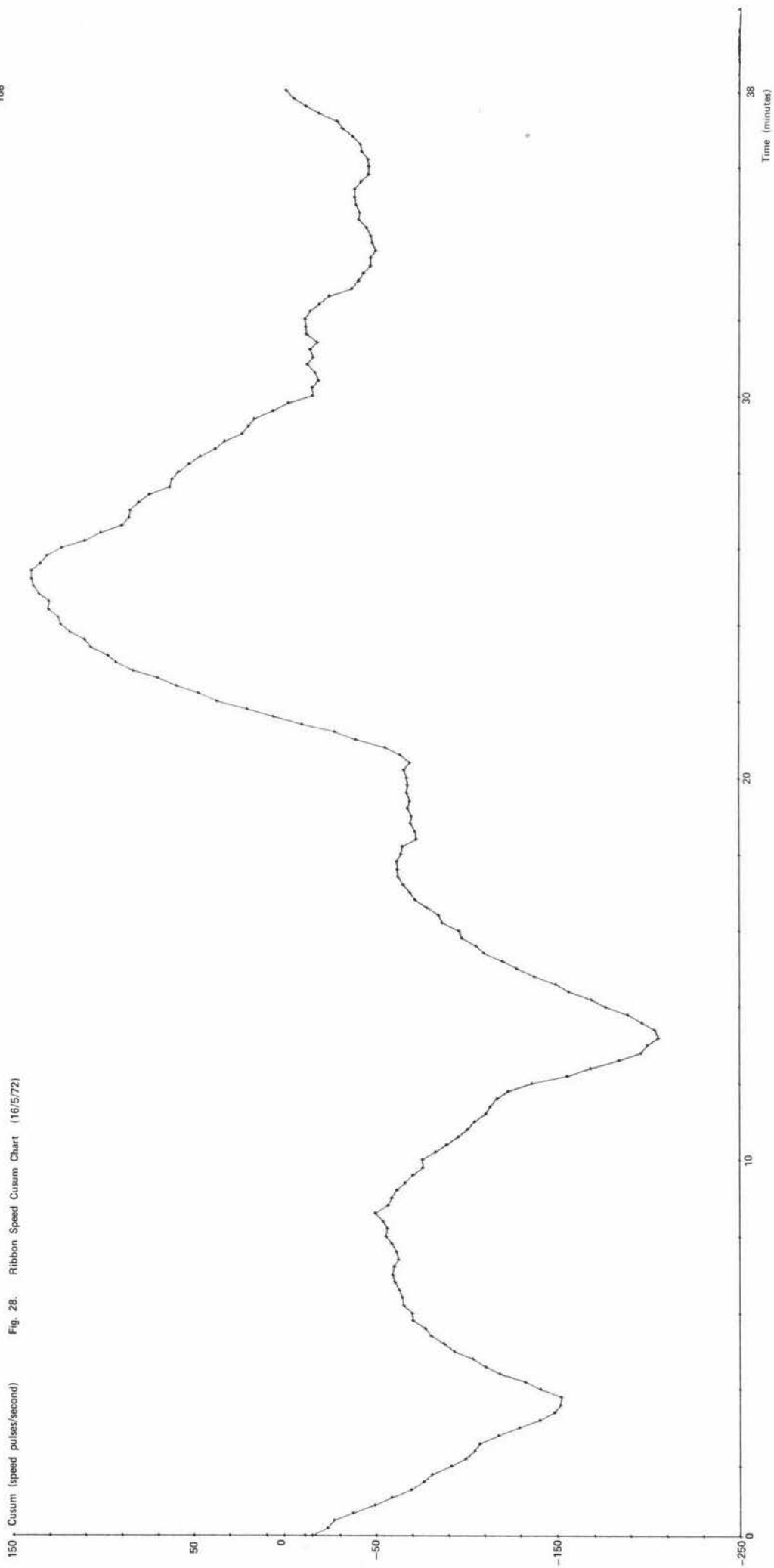
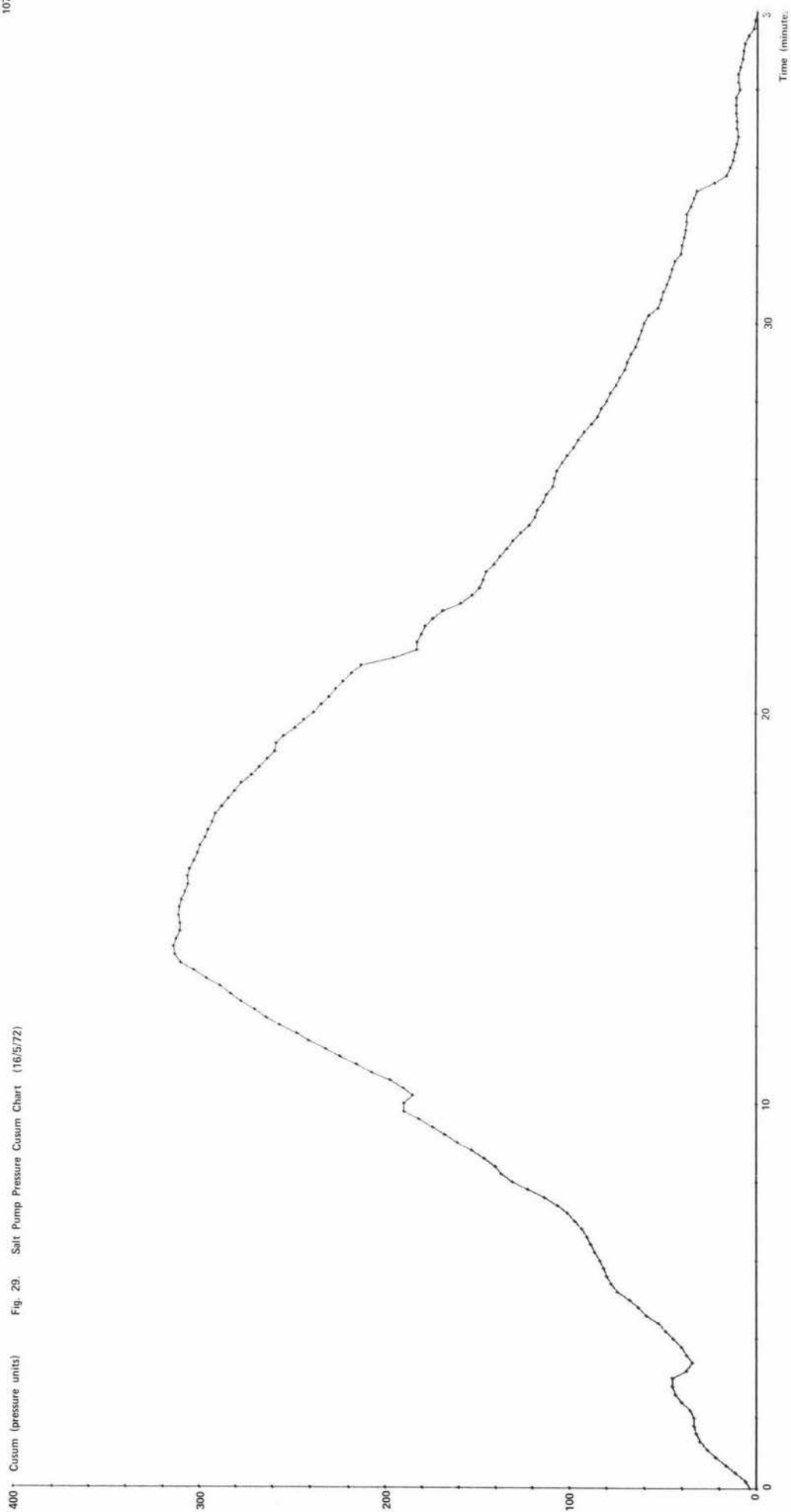


Fig. 29. Salt Pump Pressure Cusum Chart (16/5/72)



The graphs of Moisture and Salt vs. Time accurately show the effect of machine changes. At 4 minutes a change in the worker speed initiates an increase in moisture content, this is then re-corrected at 12 minutes and the process returns to steady moisture level at 15 minutes. The change in salt pump setting at 15 minutes has resulted in a near proportionate change in the butter salt content.

Salt pump setting (i)	35
(ii)	<u>32</u>
Difference	<u>3</u>
	= 8.5% based on original value

Salt content (mean) (i)	1.65 %
(ii)	<u>1.53</u> %
Difference	<u>0.12</u> %
	= 7.2 % based on original value

An apparent change in the salt content at 5 minutes has not been caused by an operator change in salt pump setting or cream flow rate. It is possible that a change in pump performance has occurred. For example, malfunction of the diaphragm due to fouling of the seat by salt particles may affect performance. There has not been any sustained change in either ribbon speed or slurry pump pressure at this stage.

The cusum charts for moisture and salt again show good relationship and they reflect process changes accurately.

The graph of ribbon speed data showed some cyclic forms, and this is also seen on the cusum chart. The cycle duration varies from 8 - 11 minutes and is characterised by a rapid rise of nearly 10 % in the level of the variable followed by a slow decrease to near the starting value. This cycle commences at approximately 4 minutes, the time at which an alteration was made in worker speed. It is possible that the initial increase in worker speed causes an increase in ribbon speed, but which slowly resumes its original level which is probably dependent on the butter flow rate. However, a decrease in worker speed at 12 minutes does not have the converse effect and decrease the ribbon speed as might be expected. Later results showed this cyclic form to occur independently of operator control changes in worker speed. It is possible that this cycle is caused by flow characteristics.

The graph of pressure data shows some recurring regions of low pressure where approximately ten consecutive pulses are at a markedly lower pressure than the remainder. These aberrations appear to be related to the cycling of the ribbon speed as the times of occurrence are in close agreement. It is possible that this is caused when the packer screws commence operation and draw the butter down the chute. The increase in speed could result in lowering of the back pressure in the worker. Although the speed change is relatively sustained the pressure rapidly resumes its normal level. Perhaps this is because the flow pattern in the worker is rapidly restored to normal despite the continuing pull of the screws in the ribbon. However, the cycle time of up to 8 minutes is far in excess of the time taken to fill the forming chamber and extrude one carton of butter. Thus although this phenomenon may be related to the packing unit the source is not the regular packing cycle.

Other causes may be related to the flow input or cream pump performance and perhaps to flow patterns in the worker.

Pressure level (i)	90 units
(ii)	<u>81</u> units
Difference	<u>9</u> units
= 10 % change based on original value	

Thus under the conditions present, the relationship between salt content, pump setting and injection pressure is well defined.

Trial G (22/5/72)

Results were obtained for ribbon speed, slurry pump pressure and butter composition.

Churn operating conditions

Variable Time (min.)	Cream Pump Setting	Salt Pump Setting	Worker (rpm)	Churn Speed
0	4.2	4.1	38	
2	No further change		32	

	Mean	Standard Deviation
Moisture (%)	15.39	0.10
Salt (%)	1.19	0.06
Ribbon speed (ft/min)	13.9	1.0
Pump pressure (units)	79	5

Moisture-Salt Correlation 'r' = 0.31 significant at 0.05 level
n = 40

Figs. 30a, 30b (page 111) show the results presented as graphs of Moisture and Salt Content vs. Time.

Figs. 31a, 31b (page 112) show the Moisture and Salt Cusum Charts.

Fig. 32 (page 113) shows the graph of Ribbon Speed vs. Time.

Fig. 33 (page 114) shows the graph of Salt Pump Pressure vs. Time.

Fig. 34 (page 115) shows the Ribbon Speed Cusum Chart.

Fig. 35 (page 116) shows the Salt Pump Pressure Cusum Chart.

Fig. 30a. Graph of Moisture Content (%) vs Time (minutes) (22/5/72)

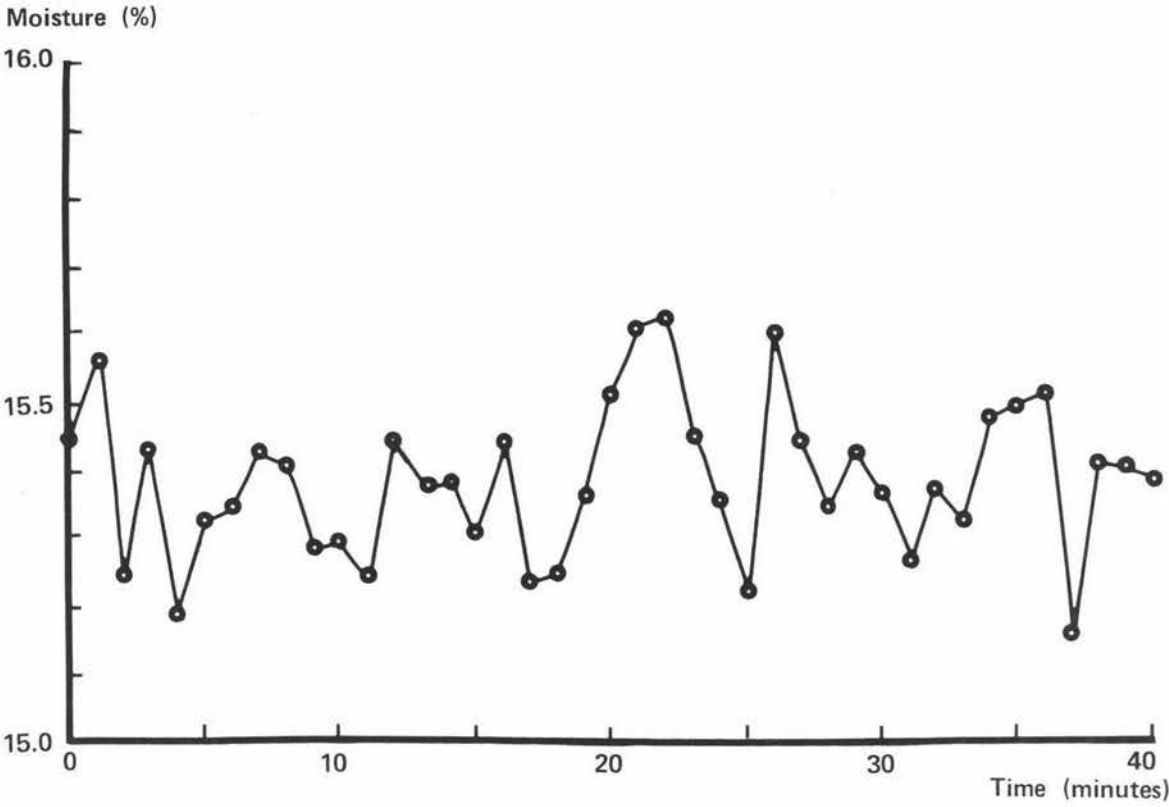


Fig. 30b. Graph of Salt Content (%) vs Time (minutes) (22/5/72)

