Method and apparatus for controlling the quality and optimizing the profit in continuous butter making for given butter and buttermilk values. The quality of the butter produced is measured for water percentage of the butter and the density and velocity of butter produced is measured. Responsive to these measurements at least the beater (12) rotation, the cream feed, the cream temperature, the butter drive or the injected water is controlled to maintain the butter quality within legal limits and to optimize profit at given butter and buttermilk values. In a preferred embodiment the beater (12) rotation and the cream temperature are varied to optimize profit.
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Description

Method And Apparatus To Control
Quality And Optimize Production of Butter

Technical Field
5 The present invention relates in general to method and apparatus to control quality and optimize production in continuous butter manufacture.

Background Art
Typical commercial continuous butter churning machines receive a continuous feed of cream from a tank having a typical holding capacity for 4 to 12 hours operation. The cream is fed into a churning section of the machine hereinafter referred to as a churner or beater. The beater is equipped with blades which rotate through the cream at a velocity adequate to make the fat globules in the cream merge together forming larger particles during the passage through the beater section. To assure the correct hardness of the fat particles leaving the beater section, which is important for removal of water and proteins (curd) from the cream, the temperature in the beater section can be adjusted by change of the cooling water flow through a cooling jacket surrounding the beater or by a heater along the cream supply line. Since the churning operation produces heat, the degree of cooling needed from the cooling water flow depends on cream temperature, cream flow rate, cream fat percentage and churning rotational speed.

The cream is fed from the beater section into a screw or auger feed. Porous wall sections of both
auger feed and the beater section permit water and curd to escape. In the auger section additional water and curd are removed by pressure generated by the screw feed. The removed water and curd is then source for the commercial product buttermilk. The auger feed has a section for injection of a brine solution, such as a mixture of sodium chloride and water, for production of salted butter. In addition, the auger also has a section for the injection of water for fine regulation of the moisture content in the butter. The concentration of salt in the brine and the brine flow rate in conjunction with the butter flow through the auger can be used to determine the salt percentage in the butter. The brine solution will of course add a small percentage of water into the butter beside salt and can effect the moisture content of the resulting butter.

The strategy for operating a butter machine is to produce butter with a fat percentage as close as possible to the legal minimum limit. Higher contents than necessary result in lower yield of production and can have serious economic impact. Similarly, butter with a fat percentage below the legal limit can result in fines. Outside the United States the laws of many countries specify butter manufacture by maximum water percentage, a minimum fat percentage or both. Since the other ingredients that go into butter are relatively constant during the production, the strategy is nearly the same for producing butter with the legal minimum butterfat content or the maximum water percentage content.

A second major goal in the operation of a butter machine is the minimization of the butterfat in the buttermilk by-product. In most cases the fat in buttermilk represents a loss of economy even in situations where the fat in buttermilk can be removed and then is available for other usage.
Further goals in operation of butter machines are the production of butter with a specific temperature suitable for the packaging machines and to produce butter with desired density. Most butter machines in the past have provided manual operational control of a machine. During manual operation the operator will set the cream flow, beater speed, auger speed, beater cooling flow and brine flow according to values determined by prior experience and usually established by operating norms for any given machine.

During the operation, samples of the produced butter will be taken periodically and analyzed in a laboratory for moisture percentage, fat percentage, curd and salt percentage. If the fat percentage (or outside the United States the moisture percentage) is not at the desired value, the machine operator will adjust the speed of the auger or brine flow. Some butter machines have a separate water injection system for moisture adjustment (dosing flow) and the operator may choose to adjust this flow. The operator may also choose to adjust the cream flow or the beater speed or both in order to impact the moisture and thereby the fat percentage by change of the size of the fat globules leaving the beater. The globule size in turn impacts the amount of water suspended in the butter and thus influences the moisture content of the butter. On some machines the operator may attempt to observe the globule size or interpret it from buttermilk flow pattern by the beater and thereby reduce the time delay for the next laboratory analysis of the butter produced.

There are many drawbacks to the old operational methods. Cream does not have identical properties for butter production even if it is always maintained at the same temperature and has the same fat percentage. Length of storage and temperature history during
storage impact the amount of crystalization which has a large impact on churning. Furthermore, the food eaten by the cows which varies both with geography and season impacts the chemical structure of the curd and fat globules and thereby also impacts churning properties.

As a result of changes in cream properties large upsets occur in moisture and fat percentage when switching from one cream tank to another or beginning operations on a new day or with a new or different batch of cream. Furthermore the cream may not remain uniform from the top to the bottom of the storage tank and a continuous change in churning properties occurs during the production from a single tank. Separate laboratory analyses of butter properties throughout the duration of production consumes labor and is only available at fairly long intervals. Consequently, due to lack of immediate information, butter production may run at uneconomical specifications for long periods of time with the resultant loss of potential profits.

Another major drawback to manual operation of a butter machine is the complexity of the adjustment. For example, the operator has many choices for moisture adjustment. The best choice depends upon the impact of the other specifications as the density or temperature or buttermilk fat loss. Thus, it is difficult to make the best choice without analysis or to find the right combination of changes to suit all the production goals simultaneously.

