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PRACTICAL APPLICATIONS OF RESEARCH: "ENOUGH TO CURdle MILK"

by

Gary Haight Richardson
A basic objective of the Faculty Association of Utah State University is, in the words of its constitution,

To encourage intellectual growth and development of its members by sponsoring and arranging for the publication of two Annual Faculty Honor Lectures in (a) the biological and physical sciences, including engineering, called the Annual Faculty Honor Lecture in the Natural Sciences; and (b) the humanities and social sciences, including education, family life, and business administration, called the Annual Faculty Honor Lecture in the Humanities.

The administration of the University is sympathetic with these aims and shares, through the Scholarly Publications Committee, the costs of publishing and distributing these lectures.

Lecturers are chosen by a standing committee of the Faculty Association. According to the Faculty Constitution:

in choosing the lecturers, the committee shall take into consideration the achievements of faculty members in all the various areas of learning represented by the teaching and research of the Institution. Among the factors to be considered shall be outstanding achievement in one or more of the following: (1) creative activity in the field of the proposed lecture; (2) publication of research through recognized channels in the field of the proposed lecture.

Gary H. Richardson was selected by the committee to deliver the Annual Faculty Honor Lecture in the Natural Sciences. On behalf of the members of the Association, we are happy to present Professor Richardson's paper.

Committee on Faculty Honor Lecture
PRACTICAL APPLICATIONS OF RESEARCH:
"ENOUGH TO CURdle MILK"

by
Gary Haight Richardson

71st Faculty Honor Lecture
April 4, 1984
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Logan, Utah
This lecture is dedicated to Dr. Carl Anthon Ernstrom, Professor and Department Head, Department of Nutrition and Food Sciences, Utah State University, an inspiring teacher and researcher who has the unique ability to work in relevant areas and to convey those research findings to the dairy industry, where they have created significant quality improvements and financial savings. He is a world-renowned figure in dairy processing and cheese manufacture and has encouraged me and numerous others to analyze this topic. An invaluable critic and counselor, he has helped insure that data is reported clearly. His ability to excite the learner in the food sciences and his dedication to providing support for the regional dairy industry have helped me pursue the research I report tonight.
Practical Applications of Research: "Enough to Curdle Milk"
by
Gary Haight Richardson*

It is a privilege to be given this opportunity and a challenge to present material in a narrow discipline in a way that might be appreciated by many. I like to think I can relate to other disciplines. Although I came to Utah State University to be a music major, a concerned father foresaw that I might not earn a living in this area (he had heard me practice) and suggested an interview with A. J. Morris before checking into the Music Department. A. J., Head of the Dairy Manufacturing Department, was as convincing and persuasive as Tony Ernstrom is, and I selected a career that carries the satisfaction involved with dealing with one of humanity's greatest needs and pleasures—eating. This practical satisfaction is further enhanced by researching nature's most nearly perfect food—milk.

Years after receiving the lowest grades of my college career from organic chemistry teacher, Dr. Theodore M. Burton, I met him in Chicago. He remembered me and asked how my work was going at Swift and Company in Chicago. I said it was going well, and he retorted, "Then you are not working!" I defensively responded by telling him how dedicated I was and expounded until the twinkle in his eye, the dimple in his cheek, and the tilt of his head, as many of you will remember, identified his ploy. He interrupted, "Any time I could spend in the laboratory was never work. It was fun." I would like to affirm my present conviction that Dr. Burton was right.

There have been times, however, when my research seemed more than I could tolerate. After only one year out of graduate school, with a loyal wife and three children to support, I was frustrated and ready to investigate other possibilities. Fortunately, my wife Fran had the best advice when she indicated she was proud to be with one who was at the frontiers of knowledge, even though it was sometimes discouraging, slow, and received less compensation than some other professions that appeared more lucrative at the time. I persevered, but because of my experience, I do empathize with students who have trouble deciding upon their careers.