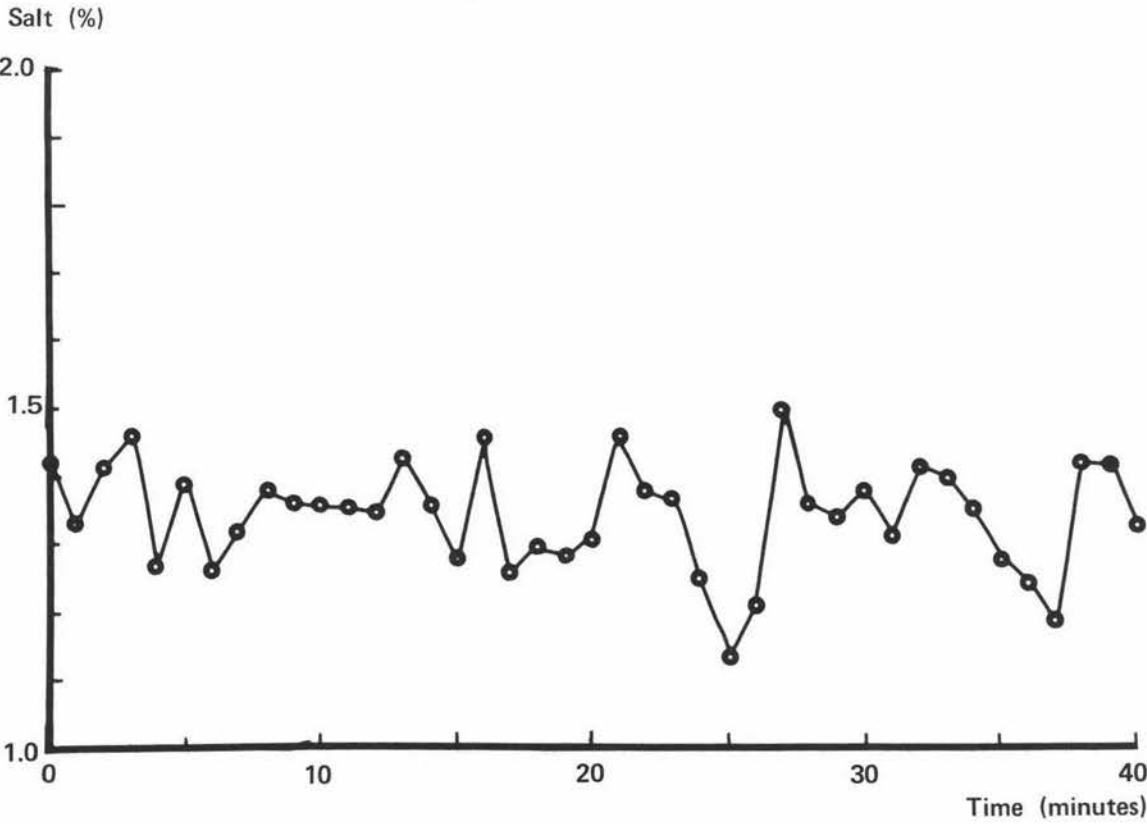


Fig. 31a. Moisture Cusum Chart (22/5/72)

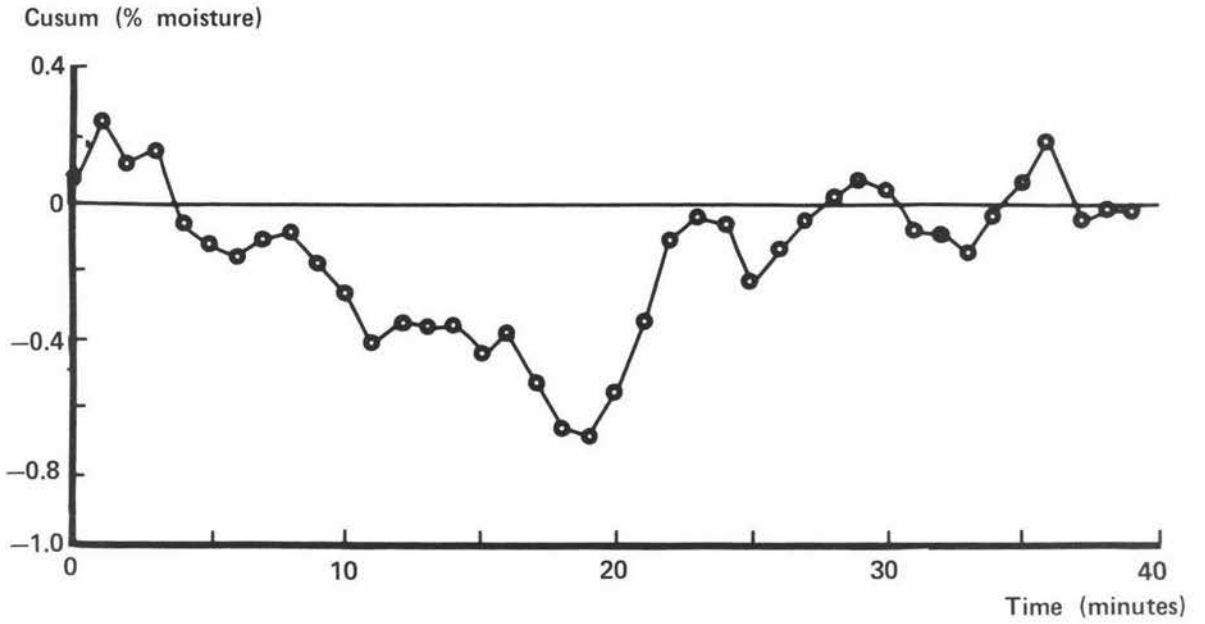
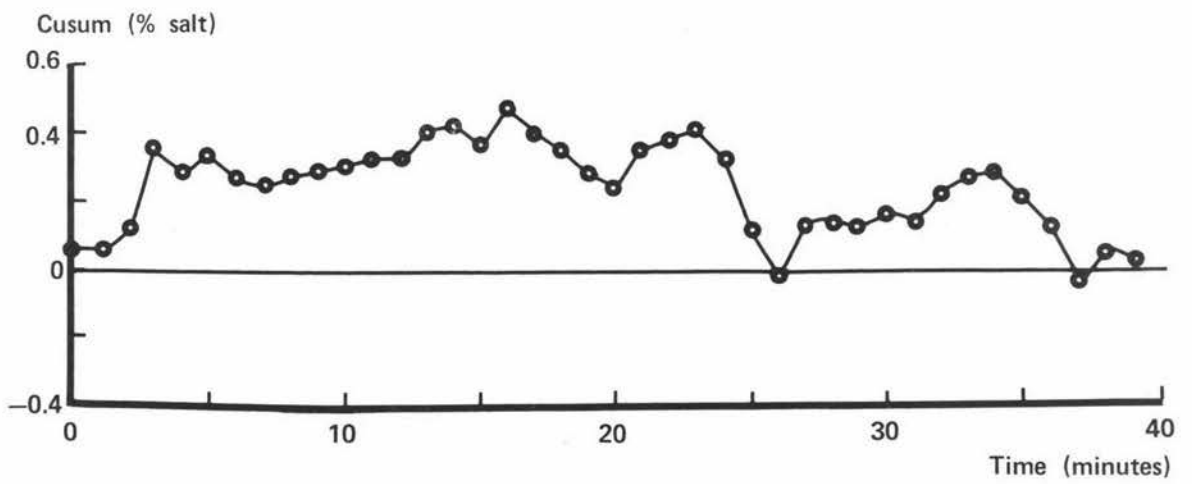


Fig. 31b. Salt Cusum Chart (22/5/72)



400 Speed (pulses/second) Fig. 32 Graph of Ribbon Speed (pulses/second) vs Time (minutes) (22/5/72)

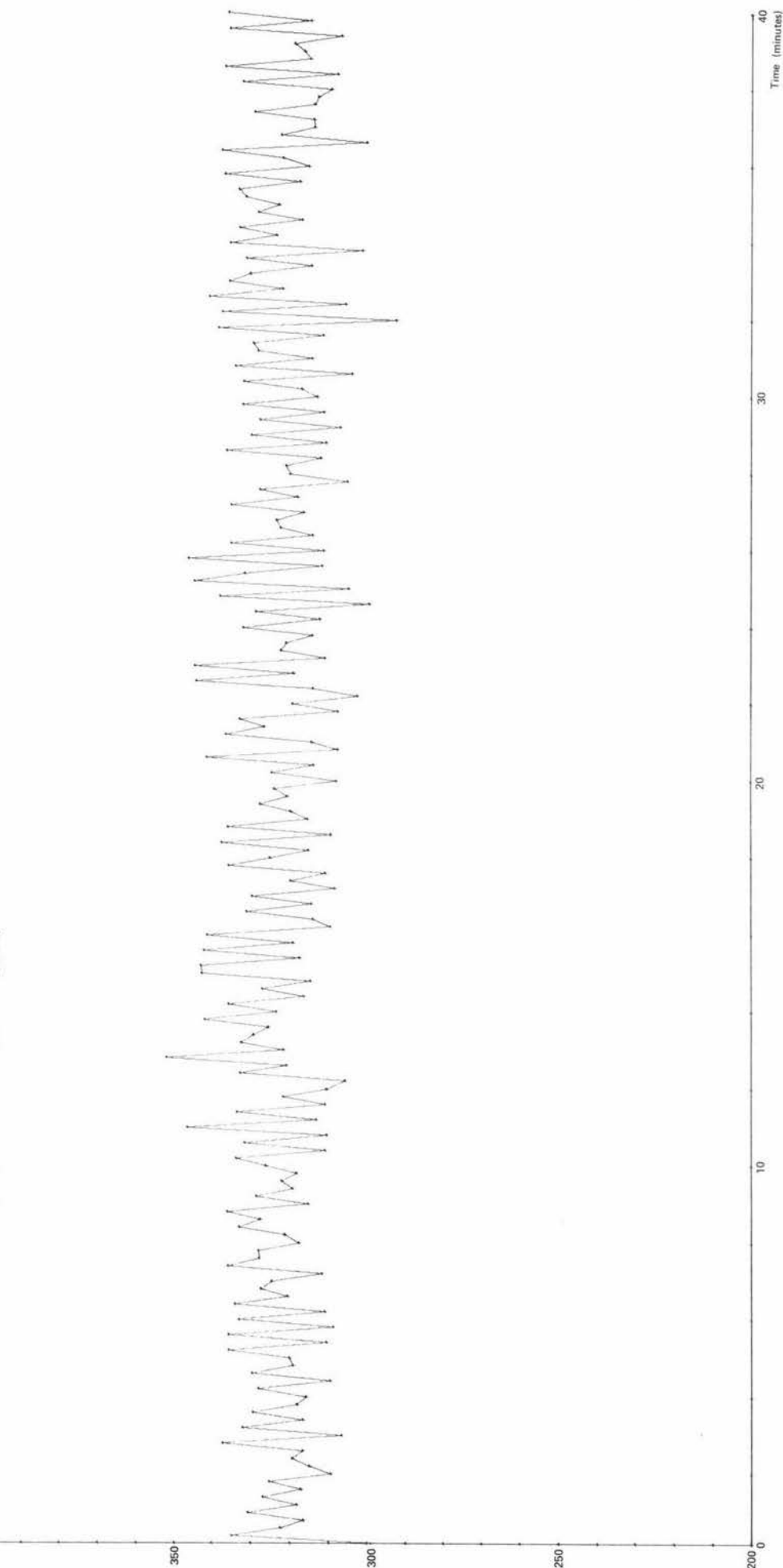


Fig. 33. Graph of Salt Pump Pressure (pressure units) vs Time (minutes) (22/5/72)