The control system for one butter machine provides a sensor for the moisture percentage in the butter leaving the auger. A sensor signal is fed to a controller which either adjusts the brine flow or the dosing water flow. The fact that the salt content in the butter varies with a moisture correction is a
drawback with this system which, however, can be eliminated by adding fresh water into the brine line and keeping the brine flow constant. While this system, when operating correctly, will maintain the moisture percentage within its control capability, such a system does not coordinate the major variables of the machine, namely cream flow, beater speed, auger speed and beating cooling flow. Thus, it has been left to the operator to make manual adjustments of these variables for the purpose of providing the wanted butter temperature, density, and yield.

Disclosure of Invention

Broadly stated, the present invention, to be described in greater detail below, is directed to method and apparatus for control of butter quality and for optimization of a continuous butter production at given butter and buttermilk values. In accordance with the invention measuring means for measuring the density and velocity of the butter and the water percentage of the butter coming from the auger means are provided. Means responsive to these measuring means are provided for varying at least one of the beater rotation, cream feeding, cream temperature, auger rotation or water injection controls.

Within the provisions for optimizing butter production with the minimum legal butterfat content and/or the maximum legal moisture content the invention includes the control of the brine flow and/or buttermilk flow.

Other features and advantages of the present invention will become apparent from a perusal of the following describing of the preferred embodiments in
conjunction with the accompanying drawings wherein similar characters of reference refer to similar elements in each of the several views.

**Brief Description of Drawings**

5 Figure 1 is a schematic block diagram illustrating aspects of the present invention.

Figure 2 is a schematic block diagram showing the sensor portion of the present invention.

Figure 3 is a schematic block diagram showing another embodiment of the sensor portion of the present invention.

Figure 4 is a schematic block diagram illustrating other aspects of the present invention.

Figure 5 is a schematic block diagram illustrating still other aspects of the present invention.

Figure 6 is a representation of the information produced on the display screen on the operator's panel.

Figure 7A is a table illustrating different compositions of the constituents of butter.

Figure 7B is a graph plotting the moisture percent composition of butter against the butterfat percent composition for a particular range.

Figures 8 and 9 are schematic block diagrams similar to Figures 4 and 5, respectively, illustrating another embodiment of the present invention.

**Best Mode For Carrying Out the Invention**

Referring now to Figure 1, a preferred embodiment of the present invention is there illustrated in schematic block diagram form. As illustrated, a
conventional commercial butter machine, such as that marketed as model M-30 by Simon Freres, Cherbourg, France, includes a major beater section 12 and an auger section 21. The beater section contains high speed beaters positioned in a hollow cylinder 13 and driven by a variable speed drive 14 controlled by a beater rpm control 15 which typically can vary the drive 14 over speeds from 400 to 2500 rpm. The cylinder 13 is provided with an outer jacket 16 for circulating cooling fluid from a system 17 via a cream temperature control 18 for controlling the temperature of cream in the beater 12. Cream from a storage tank 19 is directed to the cylinder 13 through a cream flow control valve 20. Alternatively, to control the cream temperature a heater can be provided along the transfer line between the tank 19 and the beater section.

The churned cream is fed from the beater 12 to the auger section 21 wherein an auger separates the butter from the water and curd which is withdrawn from the auger section 21 as buttermilk to the storage container 22 as controlled by the valve 22'. The fat content in the buttermilk can be measured on line such as by the instrument 22'' sold by Milko for that purpose. The auger drive 23 is variable by means of a control 24 over a range such as, for example, between 10 and 60 rpm.

Butter is forced out of the end of the auger section 21 wherein a sensor system 25 senses certain characteristics of the butter. This sensor system 25 provides a measurement of moisture percentage, density, and velocity of the butter leaving the butter machine 11. The measurements of the sensor system 25 are connected to a control system 30.
For production of salted butter a brine solution is directed from a brine tank 26 having a injection pump through a brine flow control 27 to the auger portion 21 of the butter machine. This brine injection will inject a certain amount of water into the butter, but water can also be introduced into the butter by a dosing system having a dosing tank 28 from which water is fed via a control valve 29 to the auger section 21. Controlled water is used to maintain the quality of the butter such as above the minimum fat percentage level or below the maximum water level typically set by law.

Proper operation and optimization of the entire system is maintained by the control system 30. The beater rpm control 15, the cream temperature control 18, the cream flow control 20, the buttermilk flow control 22' and fat content measurement 22'', the auger rpm control 24, the sensor system 25, the brine control 27 and the dosing control 29 are all connected to the control system 30.

Referring to Figures 2 and 3, there is shown in greater detail the sensor system 25, which consists of a radioactive isotope density sensor 213, a capacitive moisture sensor 215 and a velocimeter 217. Each of these sensors produces an electrical output signal which is electrically connected to the control system 30 through a computer interface 221 which serves to convert analog signals to a digital format and to multiplex the signals. In accord with the present invention the control system 30 has a computer 36 (shown in Figure 4) with a memory which is loaded with calibration information regarding the measured densities of butter for various known fat and moisture contents which can be made using the butter machine.

Different densities can be achieved by operating the
machine with different beater speeds, auger speeds, as well as by applying different doses of moisture or brine. Other differences in density arise from differences in the composition of the cream used or because of different amounts of air entrained in the production process.