My research opportunities have been in areas where paradoxically there are practical applications to be made, yet a great reluctance to change. Tony Ernstrom has suggested that I write a book about the frustrations associated

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with the marketing of the most efficient lactic culture program in the dairy industry (28). The bacterial production system named “The USU Lactic Culture System” was first introduced to the industry in 1971. Systems for external control of pH were installed in cheese plants and stood idle for years until a new generation of cheesemakers dared try them. The concept met with the three phases defined by Dr. Kevin Marshall of the New Zealand Dairy Research Institute: “The truth goes through three phases before being accepted. First it is opposed. Then it is ridiculed and finally it is accepted as being self-evident.” My former employer, Merle Farnham, added the fourth, “And after being so accepted, the marketers conveniently forget who contributed it.” The USU system was fought by the industry that would benefit from it on the basis of being unprofitable, and the patent office refused protection on the basis that it was too obvious. In 1976 several USU students saw the potential for the system, incorporated in Logan (Biolac Incorporated), and supported the development of the concept throughout the United States and Canada. They now supply over eighty cheese plants with the USU system and each plant saves from $16,000 to millions of dollars per plant per year, depending upon company size and the completeness of the culture program used. We have had the opportunity to introduce the concept into Ireland, New Zealand, and Australia. Yet the entire process of acceptance and utilization has been time-consuming and costly.

Despite such frustrations, however, my research has been both exciting and rewarding, and I would like to take this opportunity to explain exactly what I do. I will try and keep in mind the advice given by my uncle, Lynn Richardson, at a USU extension meeting years ago. “Just KISS IT!—Keep it Simple, Stupid.” I will attempt to keep the presentation clear and convince you that my work is exciting. Some have questioned my title, but perhaps, I can give you a new conversation topic as you observe feathering in the coffee creamer or the cheese that won’t melt. I recognize the importance of learning to laugh at one’s mistakes and make a continual effort to incorporate humor into my philosophy to help provide the proper perspective.

Last year approximately 11 million cows produced over 140 billion pounds of milk in the United States (1). The *Bos sp.* has become much more efficient because in 1954 twice as many cows were required to produce only 110 billion pounds per year (2). Approximately 54% of the milk produced is changed from a liquid to a solid in the form of cheese, butter, or frozen desserts before it is consumed.

When milk curdles or clabbers, we say it coagulates or clots. It changes to Little Miss Muffet’s “curds and whey.” Milk coagulation is critical to Utah’s economy, and in the past fifteen years, we have moved from twenty-fourth to eleventh in national cheese production. Since national cheese consumption is
increasing every year, Utah may tend to see through rose-colored glasses. Nationally, we are now consuming over twenty pounds per person but we are still far behind France or Greece with their over forty-one pounds per person per year. Utah is presently an important exporter of cheese and cheese technologists. However, California, our main market, has initiated a “Real California Cheese” campaign and manufacturing program that has openly threatened to make the state self-sustaining in cheese production in five years (2). It has successfully increased both consumption and manufacturing and is well on its way to becoming self-sustaining. USU must continue to provide improved efficiencies and products or Utah’s favorable market position will be threatened.

Before discussing the practical applications of my field, I need to provide some background information. As mentioned, milk is turned solid in many ways. Tons are semisolid in frozen desserts. Nonfat dry milk particles resemble indented apples or Cabbage Patch dolls after the water is removed by spray drying. Dried buttermilk also has some fat globules visible. Since these powders are difficult to dissolve in water, we have learned to agglomerate them to make “instant” products. Some may recall the coagulated protein that forms a thick leathery scum on the surface of hot chocolate made from fresh milk. This is due to heat coagulation of the whey proteins in milk that denature and float to the surface. Heat treatment is used to coagulate these proteins in the manufacture of products like Ricotta cheese and to increase yields in other cheese products.