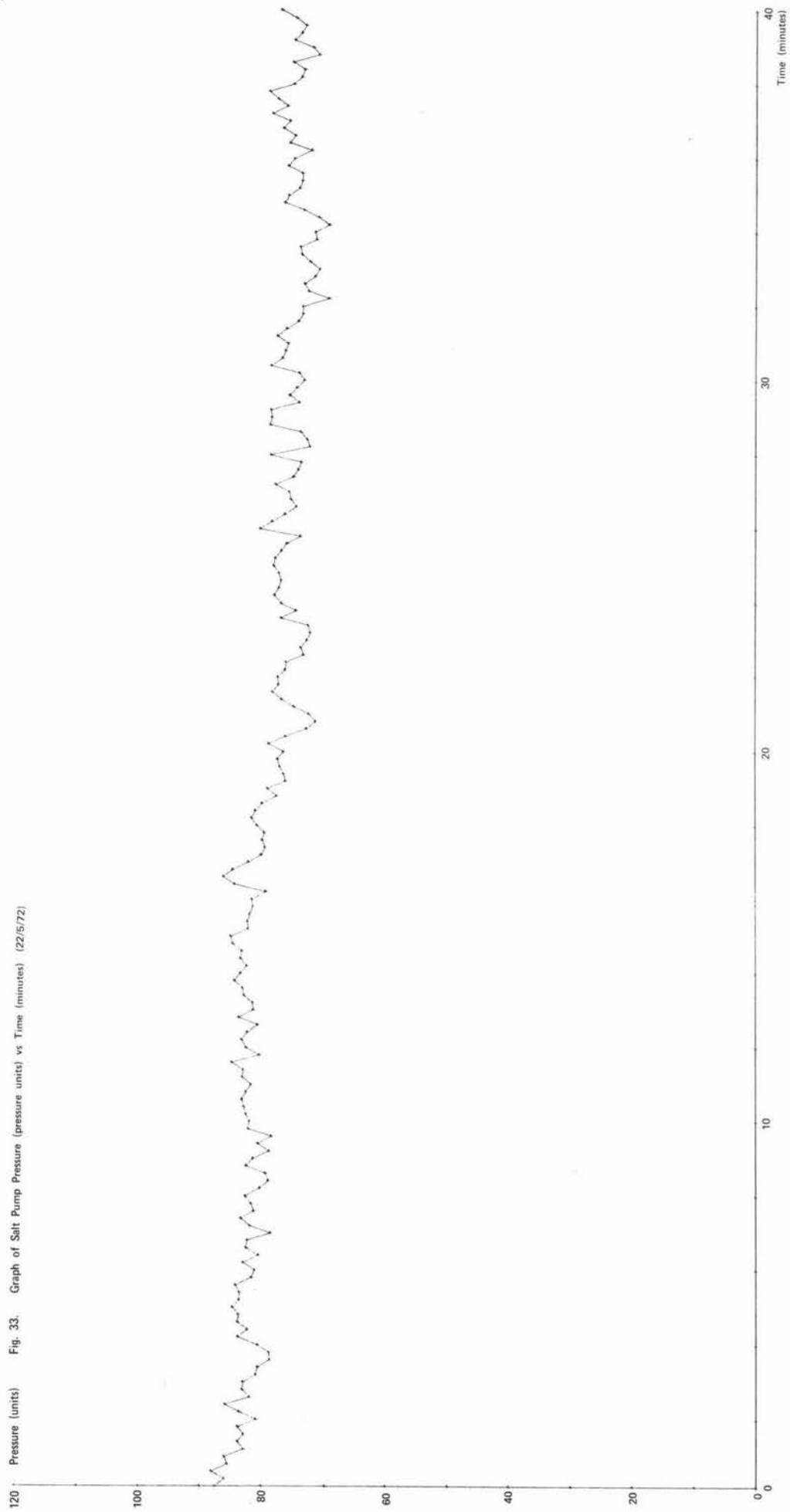


Fig. 34. Ribbon Speed Cusum Chart (22/5/72)

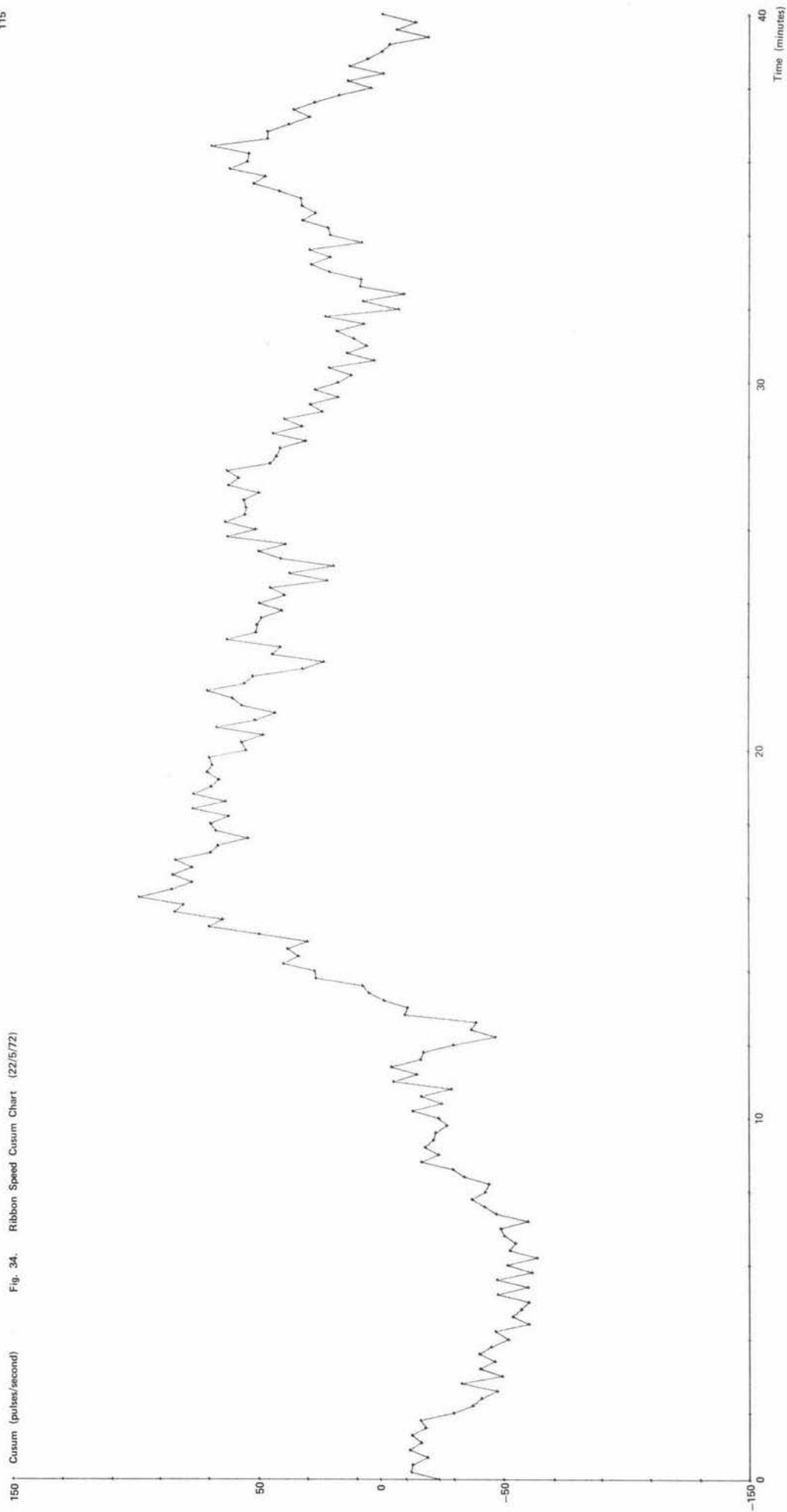
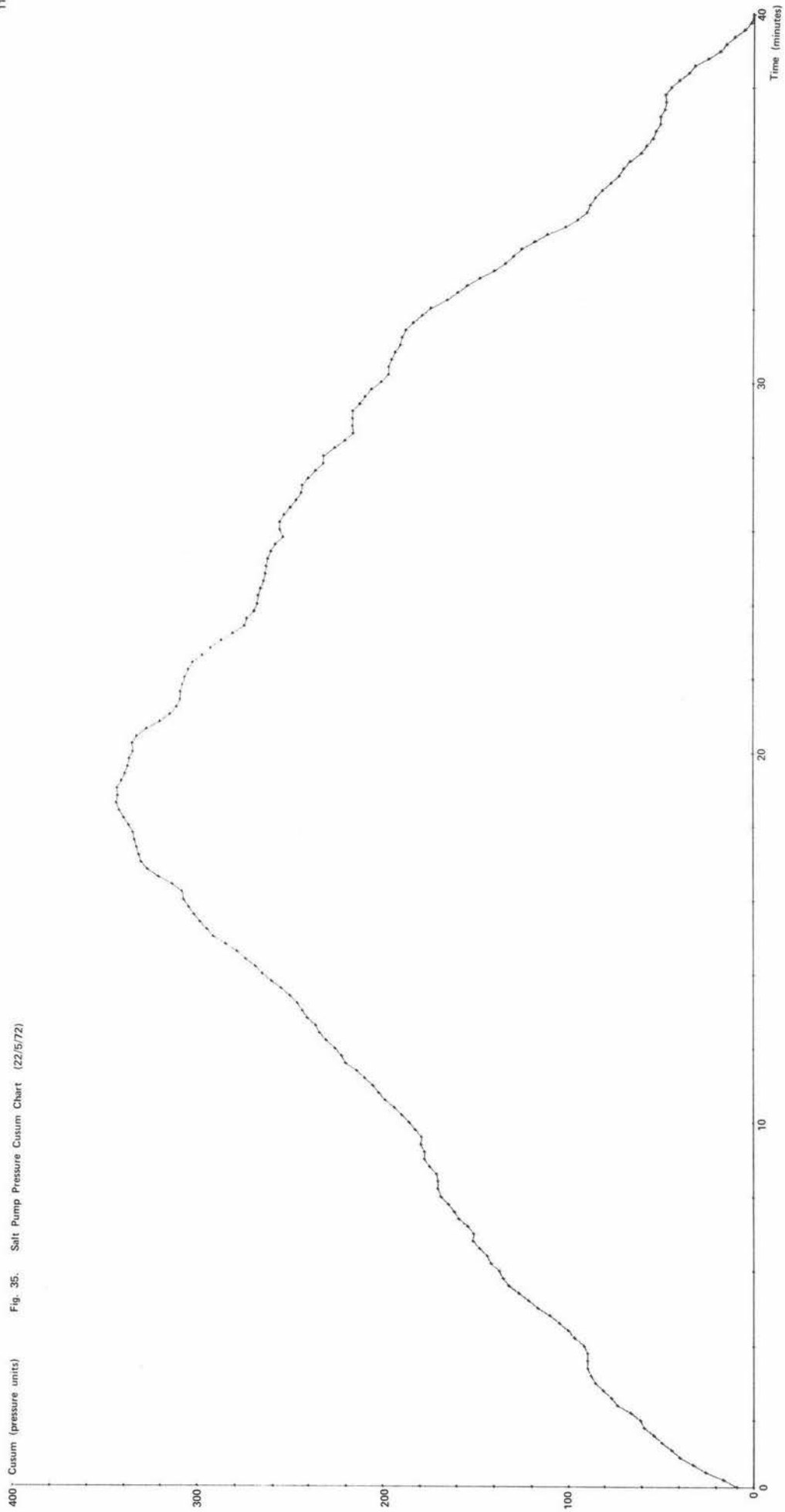


Fig. 35. Salt Pump Pressure Cusum Chart (22/5/72)



During the trial no operator changes were made to the churn after 2 minutes, thus variations occurring are the result of process variation inherent in the system.

The moisture and salt graphs again show relationship in their variation; their correlation is significant.

At 2 minutes a major change in worker speed was made, this is seen also as a change in ribbon speed but is not sustained. It would appear that the ribbon speed is only temporarily affected by changes in worker speed. The prominent and sustained changes in ribbon speed are likely to result from flow rate changes.

The moisture and salt cusum charts show that a process change has occurred at 20 minutes. The moisture and salt cusum values begin to increase. At this time a reduction in the pressure level has occurred and it is probable that an increase in salt dosage volume resulted because of this. Such an increase in the dosage volume will cause the changes in moisture and salt content.

Pressure level (i)	81.0 units
(ii)	<u>75.0</u> units
Difference	<u>6.0</u> units
	= 7.5 % change based on original value
Salt Content (i)	1.35 %
(ii)	<u>1.55</u> %
Difference	<u>0.2</u> %
	= 15 % change based on original value

This change was not sustained for longer than 4 minutes but the available data does not provide an explanation for this.

The moisture and salt values show further change at 23 and 26 minutes although significant changes do not occur in either ribbon speed or pump pressure.

The ribbon speed shows the occurrence of a short time cycle - which exhibits quite large differences in ribbon speed. This is due to

the behaviour of the ribbon during this run. The ribbon was forming ripples down its length and these were initiated at the extrusion head. A high production rate was the cause of this and the increased flow resistance was giving rise to temporary build up or slowing of the flow until the resistance was exceeded. This short time effect was not shown in the slurry pump pressure measurement as might have been expected.

The ribbon speed cycle previously discussed, one of 8 - 11 minutes duration is again present and is superimposed upon the short time cycle. The cycle in this instance has not been initiated by operator changes in the worker speed. This cycle may be caused by:

- (i) variation in the working speed which is dependent on the system and as yet, not controllable.
- (ii) butter flow rate variations.

The magnitude of the speed change is not large and is approximately 5-10%.

The pressure results do not show the same regions of low pressure as in Trial F (16/5/72) which coincided with the ribbon speed cycling. Generally the pressure level is steady and shows only minor variation.

The latter stage of the speed cusum chart corresponded to a similar pattern in the butter moisture cusum chart. A positive correlation of this type would suggest worker speed as the causative factor. This factor exhibits a positive correlation with moisture content whereas cream flow rate shows a negative relationship. (This has been discussed in Section I (page 23)).

Trial H (26/5/72)

Results were obtained for butter ribbon speed, slurry pump pressure and butter composition.

Churn operating conditions

Variable Time (min.)	Cream Pump Setting	Salt Pump Setting	Worker (rpm)	Churn Speed
0	4.2	37	44	
	No further change			

	Mean	Standard Deviation
Moisture (%)	15.36	0.10
Salt (%)	1.19	0.06
Ribbon speed (ft/min)	14.5	0.8
Pump pressure (units)	92	7

Moisture-Salt Correlation 'r' = 0.08 not significant
n = 40

Figs. 36a, 36b (page 120) show the results presented as graphs of Moisture and Salt Content vs. Time.