The density of the butter is measured by the density sensor 213. This sensor is of a known transmissive X-ray or radioisotope type. A radioactive source, such as Americium 241 is housed in canister 223. Such a source emits gamma rays with a principal energy peak at 59.7 keV. A detector 225 is positioned on the opposite side of butter column B so that the gamma rays passing through the aperture of detector 225 have passed through the butter column B. The detector 225 is of the type which produces an electrical signal proportional to the intensity \( I_1 \) of gamma rays which are detected. This electrical signal is transmitted along line 227 to the computer interface 221. Prior to reading the gamma ray intensity through the butter, an intensity signal \( I_0 \) is measured in the absence of butter. The computer 36 then computes the ratio \( R \) of the intensities in accord with equation (1). The ratio \( (R) \) of radiation transmitted through the material \( (I_1) \) to that detected in the absence of the material \( (I_0) \) may be written:

\[
R = \frac{I_1}{I_0} = e^{-upT}
\]

(1)

where \( u \) is the apparent mass absorption coefficient, \( p \) is the unknown density and \( T \) is the thickness of the material. Since the transverse dimension of the sample is known from the dimensions of the duct 211 and since at 59.7 keV the apparent mass absorption coefficient for
butter is known and is not essentially composition dependent, the unknown density may be calculated from equation (1). This calculation is made in computer 36. The computer 36 is able to compute density as fast as radiation intensity signals are received and so the computer is able to produce a dynamic signal representing the instantaneous density of butter as it emerges from the butter machine.

If the density is known, moisture content may be measured either by means of radio frequency techniques which sense the dielectric constant of the butter, or alternatively the composition may be determined by measuring the intensity of backscattered X-ray or gamma-ray radiation at a properly chosen energy as will be seen below.

At the same time that density is being measured, the instantaneous dielectric constant of the butter column is also being measured by the sensor 215. This is a capacitive sensor which measures dielectric constant in the radio frequency spectrum. Such devices are known in prior art and one such dielectric constant sensor is manufactured by Brabender Messtechnik of Duisburg, W. Germany. An explanation of this type of dielectric constant sensor is contained in the article "Kontinuierliche Wassergehaltsmessung an Butter" by W. Heinz. Preferred radio frequencies are in the range from 1MHz to 100MHz. Microwave propagation and reflection techniques may also be employed. They introduce more complexity however, with no increase in accuracy.

This gives a dynamic signal transmitted along line 229, with signal strength or intensity functionally dependent on the dielectric constant of the butter. In turn, the dielectric constant is proportional to moisture content and density in accord with known relationships. For example, Table I in the above

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mentioned article shows that when the percentage of water in butter varies from 0 to 30% the corresponding measured dielectric constant ranges from 3.2 to 11.6. Thus, the measured dielectric constant must be corrected by the measured density value to obtain a value that is proportional to moisture. This correction may be done by a computer. The memory of the computer contains information indicating how the dielectric constant of the butter varies with composition and density. Once the measured dielectric constant and measured density as well as the known curd content signals are fed into the computer the composition (water and fat content) may be calculated.

The finished butter moves as a mass through the duct 211 of known cross section from the machine. The velocity may therefore be measured by acoustical or optical doppler shift measurements or by means of a wheel 231 which is turned by butter motion which in turn drives a rotary encoder 233. A velocity signal is transmitted to the computer along line 234. Once the velocity is known and the instantaneous density is known, the mass flow can be computed in the usual manner using the known duct cross section.

In the event that salted butter is produced, the flow rate of the brine 26 is measured at flow control 27 and this flow rate is transmitted along line 43 to the computer 36. Since the brine has a known salt content, the flow rate, together with the mass flow rate of butter, indicates the amount of salt being introduced into the butter. This information is useful since the salt content also affects the dielectric constant measurement. Thus for the production of salted butter the dielectric constant must be corrected by the density as well as the salt content. Alternatively, the salt in the butter may be measured directly.
by sensing the backscattered soft gamma ray radiation of the butter, by the salt sensor 218. Salt sensor 218 comprises a soft gamma ray source 260 and a detector 262 to measure the amount of backscattered radiation. The memory of the computer 36 also contains information indicating the manner in which the dielectric constant of the butter varies with salt content. Once the salt content signal is fed to the computer 36 together with the dielectric constant, the density, and the known curd content the composition (water and fat content) may be calculated continuously. When no brine is used, the dielectric constant, the density and the known curd content are again fed to the computer 36 from which the composition is calculated continuously.

Computer 36 also receives data from a laboratory 241 where the cream and butter are periodically tested for curd content. Before the machine is started the curd content of the cream in the silo is measured. This value of curd content is entered into the computer 36 as an initial value. Once the butter production has started a sample of the butter is taken and quickly analyzed in the laboratory for curd content, this value is then entered into the computer 36. A plurality of samples of butter are taken and analyzed in the laboratory 241 for the curd content during the period to optimize the production of the butter. Once optimization has been achieved the corresponding optimized value of curd is then used for the rest of the production run. Signals representing this data are transmitted from laboratory 241 to computer 36 on a periodic basis, as needed.

The computer 36 is able to compute the density, fat, moisture and salt content by comparing the measured values of the parameters mentioned above, such as dielectric constant, mass flow, brine flow and curd
content with data from calibration trials where each of the parameters was measured in the laboratory by destructive tests. The destructive test data is stored in the computer for different runs of the butter machine representing the conditions under which the machine is expected to operate.