Cheesemaking includes other methods to convert milk to a solid. A prehistoric bedouin is credited with carrying milk in an animal stomach and, upon arrival at his destination, finding sweet curds and whey in place of an homogenous fluid. This discovery provided one of the best and tastiest ways to preserve milk. The key to milk’s ability to remain fluid or change to solid lies in casein, the chief protein in milk. Casein micelles are clumps of protein fractions held together by chemical bonds and electrical charges (Figure 1). They are actually hydrated solid particles suspended in milk and separated by these forces and water of hydration. The white appearance of milk is due to the reaction of light on these particles. If these unique protein particles are removed, the resultant whey is yellow-green. If the particles are dried, they become casein, a protein isolate used as a standard for nutritious protein, but maligned by some television ads as “glue” and defined, strangely enough, by regulatory agencies as a “nondairy” chemical. Casein can be destabilized to form a network of protein by several techniques (3, 35). Alcohol can remove water of hydration and floculation develops. Hot drinks produce feathering of dairy products as casein clumps when the milk salts are out of balance and
Figure 1. Casein micelles at low (4) and high (5) magnification using shadowing with platinum and scanning electron microscopy (SEM). Submicelle structure is evident. (Courtesy M. Kalab.)
lactalbumin forms a scum on hot milk as previously described. Freezing causes salt concentration that destabilizes milk proteins. A sweet-curdling enzyme from animal or fungal sources cuts away a fraction of casein causing it to become unstable. Casein then reacts with calcium ions and forms the sweet product typical of fresh Cheddar curd. When cottage cheese is made, destabilization is due to bacteria that produce lactic acid until the isoelectric point of the protein is reached. At this point the electrical charges on the casein are neutralized and the micelles stick together to form a three-dimensional network. Sweet curdling by rennin-like enzymes, acid production by bacteria, and combinations of these are the methods most commonly used to produce cheese products. Rennin from animal and fungal sources is combined with bacterial cultures to produce over four billion tons of cheese annually in the United States (2).

Figure 2. Coagulated casein and bacteria in yogurt. The long rods (1) (Lactobacillus bulgaricus) develop strings of gum (dextran) that produce a viscous product. The string of spheres (2) (Streptococcus thermophilus) appear suspended in space due to the shrinkage and proteolysis of the casein structure. (Courtesy M. Kalab).
Let's take (via slides) a microscopic tour of some curd products. I hope you will find these photos every bit as beautiful as other natural wonders you have seen. First, let us stop within the space normally occupied by water in a yogurt container (Figure 2). The brush-structure of the casein particles constitutes the fine network. The chains of balls help us identify the *Strepto-* (chain) *coccos* (balls) *thermophilus* (heat-loving) bacteria, and the long rods are *Lacto-* (milk) *bacillus* (rod) *bulgaricus* (named from bulgarian buttermilk). With this perspective, we can easily visualize small threads of dextrans between the bacteria and the casein network. Dextrans are gums, produced by the bacteria or added as an ingredient, that add viscosity typical of high-quality yogurt. Around the cells are voids that are due to shrinkage of the network as acid is produced and/or protein is dissolved. We are now researching the latter because protein breakdown by these bacteria can represent product loss where curds (product) and whey (by-product) are separated (29). This is not a problem in yogurt or in buttermilk because the whey remains a part of the product.

Next let's examine a natural hard cheese (Figure 3). Here are four types. Cheddar is characterized by a “chicken breast muscle” structure. Long strands of curd provide this cheese with a “long body.” Colby and stirred curd cheddar are less labor intensive and the structure is frequently crumbly. Parmesan or Mozzarella cheese is stretched in hot water and a long stringy texture is present. This "dribble-over-the-chin" property brings premium prices from pizza lovers around the world.

![Figure 3](image_url)
When cheese is melted, as in the manufacture of processed cheese products, the fat globules are made more uniform and smaller (Figure 4). In addition, we see dissolving salt crystals used to help form a stable fat emulsion. If the wrong salts are present, the cheese will not melt. Incidentally, tons of processed cheese products leave Cache Valley daily from two cheese plants that have an annual capacity to process more natural cheese than is currently produced in all of Utah.

If we examine cottage cheese, the curd looks slightly different. Here the coagulum is formed by acid production either by bacterial action or by adding acidifying agents directly. Without the appearance of bacteria, this curd evidences direct acidification and is identified on the carton as being “directly set.”

Figure 4. Transmission electron micrograph (TEM) of processed cheese. Dark areas are protein. The light areas are fat (note the fat globule at the top that is being emulsified into three smaller globules), and the crystal structures represent dissolving sodium citrate. (26).
Molds are multicellular fungi that are involved in the ripening of cheese. Although many individuals cut off the chewy, velvet-like covering of Camembert cheese, the true connoisseur consumes "the whole thing" (16). Microscopically, the Camembert mold, *Penicillium caseicolum* or *camemberti*, has a mycelium cell that resembles a tree trunk and terminates in a group of finger-like conidiophore cells (Figure 5). At the end of these cells, chains of conidiospores develop, which break off and are wafted through the air to
carry the properties of the mold to a new substrate. In Camembert cheese these structures have a whitish pigmentation, and the development of a blue spot is the curse of the cheesemaker who recognizes the contamination of an unwanted mold, such as *Penicillium roqueforti*, the mold needed for blue cheese manufacture. A picture of the surface of Camembert cheese reveals the tightly packed casein network and the much larger mycelial and sporular development of the fungus. Enzymes from this growth penetrate into the fresh curd and break down protein. The cheese must be only about one-inch thick or the center will never ripen. When the enzymatic activity has reached the center, the cheese must be consumed before overripening. When this occurs the proteins are converted to ammonia and the cheese becomes offensive. It is now possible to buy fresh Camembert and Brie cheese because of an expanding market and because several good manufacturers exist, primarily in California and Wisconsin.