Figs. 37a, 37b (page 121) show the Moisture and Salt Cusum Charts.

Fig. 38 (page 122) shows the graph of Ribbon Speed vs. Time.

Fig. 39 (page 123) shows the graph of Salt Pump Pressure vs. Time.

Fig. 40 (page 124) shows the Ribbon Speed Cusum Chart.

Fig. 41 (page 125) shows the Salt Pump Pressure Cusum Chart.

Fig. 36a. Graph of Moisture Content (%) vs Time (minutes) (26/5/72)

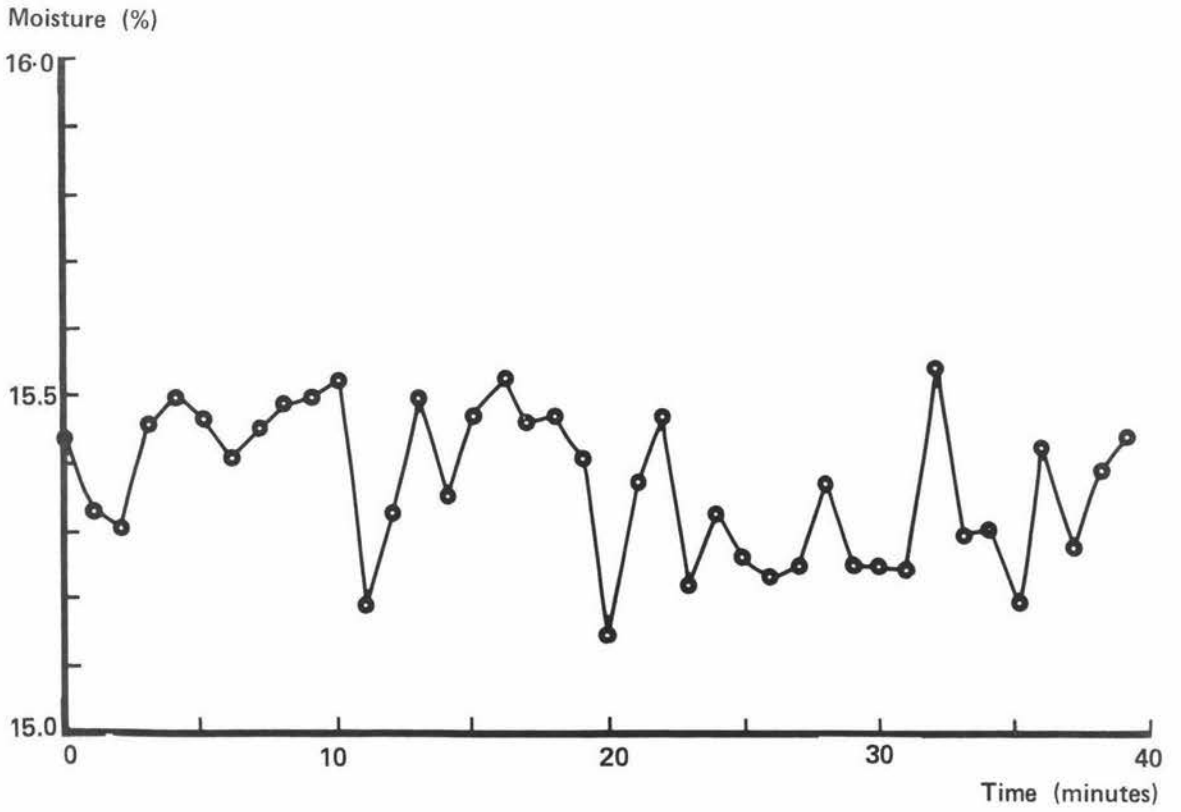


Fig. 36b. Graph of Salt Content (%) vs Time (minutes) (26/5/72)

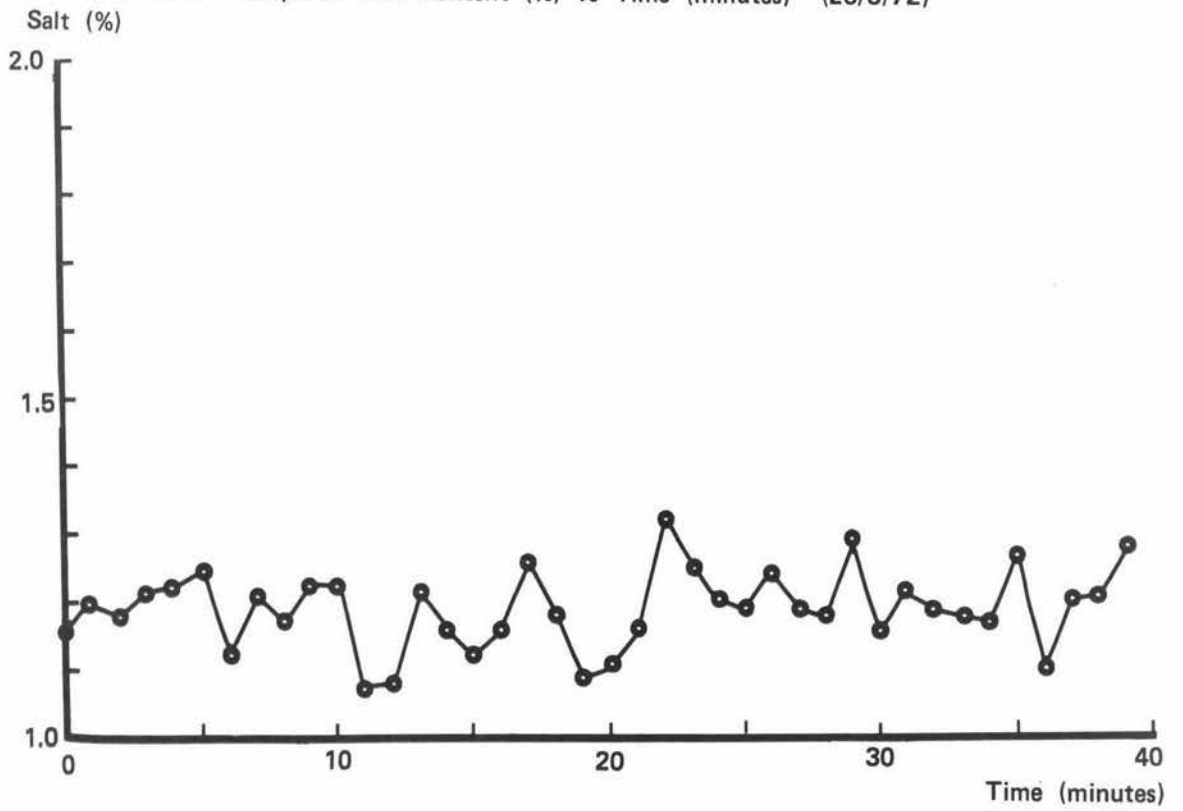


Fig. 37a. Moisture Cusum Chart (26/5/72)

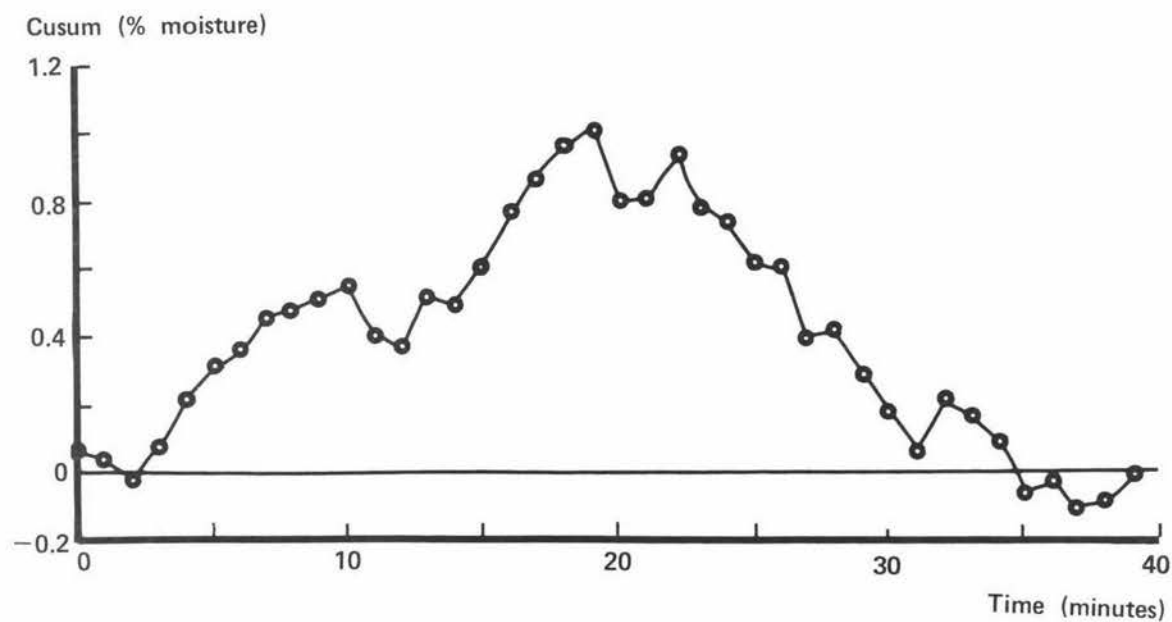


Fig. 37b. Salt Cusum Chart (26/5/72)

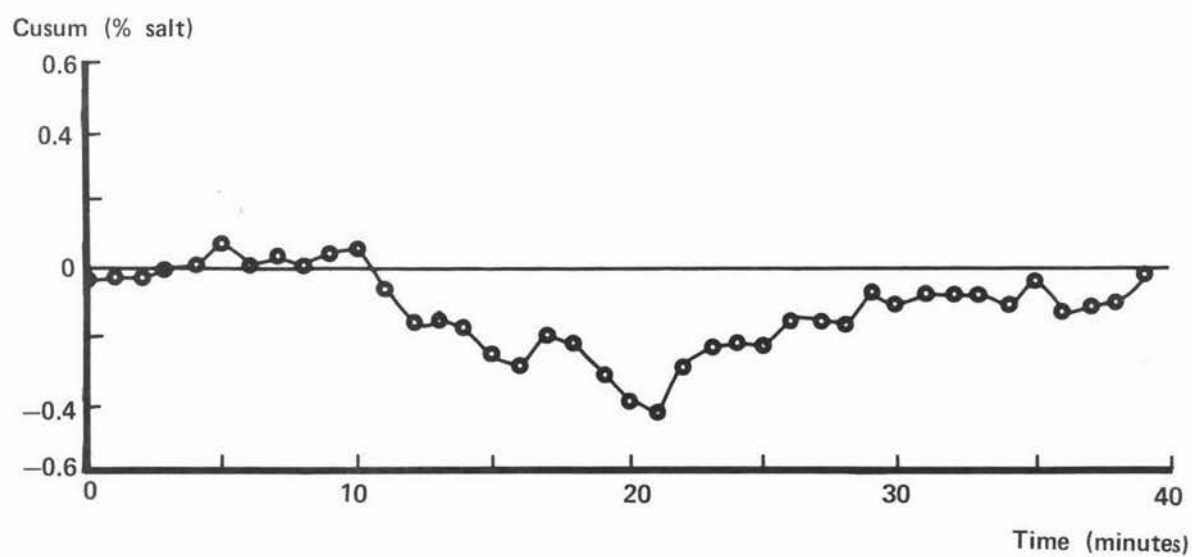


Fig. 38. Graph of Ribbon Speed (pulses/second) vs Time (minutes) (26/5/72)