Figure 3 illustrates an alternate means of measuring the corrected density of the butter. The sensor system 25 is the same as in Figure 2 except that the dielectric constant sensor 215 is replaced by a backscatter sensor 216. A radioactive source is housed in a canister 224 similar to the source housed in canister 223. Low energies provide the best discrimination, however they also represent instrumental problems. In the case of butter a good choice is X-ray or gamma-ray radiation in the approximate energy range 15 to 25kev. The density is best measured using X-ray or gamma-ray radiation of higher energy such that it is not affected by the composition variances which may occur. For butter, one chooses energies in excess of 45kev. A radiation detector is housed in the canister 226, similar to the canister 225. The detector in canister 226 is positioned for measuring radiation backscattered from the butter column. The backscatter intensity is inversely proportional to the photoelectric cross section of the butter. It is well known that water molecules have a higher photoelectric cross section than fat molecules. Accordingly, intensity of backscattered radiation decreases as the percentage of water increases. A signal proportional to the backscattered intensity is taken along line 230 and transmitted to the computer. The radiation source might be an Americium 241 source with a Beryllium window which permits emission of the Neptunium L X-rays of average energy about 17.7 kev which are nearly ideal
in energy for determining the composition of butter. The detector housed in canister 226 is optimized for detecting the Neptunium L X-rays and is made insensitive to the 59.7kev Americium 241 gamma rays. The measured density is used to provide minor corrections, as required, to the composition as determined from the backscattered energy at 17.7kev.

When salted butter is produced, the backscattered intensity depends on the salt content as well as the water and fat content because the photoelectric absorption cross sections of sodium and chlorine are considerably larger than those of butterfat and water at low energies employed. The measured brine flow rate and the measured butter mass flow rate are determined however, as described earlier, and are used to determine the salt content of the butter. The determined salt content, the known curd content, together with the density, and the backscattered intensity, along with calibration data stored in the computer are then used to determine the butter composition, namely water and fat content as previously described.

Figure 4 is a schematic block diagram representation of the controls for the butter machine 11. The operating parameters of the butter machine are controlled such as cream temperature 31, beater rpm 32, auger rpm 33, brine flow 34, and water dose flow 35 by a multi-variable digital computer 36. The cream temperature parameter 31 operates the cream temperature control 18. The beater rpm parameter 32 operates the beater rpm control 15. The auger rpm parameter 33 operates the auger rpm control 24. The brine flow parameter 34 operates the brine flow control 27. The water dose flow parameter 35 controls the water dose control 29.
The characteristics of the butter and buttermilk produced by the machine 11 and determined in the overall sensing system 40 (including the butter sensor system 25 and the buttermilk gauge 22'') are the butter density 41, velocity 42, moisture percentage 44 and buttermilk fat percentage 45.

The computer 36 has an operator panel wherein the various parameters of the butter machine can be displayed and controlled in accordance with the provisions of the present invention.

In accordance with the embodiment illustrated the operator specifies the set points for the butterfat percent, the cream flow and the butter density.

Referring now to Figure 5 there is shown a schematic block diagram which specifies certain aspects of the control system of Figure 4 in greater detail. The butter churning process performed by elements 11-22, 23, 23, and 26-29 shown in Figure 1 are referenced in Figure 5 as the process 51. The quality of the butter produced in the process principally to meet legal requirements is referenced at the top of Figure 5 for producing butter having no greater than a particular moisture content and/or not less than a particular butterfat content. For controlling the content the butterfat percent set point 52 such as established by law, the curd percent 53 such as established by a laboratory entry and the salt percent 54 such as established by a laboratory entry are utilized to calculate the moisture set point by subtracting from 100% the butterfat percent set point, the curd percent, and the salt percent. This moisture set point determination 55 is adjusted at 56 with a feedback variable for application to a multi-variable digital controller 57. A suitable implementation of the algorithms in this controller 57 is described in the article by
Dahlin, et al., "Designing and Tuning Digital Controllers", Instrumentation and Control Systems, July, 1968 and in the DDC Tuning Reference Book, published by Chilton, 1969. The density set point also adjusted at 58 via a feedback variable is directed to the controller which adjusts the auger speed 33 or either the dose flow 35 or brine flow 34 to establish the appropriate butter quality. In the lower portion of Figure 5 the optimization of the butter process is achieved for the current market price of butter and buttermilk which are the products of the process. As shown the silo cream with a butterfat content established from a laboratory entry is fed to the process 51 with the cream flow rate determined at 37 and fed to a value calculation stage 73 to be described in greater detail below. The butter density determined at 41 and the butter outlet velocity determined at 42 along with the known cross-sectional area of the butter output is fed to a compute stage 76 to establish the butter mass flow 77 which is in turn directed to the value calculation portion of a computer for optimization of butter and butterfat flow in the system. The current butter value and buttermilk value per pound are entered at 78 and 79 and the buttermilk fat percentage either determined by a laboratory entry or the on-line analysis 22 is entered at 45. From these values which also include the solids (or curd) contents of the butter the computer stage 73 will calculate 3 economic factors in the associated value in dollars per hour of production. These factors are:

OVERRUN which is defined as butter mass flow divided by the mass flow of fat in the cream entering the machine (the cream flow is measured at 37 and the fat percentage in the cream is measured by periodic laboratory analysis and fed
to the computer. The product of flow and fat fraction equals the wanted fat flow used for the overrun calculation).