Molds are aerobic and must have access to oxygen to grow; hence the surface growth on Camembert and Brie. The mold-ripened blue cheese is consumed at more than 20 million pounds annually in the United States. Blue cheese originated in a monastery in Roquefort, France, where it has been produced for a millenium (36). Only cheese made there using sheep’s milk is authorized to carry the “Roquefort” designation. Every other similar cheese must be designated alternatively, such as Gorgonzola, Stilton, and blue in the United States and Canada, or bleu if from southern France (31). Since the ripening occurs internally, each freshly pressed wheel is punctured with fifty long needles to provide passage for oxygen in and carbon dioxide out. After the mold develops in these passageways during the three to six month cave storage period, streaks in the curd develop which are blue or green due to the pigmentation of the conidia. Dr. Knight and co-workers at the University of Wisconsin isolated a white mutant of the mold that would allow the production of a “white” blue cheese (15). The resultant cheese was manufactured in Minnesota and called “Nuworld.” After the cheese aged, the cheese pigmentation was brownish-grey, and the consumer, accustomed to traditional faded blue pigmentation, soon returned to the traditional blue product.

In our Food Fermentations class we teach students the principles of this fermentation using a modification of a blue cheese crumble technique developed at Michigan State University (9). The students isolate mold from commercial blue cheese and prepare an inoculum powder from mold-covered bread-crumbs. They inoculate the milk and do not let the fresh cheese curd mat or form into cylinders. The mold develops on the outside of the crumbles and, in less than ten days instead of two to five months, a product acceptable for salad dressings is produced. In fact, the product has to be salted rapidly to retard the mold action. Such flavors, though not as well balanced, can be developed in less time using liquid milk substrates in sterile fermentors (20).
The third type of microorganism involved in the manufacture of cheese is the yeast (25). This single-cell organism is much larger than the bacterium. Yeast is used to reduce acidity on the surface of cheese and to allow the growth of flavor-forming bacteria found in such cheeses as Brick and Limburger.

Now that we have seen inside some milk coagula, I want to describe some research associated with the formation of coagulated milk products. Major contributions by USU scientists regarding milk coagulation have spanned sixty years. I was taking Dairy Chemistry from Dr. Reuben L. Hill the quarter he died so I never heard from him about the Hill Curd Tension Test, which carried his name worldwide (11). Dr. Ernstrom was the first researcher in the United States to produce crystalline rennin (5) and to identify pepsin (6) in enzyme coagulant being sold deceptively. He developed processes for improved coagulant extraction and activation and is frequently consulted for his expertise in milk coagulation and cheese manufacture (35). Dr. Rodney J. Brown, now on sabbatical leave in York, England, is an international authority on the chemistry of milk coagulation, and his students, such as Dr. Don McMahon, now with Kraft in Melbourne, Australia, have provided new insights into the complex phenomena associated with milk coagulation (19). Recently all three of these USU scientists were featured at an invitational symposium on the subject of milk coagulation (7).

The family of Dr. Hill provided some photographs and I was also able to locate an old Aggie Buzzer with a photo of Hill along with colleagues many of you will remember. I was able to obtain a picture of one of his graduate students running the Hill Curd Tension Test (11, 12). Initially the test required that a knife be pulled up through the curd, and the maximum curd tension in grams was measured on a scale. Subsequently, a knife was designed to cut into the curd from above so it could be used in more than one test. A balance was placed below to measure the tension. Commercially built drive mechanisms were marketed to provide standardization of the Hill Test (4).