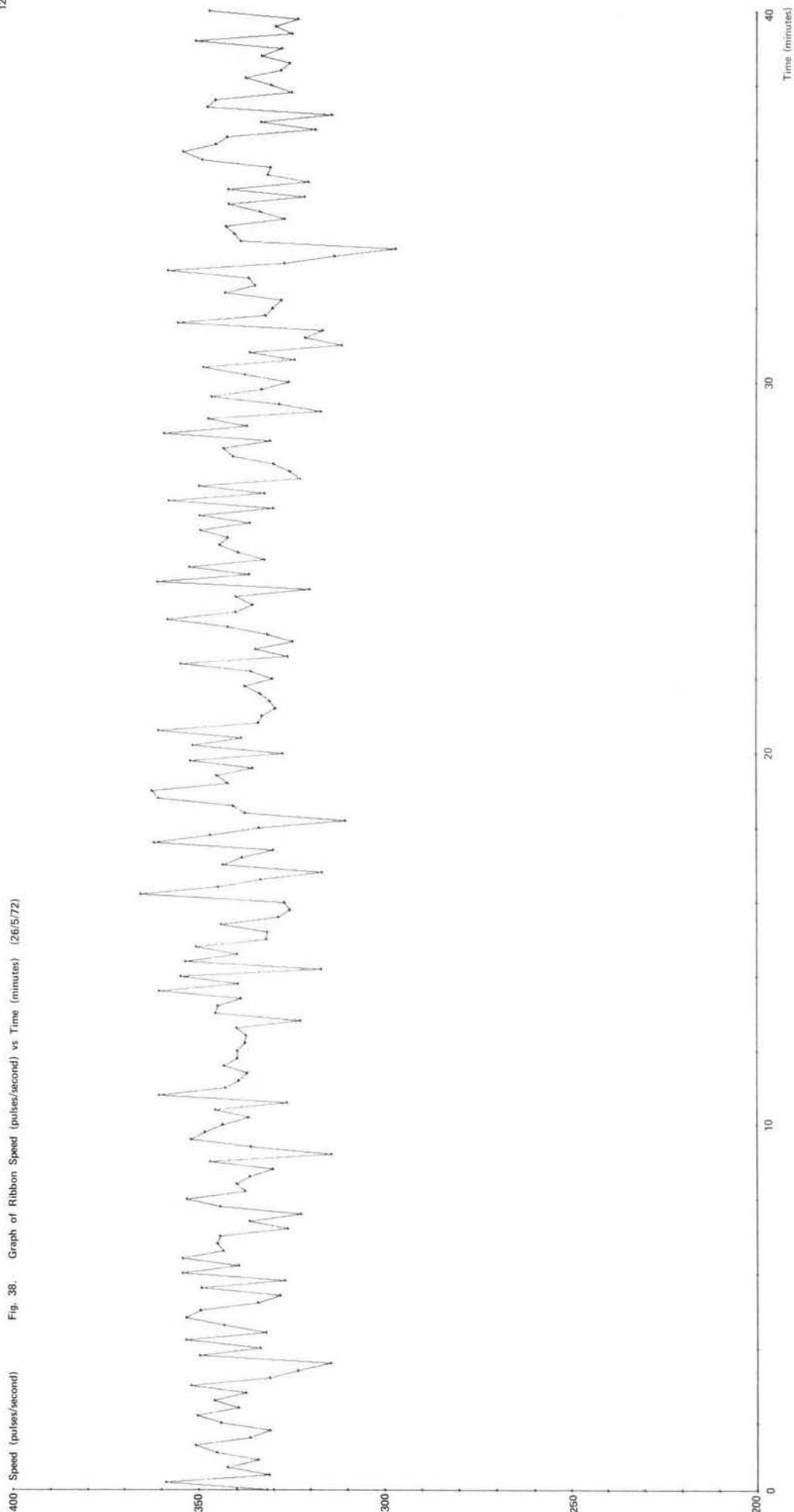
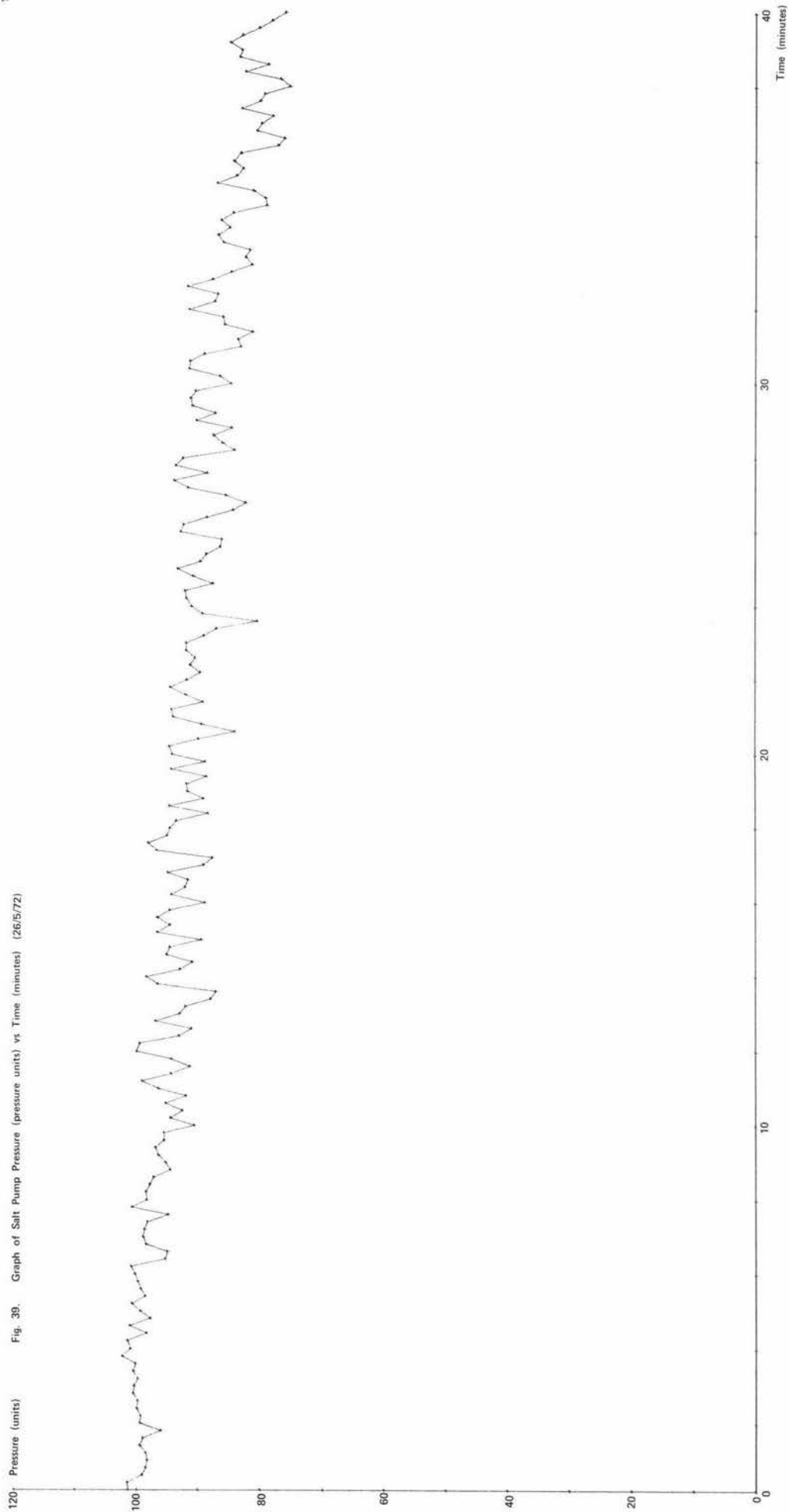


Fig. 39. Graph of Salt Pump Pressure (pressure units) vs Time (minutes) (26/5/72)



300 : Cusum (pulses/second) Fig. 40. Ribbon Speed Cusum Chart (26/5/72)

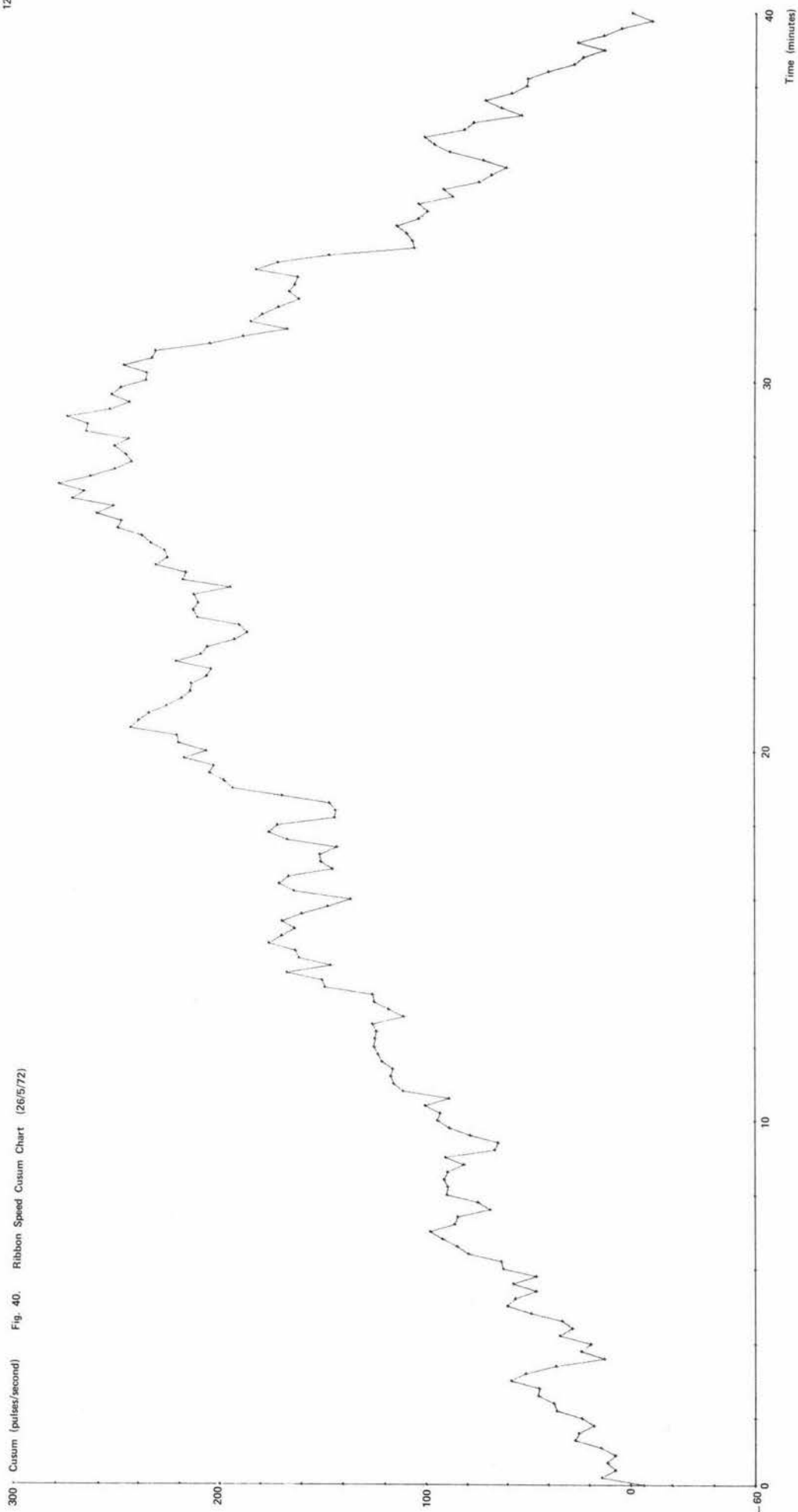
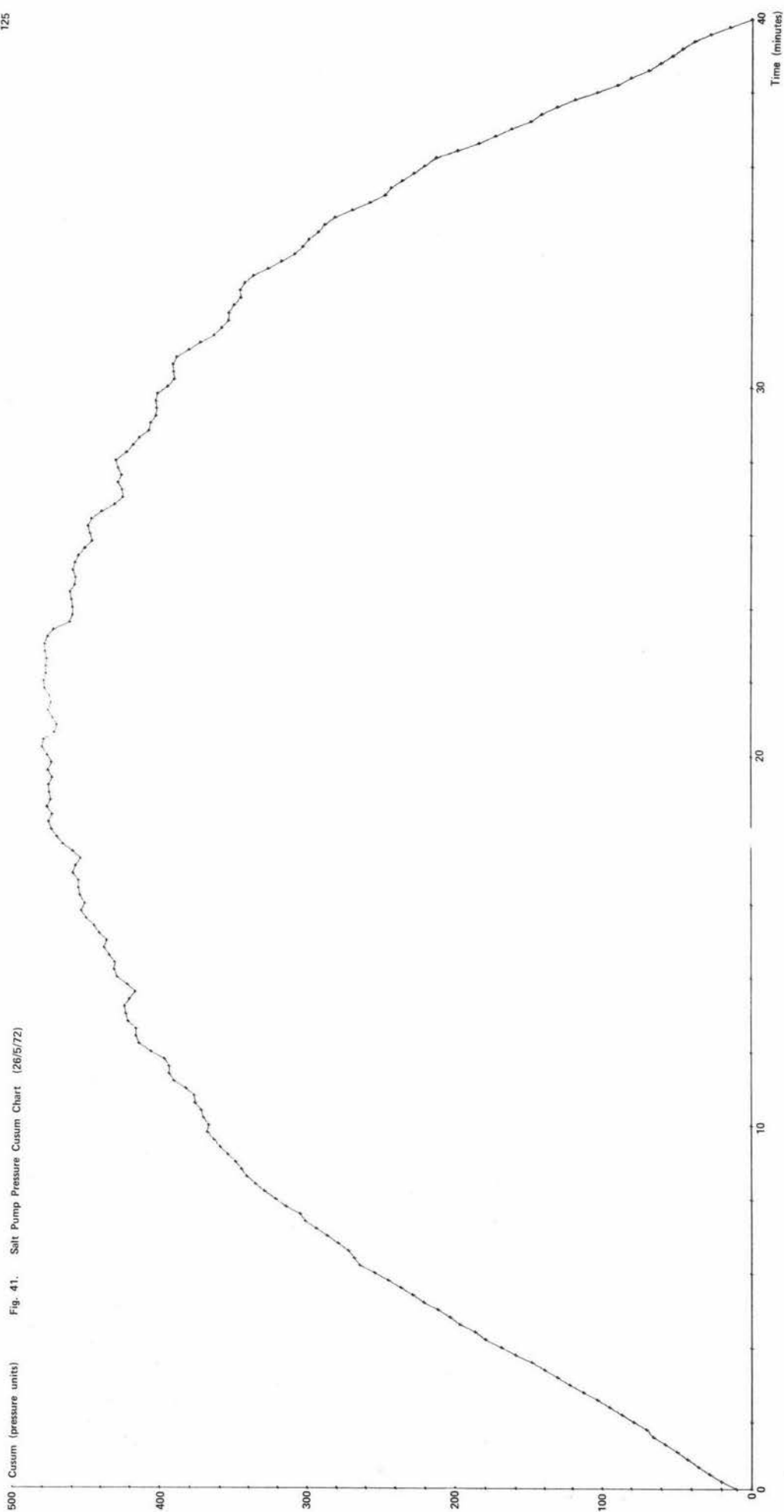


Fig. 41. Salt Pump Pressure Cumsum Chart (26/5/72)



The cusum chart for salt content and pressure indicate the expected relationship between these two variables. The salt cusum shows a general decrease followed by an increase which continues after 20 minutes. The pressure cusum shows the converse effect as expected. The changes seen in these variables are slow and the cause may be related to a slow change in pump performance. Flow variations seen in ribbon speed do not correspond with moisture and salt cusums.