SOLIDS (or curd) contents in the butter.

FAT FLOW IN THE BUTTERMILK which is determined by multiplying the fat fraction by the total flow which is measured by the computer and fed to the computer.

Each of these three variables is compared against a nominal value for the machine. The selection of the nominal value is arbitrary since the comparison is only to simplify a comparison against some typical good operation. A dollar per hour value associated with each variable is then calculated. The computer also adds the total economic value of all three economic elements.

The objective of the optimization is to make this total as large as possible by selecting machine parameters, such as cream temperature 31 and beater speed 32. The search for these parameters can be conducted either manually or automatically by the computer making a series of adjustments and evaluating the total dollar flow after each test.

Figure 6 illustrates one such manual operation which shows the display on the operator's panel for a typically operating embodiment. As shown there the nominal values and selection are shown at the top of the display giving the cream flow 91 as 22075 lbs. per hour, the fat percent in cream 92 as 39.80, the fat flow 93 as 5.3 above a nominal selected value, the beater rotation 94 as 1750 rpm which is 20 rpm above nominal operation, the auger rotation 95 at 49 rpm which is the nominal selected value and cream temperature 96 of 51°F which is 3.1° above normal value.
In the illustration in Figure 6 the nominal flows are shown at 100 as 123.0 for overrun, 1.2 for solids percent in butter and 0.6 for fat flow percent in buttermilk. For the given values of butter and butter fat at the first operating level 101, the overrun is 122.3, the solids content is 1.3 and the fat flow in the buttermilk is .7 which produces a dollars per hour valuation of $109.00 below the nominal value. By changing the cream temperature such as up 1.5° as noted at 102, the process is run and parameters recalculated typically about 10 minutes later to provide the parameters shown at 103. Here the dollar per hour has increased to only $52.00 per hour below the nominal value so that the cream temperature can again be increased by 1.5° at 104 in hopes of achieving further optimization. That further optimization established after another 10 minutes and shown at 105 produces a dollar per hour value only $47.00 below the nominal and therefore not appreciably increased from the parameters at level 103. Since further increases of cream temperature do not appear to produce appreciable optimization increases for this batch of cream a variation in the beater speed of an increase of 25 rpm as noted at 106 is established and the parameters again reevaluated 10 minutes later as noted at 107 wherein the dollars per hour has now been increased to $28.00 per hour over the nominal. This optimization procedure can continue in an effort to maximize the dollars per hour and can take the form of one dimensional changes or two dimensional changes such as by varying the cream temperature and the beater speed. Obviously the other
parameters such as auger speed, brine flow, buttermilk flow and even cream flow can be varied to achieve optimization.

Alternatively to the manual optimization described with reference to Figure 6 a search optimization at stage 84 in Figure 5 can be accomplished with the computer starting at a given starting point with all input controls at nominal values and arbitrarily increasing the cream temperature by 1°. If the dollar flow gets worse it can decrease by 1°. If the dollar flow then is still worse than the starting point the operation is already near a maximum for the cream temperature. If an improvement takes place, the computer can continue to increment in the same direction until the maximum is found. Once the best cream temperature has been found, the search can be undertaken for another variable such as beater speed and the maximum found for this variable. It is also possible in accordance with this invention to first scan with large steps and simultaneous adjustment of cream temperature and beater speed in a fixed relationship programmed into the computer. When a crude maximum has been found each variable can be optimized individually with smaller steps for better resolution. Advanced techniques such as the steepest ascent method can also be used. With the computer the search methods can use any number of process variables such as those described above rather than just a cream temperature and beater speed.

Figures 7-9 are illustrative of a preferred embodiment particularly applicable for production of butter in countries where a minimum butter fat content and a maximum moisture content are specified by law. Figure 7A is a table illustrating on lines A through E different possible percentage compositions.
of butter broken down as to solids, curd plus salt, in column I, moisture in column II and butter fat in column III. Laws of certain countries prescribe a maximum moisture content such as 16% and a minimum butter fat content such as 82%. Legal levels of these constituents are bracketed in columns II and III. From the cost of the constituents of butter, economics dictate that maximum profit will be achieved when the moisture content is the highest and the butter fat content is the lowest permitted by law. This composition for butter is shown in row C as butter having 2% curd and salt, 16% moisture, and 82% butter fat. Naturally there are numerous levels of production operation between row B and row C where the curd and salt content is between 1 and 2% and between row D and row C where the curd and salt content is between 3 and 2% and wherein the present invention can be utilized to shift the production operation toward the optimum level of row C.

Figure 7B is a graph plotting moisture percent of butter from the range slightly below 15% to slightly above 16% versus percent of butter fat in butter from slightly below 82% to 83%. The graph shows the optimum moisture and fat content at point $a$ and the shaded area of illegal composition where the maximum moisture content is above 16% and the minimum butter fat content is below 82%. This graph subdivides the 1% change along either the ordinate or the abscissa in 0.2 steps. For maximizing the profit in the butter produced, adjustment of the process steps from operational levels such as, for example, those indicated as A (82.6% butter fat, 15.8% moisture) and B (82.4% butter fat, 15.2% moisture), by controlling the dose-water flow will shift the constitution of the resulting butter along the dashed "curd lines" to goal points A' and B'.
where a change of the solids, curd plus salt, by change of the buttermilk out-take from the system can shift the percentage constituents toward the optimum goal \( \Omega \). For safety sake goals at \( A' \) and \( B' \) and then at an optimum goal \( \Omega' \) are utilized to avoid the possibility that due to some fluctuation in the overall system operation a given production would end up in the illegal region and incur fines. The goal points \( A' \), \( B' \) and \( \Omega' \) are selected to be spaced from the limits by an amount such as a standard deviation.