I was fascinated to find in our department inventory one of the original gold-plated instruments originally offered for sale. It was manufactured by the Heuser Instrument Company and marketed through the ZCMI Wholesale Druggists in Salt Lake City, Utah (13). The knife was pushed into the curd until the indicator flag dropped. A ratchet held the reading on the scale until the instrument was reset. Only one reading per sample could be taken because once the cheese was cut, channels filling with whey would produce errors for subsequent readings. Dr. Hill claimed that curd tension could be used to identify milks suitable for cheese making (hard curd) or for feeding infants (soft curd). The use of pasteurization and homogenization assures soft-curd milk for infants and avoids selection of abnormal milks. Thus, the Hill Test has been more applicable for measuring curd tension in cheese production.
Unfortunately, only one reading is obtained and no information is available on the rate of curd formation or the maximum strength possible.

Numerous workers have reported about instruments that provide continuous curd tension measurements (34, 10, 32), but few have become commercially viable for cheese plants. The cheesemaker is left to insert a thermometer or, more generally, a finger. In 1972 (27) we adapted a simple viscometer by adding a cutting wire and mounting it on a helical-path driving system. The cutting wire would thus pass through the curd and shear a new zone with each turn. Unfortunately, the cutting action was too weak at the axis, so curd built up and split ahead of the wire. The device only proved effective for the first part of the coagulation curve. This had laboratory interest but did not fill the need for commercial application.

While visiting Foss Electric in Denmark in 1980 I met Poul Gledes, inventor of the Formagraph. This was the finest device for laboratory studies of milk coagulation that I had seen. I pleaded for an evaluation unit and we were provided with the first and now the only one in the United States. We have been able to do much with this device that can measure continuously the coagulation of ten samples simultaneously (18). Foss attempted to modify this for use in cheese vats but was unsuccessful and has abandoned both the laboratory and the industry models. However, the concept was viable and we still use ours regularly. Small milk samples are moved back and forth past a loop suspended in the milk. When milk viscosity increases, pressure against the loop increases and forces the loop to rock a horizontal bar upon which is mounted a small mirror. A strobe light flashes at the extremes of the rocking cycle and the light beam is diverted by the mirror onto light-sensitive photographic paper. Students, like Don McMahon and Leslie Okigbo, have thus been able to generate Ph.D. dissertation data and numerous publications on milk coagulation and have provided new perspectives on dairy cattle management and cheese process modifications. For example, Dr. Okigbo found that some cows produce milk that will not coagulate even when mixed with normal milk (21). Thirty-eight percent of the USU dairy herd animals produced milk at the end of lactation periods that did not coagulate. If this cannot be corrected, then these animals should be used to produce “Big Macs” instead of cheese. In addition, cheesemakers have reported days when milk refuses to coagulate normally, although objective data has been unavailable for this phenomenon.

At the Utah State University Fifth Biennial Cheese Industry Conference, two top researchers spoke of the need for instrumentation to evaluate objectively what was happening in the cheese vat. They claimed that product yields were lost when curd was cut too early and that milk continued to move in the vat until coagulation started (33), thus shearing fragile bonds and producing additional losses in the whey. Dr. Norman F. Olson, University of Wisconsin,
Figure 6. Prototype instrument for continuous measurement of milk coagulation in the cheese vat. (30).
(24) reported that an Australian invention by Vanderheiden (34) was useful but too cumbersome and complex to be commercially viable. In this instrument two aneroid barometer-like bellows face each other in the milk. Into one, a fluid is pumped at three cycles per minute; into the second, a hydraulic fluid transfers pressure to a detector as the milk viscosity increases.