Over the whole run the average pressure drops by approximately 18%, the mean salt content increases by a comparable amount, although a proportionate relationship was not really expected.

Salt Content (i)	1.15 %
(ii)	<u>1.35</u> %
Difference	<u>0.2</u> %
	= 17 % change based on original value

Pressure level (i)	99 units
(ii)	<u>81</u> units
Difference	<u>18</u> units
	= 18 % change based on original value

The moisture cusum chart appears to be related to the ribbon speed cusum and the correlation is positive. This tends to indicate, as in the previous discussion of Trial G (22/5/72) the variation is occurring as a result of changing worker speed rather than cream flow rate. Evidence is also seen of the cyclic form in ribbon speed which again is superimposed upon variation caused by other factors.

These results show variation in slurry injection to have a minor effect on variation in moisture content. The salt content is generally low and has low standard deviation. This allows a dominant effect to be exerted by additional factors, in this instance variations in worker speed could be responsible.

Discussion

Thus three different situations have been seen to occur.

Trial C (6/4/72) and Trial F (16/5/72)

Operator changes in machine variables have provided a dominant influence tending to determine the salt and moisture values. Ribbon speed is well related to butter and cream flow rates.

Trial G (22/5/72)

Outside influences are minimal and variation occurs from within the system. The expected pressure-salt relationship is seen to occur and influences both salt and moisture content. A positive relationship is evident between ribbon speed and butter moisture content in latter stages of the trial and suggests variation in worker speed as the causative factor. This relationship however, is not particularly strong and has only a minor influence on moisture content.

Trial H (26/5/72)

The relationship between ribbon speed and moisture content is more definite and appears to be a major factor controlling the moisture content for this trial. The variation in worker speed is suggested as the causative factor. The moisture content is virtually independent of the salt content. Pressure variation is the dominant influence on varying salt content.

From these results it would appear that varying emphasis occurs on different relationships.

(i) Moisture and salt variation may be highly related when the effect of other factors is minimal.

(ii) A strong pressure-salt relationship may exist which also influences moisture content. The variation in pressure introduces an external factor.

(iii) Moisture-salt interdependence may be low. The moisture content is primarily related to ribbon speed effects, while the salt content is related to pressure variation.

It is seen that the overriding factors are those machine variables controlled by the operator. If this influence is absent internal pressure and ribbon speed effects become evident. Under conditions of minimal variation, the salt-moisture relationship may become the prime source of compositional variation. These conditions have actually been present during several runs and thus to aim for minimising of the external factors is surely not an impractical task.

Comparison of Ribbon Speed and Salt Pump Pressure Data

Some similarities were observed between graphs of Speed and Pressure. A correlation analysis was carried out and a displacement series used. Displacement of speed relative to pressure and pressure relative to speed was made.

The interpretation of these results did not reveal a consistent relationship between speed and pressure. It is probable that speed and pressure are indeed related, but influence of external conditions overrides these interacting effects. Removal or minimising of these external effects may cause a speed-pressure relationship to have real significance when running under less variable conditions.

The correlation analysis showed both positive and negative coefficients, although these were confined to separate runs.

A negative correlation may occur if a constant quantity of butter is passing through the worker, a speed increase will tend to reduce the internal pressure as the effective cross sectional area of flow will tend to be reduced.

A positive correlation may occur if a varying quantity of butter is passing through the working section. An increase in butter flow will increase the ribbon speed, and also tend to result in a pressure increase. This assumes that butter density is not changing significantly.

Thus, the churn conditions are a complex set of factors. The dominance of any one factor is the crucial condition and before an accurate model may be constructed a considerable quantity of further information is essential.

Conclusions

It has been shown that relationship does exist between the churn characteristics of ribbon speed, salt pump injection pressure and the butter compositional factors of moisture and salt content.

However, such relationships are complex taking several forms, each of which may be determined by the extent of influence of external factors. The data available was able to describe the type of relationship existing between the factors but there was insufficient information to determine the reason for such a relationship; why it should occur in preference to other forms.

To fully understand the mechanism which determines butter composition additional factors must be studied. Only by knowledge of these influences can an accurate model be built to attempt explanation of continuous butter manufacture. Such a model is of great assistance if a control system is to be devised for the process of continuous buttermaking.

SECTION VSUGGESTIONS FOR FURTHER STUDY

Cream flow rate and primary churn beater speed are prime factors in influencing butter composition. Accurate measurement of these factors is needed to continue investigation of the continuous butter-making system.

The speed of the screws in the working section has also been shown to exert an important influence on butter composition and must be considered in further study of this topic.

The difficulty in accurate measurement of these factors has deterred investigation up till the present time. The problems associated with this may be resolved by use of suitable analogue-digital techniques. The vast quantity of information available may be recorded in such a form that presentation of the data could be made directly to computing facilities without the time consuming transcription by human operators.

Accuracy of Measurement required

Since it is desirable to detect changes of less than one standard deviation in moisture and salt content, these values should be measured to an accuracy of at least 0.05%, expressed as actual moisture or salt content.

This level of accuracy may be related back to the quantitative effects of variation in churn factors (previously discussed in Section I (page 15 ff)). It has been mentioned that a variation in primary churn speed of 100 r.p.m. may result in a butter moisture content change of up to 0.5%. Thus the requirement for measurement of primary churn speed approaches an accuracy of ± 10 r.p.m. (assuming approximate proportionality). This level of accuracy is quite demanding as the base churn speed may reach 2000 r.p.m.

Cream flow rate also has an important influence on butter moisture content and under normal running conditions a change in flow rate of 10% may give rise to a butter moisture content change of up to 0.3%. This suggests that measurement of cream flow rate must be sufficiently accurate to detect changes of 1-2% in volume flow. Under normal conditions the cream flow rate is approximately 300 pounds per minute

(page 80) and thus the accuracy required in measurement of cream flow approaches ± 3 pounds per minute.

The speed of the screws in the working section is a major factor used in process control. Alteration of butter moisture content of up to 0.1% may be achieved by a change of only 1-2 r.p.m. in the worker speed. The accuracy required in measurement of worker speed would thus be in the region of ± 0.5 r.p.m. as changes of 0.05% butter moisture content may be considered significant.

TABLE XV ESTIMATED ACCURACY REQUIRED FOR MEASUREMENT
OF CHURN VARIABLES

Factor	Primary Churn (Beater)	Cream Flow Rate	Worker Screw Speed
Base Value	1000 - 1800 rpm	300 lb/min	30 - 60 rpm
Accuracy Required	± 10 rpm	± 3 lb/min	± 0.5 rpm
\therefore % Change Detected	± 0.5 %	± 1 %	± 1 %

SECTION VI

Conclusions

This study has investigated variation in composition of butter manufactured by the Continab MC 30 continuous churn during commercial production. From the initial study it was shown that the behaviour of the salt injection system contributed markedly to the patterns of variation found in product composition.

Further process factors, suggested by the results from the initial study, were examined with respect to their influence on product composition. Relationships were found between a number of factors including butter ribbon speed, pressure within the working section, flow rate and the variation in butter composition. The type of relationship **varied** considerably - depending upon the presence of external factors. The nature of the dominant external factors is not yet fully known.

Knowledge of the buttermaking process is not sufficiently complete to enable building of a model to describe the total system. Further work may allow building of a successful model which would allow improved process control through application of a suitable control system. If this is realised, then the reduction in process variation achieved from control could **prove** greatly beneficial to the economic operation of continuous butter manufacture.

APPENDIX I

- 1) Weight changes during cooling of empty moisture dishes, dried overnight in 100°C. oven.

Dish	Weight change during period (grams)		
	(0.5 - 1.0 hr)	(1.0 - 1.5 hr)	(1.5 - 2.0 hr)
1	+0.0002	+0.0002	-0.0002
2	+0.0002	+0.0002	-0.0001
3	-0.0006	+0.0001	0.0000
4	+0.0001	+0.0004	-0.0001
5	+0.0006	-0.0001	-0.0003
6	+0.0003	+0.0002	-0.0002
7	+0.0007	0.0000	-0.0002
8	+0.0006	0.0000	-0.0004
Standard	-0.0005	-0.0005	-0.0001

Weight change was considered to be at an acceptable level after 1.5 hrs. cooling.

- 2) Weight changes during cooling of dish + butter sample after moisture removal.

Dish	Weight change during period (grams)		
	(1.0 - 1.5 hr)	(1.5 - 2.0 hr)	(2.0 - 2.5 hr)
1	+0.0007	0.0000	0.0000
2	+0.0005	+0.0002	-0.0001
3	+0.0018	+0.0001	0.0000
4	+0.0005	+0.0001	+0.0001
5	+0.0008	+0.0006	+0.0004
6	+0.0004	+0.0003	0.0000
Standard	+0.0005	+0.0007	0.0000

Weight change was considered to be at an acceptable level after 2.0 - 2.5 hrs. cooling.

APPENDIX IISUMMARY OF ANALYSIS OF VARIANCEFactors Considered

(1) P-Position. Nine positions were analysed in duplicate. The level of this factor = 9. Degrees of freedom = 8.

(2) T-Time - the number of samples taken.

For run (a) - 14 slice samples

(b) - 11 slice samples

The factor level (a) - 14

(b) - 11

Degrees of freedom (a) - 13

(b) - 10

(3) R-Repetitions - the duplicate results give rise to some variation and this factor was analysed separately. However, the mean sum of squares of this factor was low in comparison with others. Indeed it should not provide a significant source of variation. The higher order factors incorporating this source factor, also had low mean sum of squares in comparison with others. The zero and higher order factors which included R were summed as the Residual for the purposes of this analysis.

Trial (28/9/71)

MOISTURE CONTENT

FACTOR	SSQ	DF	MSQ	μ^2
P	0.04996	8	0.00624	2.96
T	5.13669	13	0.39513	187.27
PxT	0.56400	104	0.00542	2.57
RESIDUAL	0.26545	126	0.00211	
TOTAL	6.01610	251		

PxT Interaction

$$\begin{array}{ll}
 V_1 = 104 & V_2 = 126 \\
 f_{0.01} = 1.66 & S_1^2 = 2.57 \\
 (60, 120) & \frac{S_1^2}{S_2^2}
 \end{array}$$

Thus PxT is significant at level $f_{0.01}$.

Trial (28/9/72)

SALT CONTENT

FACTOR	SSQ	DF	MSQ	ψ^2
P	0.01489	8	0.00186	1.69
T	1.26494	13	0.00973	8.85
PxT	0.31761	104	0.00305	2.77
RESIDUAL	0.14008	126	0.0011	
TOTAL	1.7352	251		

PxT Interaction

$$\begin{array}{rcl}
 V_1 & = & 104 \\
 f_{0.01} & = & 1.66 \\
 (60, 120) & &
 \end{array}
 \qquad
 \begin{array}{rcl}
 V_2 & = & 126 \\
 \frac{S_1^2}{S_2^2} & = & 2.77
 \end{array}$$

Thus PxT is significant at level $f_{0.01}$.

Trial (28/10/71)

MOISTURE CONTENT

FACTOR	SSQ	DF	MSQ	ψ^2
P	0.02684	8	0.00333	1.164
T	0.25378	10	0.02538	8.874
PxT	0.45636	80	0.00570	1.99
RESIDUAL	0.23090	99	0.00286	
TOTAL	0.96788	197		

PxT Interaction

$$\begin{array}{rcl}
 V_1 & = & 80 \\
 f_{0.01} & = & 1.84 \\
 (60, 60) & &
 \end{array}
 \qquad
 \begin{array}{rcl}
 V_2 & = & 99 \\
 \frac{S_1^2}{S_2^2} & = & 1.99
 \end{array}$$

Thus PxT is significant at level $f_{0.01}$.

Trial (28/10/71)

SALT CONTENT

FACTOR	SSQ	DF	MSQ	ψ^2
P	0.06496	8	0.00812	1.457
T	0.49101	10	0.04910	
PxT	0.66856	80	0.00835	
RESIDUAL	0.67611	99	0.00683	
TOTAL	1.90064	197		

PxT Interaction

$$\begin{array}{rcl}
 V_1 & = & 80 \\
 f_{0.05} & = & 1.4 \\
 (75, 100) & &
 \end{array}
 \qquad
 \begin{array}{rcl}
 V_2 & = & 99 \\
 S_1^2 & = & 1.457 \\
 \hline
 S_2^2 & &
 \end{array}$$

Thus PxT is significant at level $f_{0.05}$.

Comment

The significance of PxT interaction indicates that a portion of the variation in results may be explained only by a combination of both position and time variables. The importance of time is clear because of the extremely high mean of squares values assigned to it, although its statistical significance may not be validly tested as a higher order interaction (PxT) has proved significant.

APPENDIX IIIANALYSIS OF RESULTS USING CUMULATIVE SUM (CUSUM) TECHNIQUES (32)

The basic procedure for calculation of Cumulative Sums consists of subtracting a constant quantity (e.g. a target value) from each value in the series and summing the resulting differences. The successive accumulated differences termed the Cumulative Sums may be graphed to give a 'Cusum Chart'.

The cusum technique has the advantage of detecting changes in the mean value of the process variable. Historical trends are clearly shown and the onset of any change in the process variable is evident. A reliable estimate of the current average value may be made rapidly. The cusum technique contrasts with quality control methods such as the 'Shewhart' chart where actual values are plotted. This type of chart is used to detect process values which fall outside warning and/or tolerance values. It may not readily show changes in the process mean value when fluctuations occur.

The main application of cusum techniques has been in industrial quality control. Process or product variables may be determined at regular intervals and compared with pre-specified levels. Movements away from the target values may be detected readily and their magnitudes determined so as to enable corrective action.