In countries such as the United States where there is no maximum limit on moisture the constitution of the butter can be adjusted by change of the buttermilk out-take along the "curd line" from \( A \) upward through the 16% moisture limit to a goal point that lies on the same vertical line as \( B' \) and \( \Omega' \).

Figures 8 and 9 illustrate achieving maximum profitability by adjustment of the buttermilk take out and the brine flow in the situation where there are legal limits on both butter fat and moisture content. In Figures 8 and 9 an item designated with a three digit number will typically have the last two digits the same as a similar item in the embodiment of Figures 4 and 5.

As shown in Figure 8 the operating parameters of the butter machine 111 adjusted by the computer 136 and controls are the cream flow 137a, the cream temperature 131, the beater speed 132, the auger speed 133, the buttermilk flow 138, the water dose flow 135, and the brine flow 134. The levels of cream flow 137, and the butter, buttermilk and brine composition are fed to the computer 136.

The characteristics of the butter and buttermilk produced by the machine 111 and determined in the overall sensing system 140 are the butter density 141,
velocity 142, moisture percent 144, and curd percent 146, the buttermilk flow 145a, fat percent 145b and curd percent 145c, and the brine salt percent 143. The curd percent can be determined such as by the method and apparatus described in United States Patent 3,040,562. The butter fat content can be simply calculated from the moisture percent and curd and salt percent. The brine salt percent 143 can be predetermined by the amount of salt added or can be measured on-line. The salt percent can be set by adjusting the brine flow control in proportion to actual butter mass flow as seen in Figure 9.

The computer and controls 136 can provide to the operator display 139 the appropriate constituents in the butter being produced and allow for manual or automatic search to reach the set points for the butter fat percent, cream temperature, beater speed, butter density and salt percent.

Referring now to Figure 9, there is shown a schematic block diagram which specifies certain aspects of the control system of the embodiment illustrated in Figure 8. The operation of the process elements is referenced as the process 151. From the process the butter moisture 144, butter density 141 and butter outlet velocity are determined, and the butter mass flow 177 is obtained through computation 176a from the butter density 141 and the butter outlet velocity 142. The butter mass flow 177 is then multiplied at 177a by the butter price 178 such as in dollars per ton to produce the butter value 178a in dollars per hour.

Also from the process the buttermilk flow rate 145a, the buttermilk fat percent 145b and buttermilk curd percent 145c are computed at 176b along with the buttermilk curd price 145d such as in dollars per ton and the buttermilk fat price 179 such as in dollars per
ton to produce the buttermilk value 179a such as in dollars per hour which, when added at 173 to the butter value produces a total output value 181 such as in dollars per hour. This value is utilized in the search optimizer 182 which is illustrated as a one dimensional search by adjustment of selective machine parameters such as cream temperature 131, beater speed 132 or cream flow 137a. As pointed out previously, the search for these parameters can be conducted either manually or automatically by the computer making a series of adjustments and evaluating the total dollar flow after each test and the adjustment can also utilize a first scan with large steps and simultaneous adjustment of two parameters or the steepest ascent method.

In the embodiment of Figure 9 the calculation of the maximum permissible moisture set point is determined using (a) the salt percent set point 154, (b) the determined butter curd percent 146 and a moisture percent goal 155a which is established by the on line calculation of the standard deviation of moisture and fat percentage. The moisture set point determined at 155 is adjusted at 156 with a feedback variable for application of a multi-variable digital controller 157 such as previously described with respect to the embodiment of Figure 5. The density set point is also adjusted at 158 via a feedback variable from the butter density determination 141 and is directed to the controller which adjusts the auger speed 133 and the dose flow 162 to establish appropriate butter quality.

Buttermilk flow for optimum curd percent is calculated at 191 from the buttermilk curd percentage 192, the butter curd percent on-line determination 146, and a butter fat percent goal 193 established as an operational entry from experience with the butter
machine. The buttermilk flow computation 191 serves to adjust a valve which determines the buttermilk removal 194 from the churn.

In a variation of the foregoing, rather than 5 controlling the amount of curd in the butter by controlling the amount of curd removed through buttermilk flow, through valve 22', the amount of curd in the butter may be controlled by controlling the amount of curd injected into the churn. The computer 36 would control the amount of curd injected in such a manner as to establish a "curd line" going through the optimal point \( \Omega \) in Figure 7B. Once the "curd line" has been set, the amount of moisture into the churn is adjusted until point \( \Omega \) is reached. One example of the application of this is in the Niezo process, which is used in Holland. In that process, curd (with bacteria) is injected into the churn to create sour butter. With the present invention, the Niezo process would be controlled such that the amount of curd along with 20 water injected into the churn are controlled to produce butter with the desired composition.
Claims

1. In a method for optimization of continuous manufacture of butter at given butter and buttermilk values including the steps of feeding cream at a selectable control rate, beating the fed cream at a selectable beater rotation control rate, controlling the temperature of the cream, pushing the churned cream into butter at a selectable auger rotation control rate, and removing buttermilk at a variable rate the improvement comprising measuring the mass flow of butter coming from the auger pushing step and varying at least one of the feeding, beating, temperature, or pushing controls responsive to the mass flow measuring step to optimize profit at given butter and buttermilk values.