Immediately after that conference I began talking to scientists in other disciplines on campus, brought from home a forty-year old erector set, and started playing with ideas in the laboratory. I decided first to throw out the signal transmitter and simply raise and lower a disk in milk that would act as a receiver. With good advice from Water Laboratory experts, I eliminated hydraulics and selected a solid disk. The main problem was to select a sensitive detector for the change in forces on the moving disk. I was advised to contact my neighbor, Derle Thorpe, a strain-gage expert. Because he was an expert on concrete, I was concerned; especially when he described how he could measure the force of a person pushing on the side of a block of granite. I cautioned him that this was very gentle milk coagulation and I was making measurements in an entirely different world. Within two hours, Thorpe brought over a strain gage from a wind tunnel and demonstrated that it could give a continuous readout of curd tension changes. We were delighted, and he and Rene Winward, Department of Civil and Environmental Engineering, assembled two prototypes (Figure 6) for further testing here and by Dr. Olson in Wisconsin. From a logical standpoint, the Vat Timer should not work. As the disk moves up and down in the milk, whey pockets should be produced and should reduce the ability to obtain accurate measurements. But it does work. The disk can move up and down for more than one inch and, instead of breaking up, the milk cannot get away from the approaching plane, so it attaches to the stainless steel surface, and the forces generated by the moving disk are gently dissipated into the coagulating milk (30). Thus infinite measurements can be obtained, even beyond the practical cutting-strength requirements. The curves developed were the same as those found with the Formagraph and other laboratory instrumentation so laboratory data and cheese plant data could be correlated.

I truly enjoy simple things. No one thought that such a simple combination of well-known devices could measure milk coagulation. The instrument has received a favorable response from the patent office, and the cheese and the paint industries are requesting evaluation instruments. No Utah firm was interested but a progressive company in North Carolina (CEM Corporation) contracted with the USU Foundation to develop and market the CTM (Curd Tension Monitor) 1000 (Figure 7). The nation's largest cheese manufacturer indicated a willingness to pay over $10,000 per instrument if it would do what is claimed. Full production and advertisement campaigns are scheduled for spring 1985. Models are being developed to operate from the closed tops of
Figure 7. Commercial instrument for continuous measurement of milk coagulation in the cheese vat.
eight hundred new automated cheese vats used around the world. The produc-
tion model was brought out in December 1984 and used to measure milk
coagulation in the vats during a recent cheese short course. All participants
were interested in seeing that it was now possible to measure curd tension
continuously and to signal when the vat was ready to be cut.

Why are we excited about this instrument’s potential? Workers using the
Vanderheiden device have concluded that it is not worth the investment since
one can cut curd over a wide range of theoretical curd strength maximum and
have no effect upon cheese yield (17). We have used this claim to prove the
instrument’s value because this means a cheesemaker can reduce the curd
strength to a minimum, maximize savings in enzyme coagulant costs, and,
thereby, pay for the instrument within a few months. Additionally, Dr.
Ernstrom has found that some Utah cheese plants were losing yield because of
cutting when the curd was too weak. Now the optimum curd strength can be
set in each vat and prevent the losses associated with cutting too early.

Finally, the coagulation curve developed by these instruments can be
expressed mathematically and a gel strength maximum value (Gmax) can be
obtained for each vat of milk (19). If the milk casein is of the best quality, the
Gmax would be the highest possible. Conversely, if milk comes from cows late
in lactation, or if it has been stored cold and proteolytic organisms have
attacked the casein, or milk proteinases (23), or if other treatments have
causd deterioration of the casein, then the Gmax will be reduced. Thus, when
combined with the total protein tests generated on infrared milk test instru-
ments, the CTM will provide protein quality indicator data that ultimately
may be useful in milk premium payment programs and in changing herd and
cheese plant operations. Dr. Okigbo has already improved the properties of
noncoagulating milk from individual cows by modifying the enzyme coagu-
ulant, calcium chloride, and acid concentrations (22). These could well improve
the way the blended milk performs in the cheese vat. For these reasons, we are
excited about the potential value of the CTM 1000 to the cheese industry. All
local cheese plants are awaiting trial instruments so data can be collected to
establish the value of the instruments for improving cheese plant operations.

To curdle milk scientifically and economically is a continuing goal. There
is room for simple developments and curious developers. Our work is the
result of team efforts that have spanned years. The research environment at
Utah State University has been ideal for my research team and we thank the
many who have created it. Such support allows the kind of environment and
freedom expressed by Dominick Labino (8), one of our nation’s top inventors,
who recently claimed, “A guy working alone in his basement is likelier to come
up with something important, than someone who has to go to meetings.” I
also agree with his statement, “I like to have fun.” I am not in full agreement,
however, with his comment, “He who has the most toys wins.” But I do
appreciate the opportunity that has been provided me to play with a few toys along the way.

Applied research has provided an exciting life for me. Those who contribute in the basic sciences provide data for new developments. Both research and practical application must be encouraged for we have not yet reached the ultimate control, efficiency, and product quality associated with changing milk from a liquid to a solid.
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