Determination of Cumulative Sums and Chart Plotting

Consider a set of results $x_1, x_2, x_3, \dots x_n$ obtained at equal time intervals, and a reference value (which may be zero) K .

If the calculation $S_1 = (x_1 - K)$ is performed, a difference is obtained, and the origin of measurement is in fact changed to K . K may be a target value to which the variable (x) is supposed to approach.

If consecutive differences are calculated and then summed

$$\begin{aligned}
 S_2 &= (x_1 - K) + (x_2 - K) \\
 S_3 &= (x_1 - K) + (x_2 - K) + (x_3 - K) \dots \text{and so on.} \\
 \text{then } S_n &= S_{n-1} + (x_n - K) \\
 &= x_1 + x_2 + x_3 + x_n - nK
 \end{aligned}$$

Successive values of $S_1, S_2, S_3, \dots S_n$ are plotted at equal time intervals to construct the cusum chart.

- (1) If the values of x are greater than K , (the target or reference value), a graph of positive slope will be drawn.
- (2) Similarly, a graph of negative slope will be drawn if x is less than K . The value or degree of the slope indicates the magnitude of the difference between x and K .
- (3) If x approaches closely to K , then a steady line of slope 0 will be drawn.

Thus any prolonged change in the mean value of x will result in a change in the slope of the plotted cusum. By determining the relative changes in slope significance of the change in mean may be determined. Suitable methods have been devised for testing of significance. An example is the V-mask test.

Cusum charts have been used in this project to indicate changes in the mean value of the variable. Generally the reference value (K) has been selected as the grand mean of the set of results, hence the initial and final plotted values closely approach zero. The cusum chart has been constructed and regions of changing slope have been investigated to determine if important changes in the mean value have occurred.

In some cases comparison has been made between cusum charts of different variables to determine if a relationship exists between these variables. The cusum chart is well suited to this, as changes in slope may be readily examined.

It is important in the use of cusum charts to select suitable graph scales. If quantitative significance tests are being conducted the scales must be correctly sized. If such tests are not being used, then the scale sizing is less critical, the criterion being the sensitivity and ability to show an important change in the mean value of the process variable.

Correlation

Correlation analysis is a technique used to investigate the type and extent of relationship which exists between two variables. If paired values of two variables x and y are plotted as a point (x,y) the plotted points form a scatter diagram. Fig. 42 (page 141) shows the three possibilities -

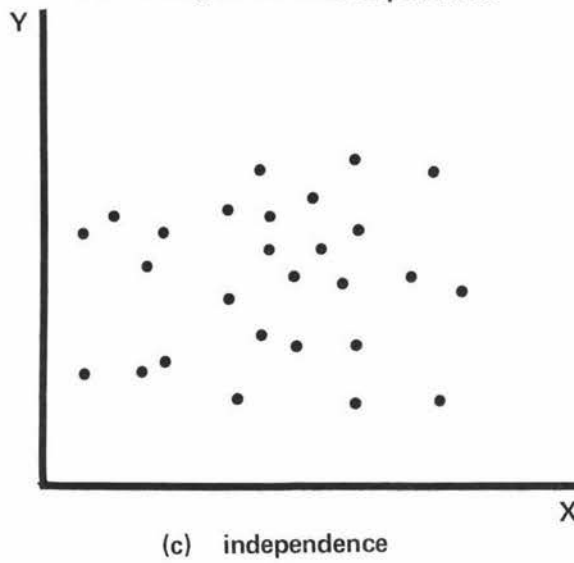
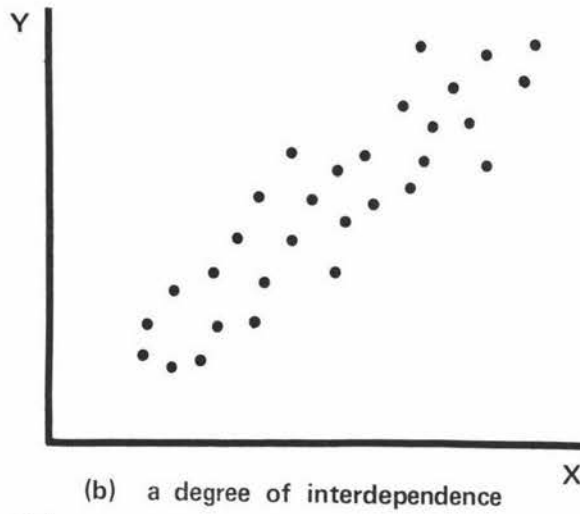
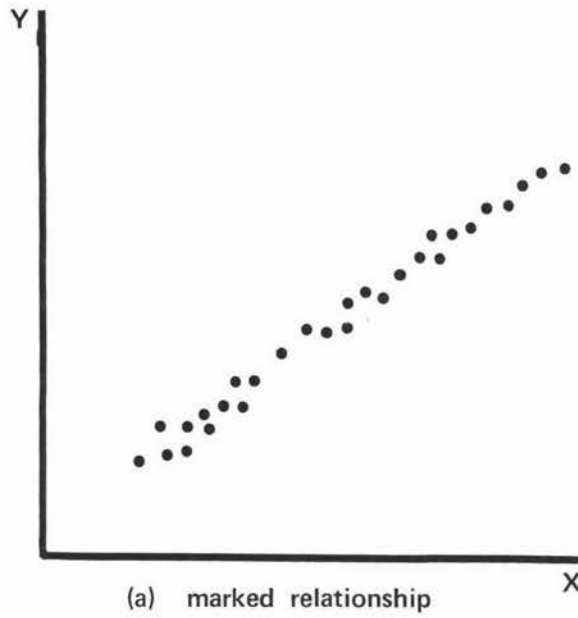
- (i) marked relationship
- (ii) a degree of interdependence
- (iii) independence

reflected in a scatter diagram.

A correlation coefficient may be calculated as a quantitative guide to the degree of dependence between x and y . The correlation coefficient does not indicate which variable is dependent and which is independent. Such distinction is a problem of interpretation and may require additional information.

Statistical methods for determination of correlation are helpful techniques to evaluate relationships but interpretation of results is an important factor. Interdependency may be indicated by correlation analysis yet in fact this may be refuted by subsequent interpretation and investigation. Correlation analysis has been used in many sections of the project. Interpretation of such results is found in the relevant discussion for each section.

Fig. 42. Scatter Diagram — Graph of Y vs X



APPENDIX IVSALT SLURRY INJECTION PUMP PERFORMANCE

The pump from a Continab MB 5 was tested for performance under varying conditions. The pump was obtained from the Dairy Research Institute.

Procedure

The dosing quantity for 10 consecutive pulses was determined for a number of cycles. The fluid used was water. A valve was placed on the delivery line and was varied to alter the applied delivery head. A pressure gauge was also placed in the line to determine the applied delivery head. The pressure measured was that pressure in excess of the static head of the particular system. A variable diameter pulley was fitted to enable alteration of the pumping rate (pulses/second).

A series of trials was conducted and pump performance determined under varying conditions of fluid level in the reservoir, delivery head and pumping rate.

A summary of these results is presented below. In all cases, the quantity for each sample has been collected from 10 consecutive pulses and has been expressed as weight in grams.

	Speed	Applied Delivery Pressure (psi)	Fluid Level in Reservoir	Sample Size	Mean Quantity (sum of 10 pulses) (grams)	Standard Deviation
(1)	Normal	0	High	20	35.5	0.63
(2)	Normal	10	High	20	32.1	1.3
(3)	High	0	Low	20	36.4	1.3
(4)	High	10	Low	10	26.9	1.1

Significance tests were carried out to compare performances under different conditions, using the criterion

$$t = \frac{(x_1 - x_2)}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$$\text{where } S_p \text{ (pooled variances)} = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}$$

where t - a value of the t distribution

x_1, x_2 - mean value of sample 1, 2

n_1, n_2 - size of sample 1, 2

S_1, S_2 - sample variances (1, 2)

$V = (n_1 + n_2 - 2)$ - degrees of freedom.

Sample Calculation

To test if the difference in pressure between Trial (1) and (2) has significantly changed the dosing quantity.

$$\begin{aligned} V &= n_1 + n_2 - 2 \\ &= 38 \end{aligned}$$

$$t_{0.01} = 2.576$$

$$\begin{aligned} S_p &= \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \\ &= \frac{19(0.63)^2 + 19(1.3)^2}{(20 + 20 - 2)} \\ &= \frac{19(0.4 + 1.6)}{38} \end{aligned}$$

$$S_p = \underline{1}$$

$$t = \frac{(x_1 - x_2)}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

$$= \frac{35.5 - 32.1}{1 \sqrt{\frac{1}{20} + \frac{1}{20}}}$$

$$= \frac{3.4}{0.316}$$

$$t = \underline{10.8}$$

Thus there is a significant difference in the mean dosage given by the pump, between trials (1) and (2). A decrease in dosing quantity occurs if the delivery head is increased. This was shown to be true for both low and high levels in the reservoir.

It was shown that a decrease in reservoir level decreased the dosage markedly when the delivery head was at 10 psi. It should be noted that the decrease occurred even though the rate of pumping was increased. Compare trials (2) and (4). This was not true when the delivery head was 0 psi. The increased rate of pumping has increased the dosing quantity in spite of lower reservoir level. This is probably a result of improved sealing of the diaphragm at higher pumping rate. It is likely that the dosing quantity would have decreased as the reservoir level dropped, had the pump speed remained the same and it should be noted that between trials (1) and (3) there is not such a significant change in mean as with the other trials.

Note: At the time of this investigation, the pressure under which the pump operates in general production had not been determined. Consequently the pressures applied are somewhat lower than in actual production conditions.

APPENDIX VTEST FOR NORMALITY - MOISTURE VALUES

Grand Mean = 15.584

Standard Deviation = 0.173

Class Mean	$X - \mu$	$Z = \frac{X - \mu}{\sigma}$	Normal Prob.	Area	Expected Frequency	Observed Frequency	χ^2
15.20	-0.384	-2.26	0.0119	0.0119	2.31	2	
15.25	-0.334	-1.96	0.0250	0.0131	2.54	5	0.842
15.30	-0.284	-1.67	0.0475	0.0225	4.37	5	
15.35	-0.234	-1.38	0.0838	0.0363	7.04	8	0.1303
15.40	-0.184	-1.08	0.1401	0.0563	10.922	15	1.523
15.45	-0.134	-0.79	0.2148	0.0747	14.49	19	1.402
15.50	-0.084	-0.49	0.3121	0.0973	18.88	22	0.517
15.55	-0.034	-0.20	0.4207	0.1086	21.07	29	2.986
15.60	+0.016	+0.09	0.5359	0.1152	22.35	12	4.791
15.65	0.056	0.39	0.6517	0.1158	22.47	16	1.860
15.70	0.116	0.68	0.7517	0.1000	19.40	12	2.822
15.75	0.166	0.98	0.8365	0.0848	16.45	22	1.872
15.80	0.216	1.27	0.8980	0.0615	11.93	11	0.073
15.85	0.266	1.56	0.9406	0.0426	8.26	5	1.289
15.90	0.316	1.86	0.9686	0.0280	5.43	9	5.432
15.95	0.366	2.09	0.9817	0.0131	2.54	0	2.748
16.00	0.416	2.45	0.9929	0.0112	2.17	0	
16.05	0.466	2.74	0.9969	0.0071	1.38	2	
							<u>25.20</u>

Number of cells = 14

Degrees of freedom = 11

$$\chi^2_{0.01} = 24.73$$

$$\chi^2_{0.005} = 26.76$$

Since the calculated χ^2 value is within the acceptable limits, the frequency distribution of Moisture Values can be said to approximate to a normal distribution.

TEST FOR NORMALITY - SALT VALUES

Grand Mean = 1.57

Standard Deviation = 0.11

Class Mean	$Z = \frac{x - \mu}{\sigma}$	Normal Prob.	Area	Expected Frequency	Observed Frequency	ψ^2
1.20	-3.391	0.0003	0.0003	0.06		
1.25	-2.936	0.0016	0.0013	0.25	1	
1.30	-2.482	0.0066	0.0050	0.97	1	0.20
1.35	-2.027	0.0212	0.0146	2.83	3	
1.40	-1.573	0.0582	0.0370	7.18	12	3.25
1.45	-1.181	0.1190	0.0600	11.79	16	1.50
1.50	-0.664	0.2546	0.1356	26.30	33	1.71
1.55	-0.209	0.4168	0.1622	31.46	37	0.98
1.60	+0.245	0.5987	0.1819	35.28	28	1.49
1.65	+0.700	0.7580	0.1593	30.90	26	0.78
1.70	1.154	0.8749	0.1169	22.67	24	0.08
1.75	1.609	0.9463	0.0714	13.85	5	5.66
1.80	2.064	0.9803	0.0340	6.59	6	0.05
1.85	2.578	0.9941	0.0138	2.68	1	1.07
1.90	2.973	0.9955	0.0059	1.15	0	
1.95	3.881		0.0015	0.3	1	
						<u>16.77</u>

Number of cells = 11

Degrees of freedom = 11-3

= 8

$$\psi^2_{0.05} = 15.51$$

$$\psi^2_{0.025} = 17.54$$

Since the calculated ψ^2 value is within the acceptable limits, the frequency distribution of salt values can be said to approximate to a normal distribution.