2. Improvement of Claim 1 including varying at least two of said feeding, beating, temperature, buttermilk flow and pushing controls to optimize profit at given butter and buttermilk values.

3. The method of Claim 2 wherein the varying step includes varying the beater rotation control and the cream temperature control steps.

4. The method of Claim 1 including the step of measuring the fat percent of the buttermilk from said buttermilk removing step.

5. The method of Claim 1 wherein said mass flow measuring step includes measuring the density of the butter and measuring the velocity of the butter through a given area.
6. The method of Claim 4 including the steps of measuring curd percent of the butter and the buttermilk and adjusting the buttermilk flow for optimizing profit.

7. The method of Claim 4 including the steps of measuring curd percent of the butter and adjusting the amount of curd injected into the process for the manufacture of the butter for optimizing profit.

8. In a method for controlling continuous manufacture of butter within given quality limits including the steps of feeding cream at a selectable control rate, beating the fed cream at a selectable beater rotation control rate, controlling the temperature of the cream, pushing the churned cream into butter at a selectable auger rotation control rate, and removing buttermilk at a variable rate, the improvement comprising:
   measuring the density of the butter coming from the pushing step;
   measuring the butterfat content or a water percentage of the butter coming from the pushing step; and
   varying at least one of the feeding, beating, temperature, or pushing controls responsive to the density measuring and butter fat or water measuring steps to maintain the quality of the butter within legal limits.

9. Improvement of Claim 8 including varying at least two of said feeding, beating, temperature, buttermilk flow, and pushing controls to maintain the quality of the butter.
10. The method of Claim 8 wherein the varying step includes varying the beater rotation control.

11. The method of Claim 8 including adding water to the butter during the pushing step and changing the amount of added water during the varying step to maintain the quality of the butter.

12. The method of Claim 8 including the steps of measuring the fat and curd percent of the buttermilk from the buttermilk removing step, measuring the curd percent of the butter and adjusting the buttermilk flow for optimizing profit.

13. The method of Claim 8 including the steps of measuring the curd percent of the butter and adjusting the amount of curd injected into the process for the manufacture of the butter to optimize profit.

14. The improvement of Claims 1 or 8 including the step of adding water to the butter during the pushing step, establishing the salt percent of the butter, and adjusting the buttermilk flow and the amount of added water during the varying step.

15. Apparatus for optimization of a continuous butter making machine at given butter and buttermilk values including a beater means for churning cream, means for controlling the rotation of the beater means, means for feeding cream to the beater means, means for controlling the feed of cream to the beater means, means for controlling the temperature of the cream, auger means for pushing churned cream into butter, means for controlling the rotation of the auger means, means for controlling the removal of buttermilk, the
improvement comprising means for measuring the mass flow of butter coming from said auger means and means responsive to said mass flow measuring means for varying at least one of said controlling means to optimize profit at given butter and buttermilk values.

16. The apparatus improvement of Claim 15 including means for varying at least two of said controlling means to optimize profit at given butter and buttermilk values.

17. The apparatus improvement of Claim 16 wherein said varying means varies the beater rotation controlling means and the cream temperature controlling means.

18. The apparatus improvement of Claim 15 including means for measuring the fat percent of the buttermilk coming from the buttermilk removing means.

19. The apparatus improvement of Claim 15 including means for measuring fat percent of the cream going to the cream feeding means.

20. The apparatus improvement of Claim 15 wherein said mass flow measuring means includes means for measuring the density of the butter and means for measuring the velocity of the butter through a given area.

21. The apparatus improvement of Claim 15 including means for measuring the curd percent of the buttermilk and the butter.
22. Apparatus for controlling a continuous butter making machine within given quality limits including:
   a beater means for churning cream;
   means for controlling the rotation of the beater means;
   means for feeding cream to the beater means;
   means for controlling the feed of cream to the beater means;
   means for controlling the temperature of the cream;
   auger means for pushing churned cream into butter;
   means for controlling the rotation of the auger means;
   means for controlling the removal of buttermilk, the improvement comprising:
   means for measuring the density of the butter coming from the auger means;
   means or a water percentage means for measuring the butter fat content or a water percentage of the butter coming from said auger means;
   means responsive to said density measuring means and said butter fat or water measuring means for varying at least one of said controlling means to maintain the quality of the butter within legal limits.

23. The apparatus improvement of Claim 22 including means for varying at least two of said controlling means to maintain the quality of the butter.
24. The apparatus improvement of Claim 23 wherein said varying means varies the beater rotation controlling means.

25. The apparatus improvement of Claim 22 including means for adding water to the auger means, and means for controlling the amount of water added by said water adding means said responsive means varying said water control means to maintain the quality of the butter.

26. The apparatus improvement of Claim 22 including means for measuring the curd percent of the buttermilk and the butter.

27. A sensor system for continuously measuring the composition of butter as it emerges from the manufacturing process, said system comprises:

   a first sensor means adapted to measure a parameter of said butter;
   a second sensor means adapted to measure a second parameter of said butter;
   memory means adapted to store a plurality of pre-determining values of said first and second parameters and their correlations with the composition values of said butter; and computer means for comparing said measured values of said first and second parameters to said stored values to determine the composition of said butter.

28. The system of Claim 27 wherein said memory means further adapted to store known curd value of said butter.
29. The system of Claim 28 wherein said memory means further adapted to store salt content value of said butter.

30. The system of Claim 27 wherein said first parameter is substantially the density of said butter.

31. The system of Claim 30 wherein said first sensor means is a transmissive x-ray or gamma ray gauge.

32. The system of Claim 27 wherein said second parameter is substantially the dielectric constant of said butter.

33. The system of Claim 32 wherein said second sensor means is a capacitive sensor.

34. The system of Claim 27 further including a third sensor means adapted to measure the velocity of said butter.
OPTIMIZATION
CR F = 22075  FAT = 39.80  FFL = +5.3
BEAT = 1750  (+20)  AUG = 49  (0)
CR T = 51 F  (+3.1)

OV-RUN **  B-SOL% *  BM-F% ** $ / H

123.0  1.2  0.6
123.4  42  1.2  0  0.5  -13  28
BEAT  +25

122.6  -42  1.1  8  0.5  -13  -47
CR T  +1.5

122.5  -52  1.2  0  0.6  0  -52
CR T  +1.5

122.3  -105  1.3  -17  0.7  13  -109
CR T  +3.0

FIG. 6.
<table>
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<tr>
<th></th>
<th>% SOLIDS (CURD &amp; SALT)</th>
<th>% MOISTURE MAXIMUM PERMITTED</th>
<th>% BUTTER FAT MAXIMUM PERMITTED</th>
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<tr>
<td>A</td>
<td>0</td>
<td>16</td>
<td>84</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>16</td>
<td>83</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>16</td>
<td>82</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>15</td>
<td>82</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>14</td>
<td>82</td>
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**FIG. 7A.**

![Diagram showing moisture and butter fat percentages](image-url)
# INTERNATIONAL SEARCH REPORT

International Application No: PCT/US80/01691

## I. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both National Classification and IPC:

- INT. CL. A23C 15/02; A01J 15/12; G01N 33/06

## II. FIELDS SEARCHED

<table>
<thead>
<tr>
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<td>U.S.</td>
<td>426/231, 238, 244, 530, 581, 664, 417; 99/456, 459, 460, 464, 465, 466; 23/231; 73/32R, 61R; 250/358R; 324/62</td>
</tr>
</tbody>
</table>

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched:

**CHEMICAL ABSTRACTS - BUTTER MANUFACTURE, 1972 - JUNE 1980**

## III. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of Document, 15 with indication, where appropriate, of the relevant passages 16</th>
<th>Relevant to Claim No. 14</th>
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<tbody>
<tr>
<td>A</td>
<td>US A, 3,841,610, PUBLISHED 15 OCTOBER 1974, HANZAWA ET AL.</td>
<td>1-26, 32, 33</td>
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<td>A</td>
<td>US A, 3,109,740, PUBLISHED 05 NOVEMBER 1963, ROBICHAUX</td>
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<td>5, 8-14, 20, 22-26, 30</td>
</tr>
<tr>
<td>A</td>
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<td>4, 6, 8-14, 18, 19, 21-26</td>
</tr>
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<td>A</td>
<td>N, AUTOMATIC CONTROL PRINCIPLES AND PRACTICE, REINHOLD PUBLISHING CORPORATION, N.Y., ISSUED 1958, HOLZBOCK, W.G., PAGES 1-3 AND 240-242.</td>
<td>1, 8, 15, 22, 27</td>
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1. Special categories of cited documents:
   - *A* document defining the general state of the art
   - *E* earlier document but published on or after the international filing date
   - *L* document cited for special reason other than those referred to in the other categories
   - *O* document referring to an oral disclosure, use, exhibition or other means
   - *P* document published prior to the international filing date but on or after the priority date claimed
   - *T* later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention
   - *X* document of particular relevance

## IV. CERTIFICATION

- Date of the Actual Completion of the International Search: 25 MARCH 1981
- Date of Mailing of this International Search Report: 27 MAR 1981
- International Searching Authority: ISA/US
- Signature of Authorized Official: DAVID M. NAFF

Form PCT/ISA/210 (second sheet) (October 1977)
### FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

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<td>A</td>
<td>US, A, 2,992,332, PUBLISHED 11 JULY 1961, MADIGAN</td>
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### OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE

This international search report has not been established in respect of certain claims under Article 17(3) (a) for the following reasons:

1. Claim numbers______, because they relate to subject matter not required to be searched by this Authority, namely:

2. Claim numbers______, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

### OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING

This International Searching Authority found multiple inventions in this international application as follows:

- INVENTION I. CLAIMS 1-26
- INVENTION II. CLAIMS 27-34

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

Remark on Protest
- The additional search fees were accompanied by applicant's protest.
- No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (supplemental sheet (2)) (October 1977)