APPENDIX VITABLE XVI

SUMMARY OF RESULTS FOR VARIABLES OTHER
THAN MOISTURE OR SALT

Date	Variable	Sample Size	Mean Value	Standard Deviation
7/2/72	Cream Fat Content	40	39.5	0.3
3/3/72	Cream Fat Content	40	39.5	0.6
6/4/72	Cream Fat Content	40	39.6	0.5
	Ribbon Speed	1037	271.6	14.4
3/5/72	Ribbon Speed	624	280.4	7.3
16/5/72	Ribbon Speed	1005	257.3	6.8
	Salt Pump Pressure	2124	85.1	5.3
22/5/72	Ribbon Speed	1040	323.1	23.3
	Salt Pump Pressure	1619	78.6	5.0
26/5/72	Ribbon Speed	1040	338.2	18.0
	Salt Pump Pressure	1760	92.1	7.3
6/4/72	Ribbon Speed	405 (1-404)	258.9	12.8
6/4/72	Ribbon Speed	633 (405-1037)	279.7	8.7

Units: Fat Content (%)

Ribbon Speed pulses/unit time

Pressure (undefined)

APPENDIX VIILISTING OF SELECTED COMPUTER PROGRAMS
USED IN DATA PROCESSING

Program 1 - Analysis of slices and time sequenced series, moisture and salt values.

Data Input: Each pair of duplicate moisture and salt values were punched on one card.

Moisture value - Format F 7.4

Salt value - Format F 5.3

Program 2 - Calculation of standard deviation and correlation coefficient, displacement analysis included.

Data Input: The mean moisture and salt values of duplicate analyses were punched on one card.

Moisture value - Format F 7.4

Salt value - Format F 5.3

Program 3 - Ribbon speed and salt pump injection pressure data and and cusum plotted. Each data value plotted is mean of 8 consecutive raw data values.

Data Input:

Ribbon Speed - Format F 3.0

Salt Pump Pressure - Format F 2.0

For salt pump pressure, values greater than 100 were punched as 'units' and 'tens' digits only. The program restored the 'hundreds' digit.

PROGRAM FOR ANALYSIS OF SLICES AND TIME SEQUENCED SERIES

```

DIMENSIONX( 20,20 ),S( 20,20 )
XSUM=0.
XSQ=0.
SSUM=0.
SSQ=0.
XNA=0.
XNB=0.
XTOT=0.
XMEAN=0.
SMEAN=0.
SDEVX=0.
SDEVS=0.
SDEVY=0.
SDEVT=0.
YMEAN=0.
TMEAN=0.
ZMEAN=0.
UMEAN=0.
SDEVZ=0.
SDEVU=0.
READ100,NA,NB
DO1I=1,NA
DO1J=1,NB,2
1 READ200,X(I,J),S(I,J),X(I,J+1),S(I,J+1)
DO2I=1,NA
DO2J=1,NB
XSUM=XSUM+X(I,J)
XSQ=XSQ+X(I,J)**2
SSUM=SSUM+S(I,J)
2 SSQ=SSQ+S(I,J)**2
XNA=NA
XNB=NB

```

```

XTOT=XNA*XNB
XMEAN=XSUM/XTOT
SMEAN=SSUM/XTOT
SDEVX=SQRTF((XTOT*XSQ-XSUM**2)/(XTOT*(XTOT-1.)))
SDEVS=SQRTF((XTOT*SSQ-SSUM**2)/(XTOT*(XTOT-1.)))
PRINT 700
PRINT 750
PRINT 300,XMEAN,SDEVX,SMEAN,SDEVS
PRINT 800
PRINT 750
DO 4 I=1,NA
  YSUM=0.
  YSQ=0.
  TSUM=0.
  TSQ=0.
  DO 3 J=1,NB
    YSUM=YSUM+X(I,J)
    YSQ=YSQ+X(I,J)**2
    TSUM=TSUM+S(I,J)
  3 TSQ=TSQ+S(I,J)**2
  YMEAN=YSUM/XNB
  TMEAN=TSUM/XNB
  SDEVY=SQRTF((XNB*YSQ-YSUM**2)/(XNB*(XNB-1.)))
  SDEVT=SQRTF((XNB*TSQ-TSUM**2)/(XNB*(XNB-1.)))
  PRINT 300,YMEAN,SDEVY,TMEAN,SDEVT
  4 CONTINUE
PRINT 900
900 FORMAT(1H1,40X,26HRESULTS FOR LIKE LOCATIONS//)
PRINT 750
DO 6 J=1,NB,2
  ZSUM=0.
  ZSQ=0.
  USUM=0.
  USQ=0.

```

```

DOSI=1,NA
ZSUM=ZSUM+X(I,J)+X(I,J+1)
ZSQ=ZSQ+X(I,J)**2+X(I,J+1)**2
USUM=USUM+S(I,J)+S(I,J+1)
5 USQ=USQ+S(I,J)**2+S(I,J+1)**2
XNAB=XNA*2.
ZMEAN=ZSUM/XNAB
UMEAN=USUM/XNAB
SDEVZ=SQRTF((XNAB*ZSQ-ZSUM**2)/(XNAB*(XNAB-1.)))
SDEVU=SQRTF((XNAB*USQ-USUM**2)/(XNAB*(XNAB-1.)))
PRINT300,ZMEAN,SDEVZ,UMEAN,SDEVU
6 CONTINUE
100 FORMAT(2I2)
200 FORMAT(10X,F7.0,F5.0,F7.0,F5.0)
300 FORMAT(1H0,20X,F10.5,13X,F10.5,14X,F10.5,13X,F10.5)
700 FORMAT(1H1,40X,15HOVERALL RESULTS//)
750 FORMAT(1H,15X,14HMOISTURE MEAN,8X,17HMOISTURE STD DEV,12X,
110HSALT MEAN,8X,13HSALT STD DEV ///)
800 FORMAT(1H1,40X,29HRESULTS FOR INDIVIDUAL SLICES//)
END

```


PROGRAM FOR CALCULATION OF STANDARD DEVIATION AND CORRELATION
COEFFICIENT- DISPLACEMENT ANALYSIS INCLUDED

```

    DIMENSIONX(40),S(40),F(40)
1  READ100,N
1 00  FORMAT (I2)
    DO3I=1,N
3  READ200,X(I),S(I),F(I)
200  FORMAT(10X,F7.0,F5.0,F4.0)
    XSUM=0.
    XSQ=0.
    SSUM=0.
    SSQ=0.
    FSUM=0.
    FSQ=0.
    XPROD=0.
    SDEVF=0.
    SDEVS=0.
    SDEVX=0.
    FPROD=0.
    R=0.
    XN=0.
    M=0
    DO4I=1,N
    XSUM=X(I)+XSUM
    XSQ=X(I)**2+XSQ
    SSUM=S(I)+SSUM
    SSQ=S(I)**2+SSQ
    FSUM=F(I)+FSUM
    FSQ=F(I)**2+FSQ
4  XPROD=X(I)*S(I)+XPROD
    XN=N
    NT=N
    FMEAN=FSUM/XN

```

```

SMEAN=SSUM/XN
XMEAN=XSUM/XN
SDEVX=SQRTF((XN*XSQ-XSUM**2)/(XN*(XN-1.)))
SDEVF=SQRTF((XN*FSQ-FSUM**2)/(XN*(XN-1.)))
SDEVS=SQRTF((XN*SSQ-SSUM**2)/(XN*(XN-1.)))
R=(XN*XPROD-(XSUM*SSUM))/SQRTF((XN*XSQ-XSUM**2)*(XN*SSQ-SSUM**2))
PRINT 300
300 FORMAT(1H ,40X,24H CORRELATION COEFFICIENTS///)
PRINT 400,R
400 FORMAT(1H ,20X,13H MOISTURE-SALT,F8.5///)
PRINT 130
130 FORMAT(1H ,5X,13H MOISTURE MEAN,5X,16H MOISTURE STD DEV,8X,9H SALT ME2
2AN,5X,12H SALT STD DEV,8X,8H FAT MEAN,5X,11H FAT STD DEV///)
PRINT 150,XMEAN,SDEVX,SMEAN,SDEVS,FMEAN,SDEVF
150 FORMAT(1H ,8X,F10.5,8X,F10.5,11X,F10.5,6X,F10.5,8X,F10.3,5X,F10.3/3
3//)

```

SECTION FOR DISPLACEMENT ANALYSIS

```

PRINT 500
500 FORMAT(1H ,25X,19H DISPLACEMENT VALUES,24X,14H CORRELN COEFFT//)
5 FSUM=0.
FSQ=0.
XSUM=0.
XSQ=0.
FPROD=0.
DO 6 I=1,N
XSUM=X(I)+XSUM
XSQ=X(I)**2+XSQ
FSUM=F(I)+FSUM
FSQ=F(I)**2+FSQ
6 FPROD=F(I)*X(I)+FPROD
XN=N
R=(XN*FPROD-(XSUM*FSUM))/SQRTF((XN*XSQ-XSUM**2)*(XN*FSQ-FSUM**2))
M=NT-N

```

```
PRINT600,M,R
600 FORMAT(1H ,33X,I4,39X,F8.5)
    IF(M-30)7,10,10
7  N=N-1
    DO8I=1,N
8  X(I)=X(I+1)
    GOT05
10 CALL EXIT
    END
```

PROGRAM FOR RIBBON SPEED AND INJECTION PRESSURE DATA AND CUSUM
PLOT, USING MEAN OF 8 CONSECUTIVE VALUES

```

DIMENSION SP(26), PR(40), SMN(220), PMN(220), CUSUM(220), CUSUMP(220)
50 READ 40, MS, MP, XM
40 FORMAT(2I2, F4.0)
   PRINT 41, MS, MP, XM
41 FORMAT(1H 3HMS=, I4, 10X, 3HMP=, I4, 10X, 3HXM=, F8.0, //)
   L=0
   DO 8 K=1, MS
     READ 100, (SP(I), I=1, 26)
100  FORMAT(26F3.0)
     DO 8 I=1, 5
       J=((I-1)*5)+1
       S=(SP(J)+SP(J+1)+SP(J+2)+SP(J+3)+SP(J+4))/5.
       L=L+1
       SMN(L)=S
8    CONTINUE
     PRINT 200
200  FORMAT(1H , 20X, 22HMEAN OF 5 VALUES SPEED//)
     PRINT 210, (SMN(I), I=1, L)
210  FORMAT(15F8.0)
     M=0
     DO 28 K=1, MP
       READ 110, (PR(I), I=1, 40)
110  FORMAT(40F2.0)
       DO 26 I=1, 40
         IF (PR(I)-13.) 24, 24, 26
24    PR(I)=PR(I)+100.
26    CONTINUE
       DO 28 I=1, 5
         J=((I-1)*8)+1
         P=(PR(J)+PR(J+1)+PR(J+2)+PR(J+3)+PR(J+4)+PR(J+5)+PR(J+6)+PR(J+7))/
18.

```

```

      M=M+1
      PMN(M)=P
28  CONTINUE
      PRINT 220
220  FORMAT (1H1,20X,25HMEAN OF 8 VALUES PRESSURE//)
      PRINT 230, (PMN(I), I=1, M)
230  FORMAT (15F8.0)
      SECTION FOR CUSUM CALCULATION

      PRSUM=0.
      SPSUM=0.
      COSUM=0.
      DIFF=0.
      XLT=L
      PRINT 400
400  FORMAT (1H1,30X,31HSPEED CUSUM VALUES (MEAN OF 8)//)
410  FORMAT (1H1,30X,31HPRESS CUSUM VALUES (MEAN OF 8)//)
      DO 411 I=1, L
      SPSUM=SPSUM+SMN(I)
411  PRSUM=PRSUM+PMN(I)
      SPMUN=SPSUM/XLT
      PRMUN=PRSUM/XLT
      DO 412 I=1, L
      DIFF=SMN(I)-SPMUN
      COSUM=COSUM+DIFF
412  CUSUM(I)=COSUM
      PRINT 500, (CUSUM(I), I=1, L)
500  FORMAT (1H ,15F8.0)
      PRINT 410
      COSUM=0.
      DO 413 I=1, L
      DIFF=PMN(I)-PRMUN
      COSUM=COSUM+DIFF
413  CUSUMP(I)=COSUM
      PRINT 500, (CUSUMP(I), I=1, L)

```

SECTION FOR PLOTTING OF DATA AND CUSUM VALUES (MEAN OF 8)

```

XMIN=1.
XMAX=XL T
XL=20.
XD=10.
YL=10.
YD=10.
YMAX=4 00.
YMIN=200.
CALLPLOT(1,XMIN,XMAX,XL,XD,YMIN,YMAX,YL,YD)
DO414 I=1,L
X=I
CALLPLOT(0,X,SMN(I))
414 CONTINUE
CALLPLOT(7)
XMIN=1.
XMAX=XL T
XL=20.
XD=10.
YL=10.
YD=10.
YMAX=1 20.
YMIN=0.
CALLPLOT(1,XMIN,XMAX,XL,XD,YMIN,YMAX,YL,YD)
DO415 I=1,L
X=I
CALLPLOT(0,X,PMN(I))
415 CONTINUE
CALLPLOT(7)
XMIN=1.
XMAX=XL T
XL=20.
XD=10.

```

```
      YL=10.
      YD=20.
      ACCEPT ,YMAX,YMIN
      CALLPLOT(1,XMIN,XMAX,XL,XD,YMIN,YMAX,YL,YD)
      DO416 I=1,L
      X=I
      CALLPLOT(0,X,CUSUM(I))
416  CONTINUE
      CALLPLOT(7)
      XMIN=1.
      XMAX=XL
      XL=20.
      XD=10.
      YL=10.
      YD=20.
      ACCEPT ,YMAX,YMIN
      CALLPLOT(1,XMIN,XMAX,XL,XD,YMIN,YMAX,YL,YD)
      DO417 I=1,L
      X=I
      CALLPLOT(0,X,CUSUMP(I))
417  CONTINUE
      CALLPLOT(7)
      GOTO50
418  CALL EXIT
      END
```

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