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An introduction to aseptic processing and packaging of high-viscosity and particulate foods

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AN INTRODUCTION TO ASEPTIC PROCESSING AND PACKAGING OF HIGH-VISCOSITY AND PARTICULATE FOODS

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INTRODUCTION

Aseptic processing and packaging are extensively used in thermal processing of low-viscosity foods such as milk and fruit juices. Much of the research today is concentrated on extending the aseptic processing area to high viscosity foods and foods containing particles. The driving forces behind this development are shown in Table 1.

Benefits of aseptic processing and packaging

* Better food quality (HTST/UHT)
* Reduced packaging and total costs
* New package/product opportunities

In this presentation, the differences between the flow properties of low-viscosity and high viscosity fluid foods is demonstrated. The influence of these differences on the flow conditions and the choice and design of equipment is discussed. The addition of solid particles to the system further complicates the flow. The flow of particles must be controlled, so that they are maintained in suspension and not separated out from the fluid. Furthermore, particle heat transfer is important for attaining sterility. The performance of equipment for processing of viscous and particulate foods is discussed, together with the development of processing systems for separate flow of liquids and particles.
Finally, some economical considerations are presented.

HIGH VISCOSITY FOODS

When applying high temperature short time (HTST) treatment to high viscosity foods, continuous processes involving heat exchangers are most commonly used. In viscous flow processes, it is important to consider the often very complex rheological behaviour of high viscosity foods. These are often described as being non-Newtonian, so called "power law" fluids. The rheological properties depend on a large number of product and processing factors. Recent studies have e.g. shown that the viscosity of starch solutions is influenced not only by the type of starch but also by the rate of shear and that the viscosity changes with time during shearing. This means that the method and the intensity of the processing greatly influence the viscosity of the starch solution, which in turn to a large extent will determine the flow properties of the product in the equipment.

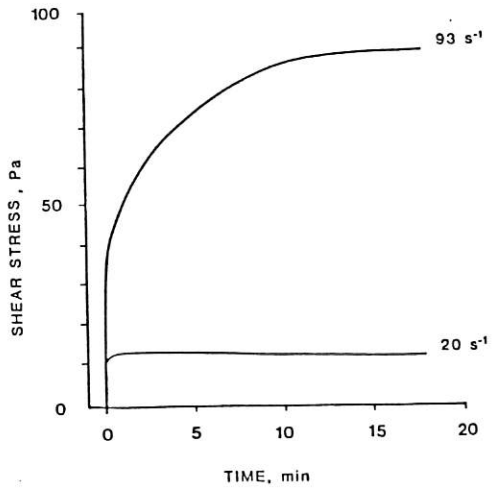

Figure 1.

Time dependence of the shear stress (viscosity) at high and low shear rates for a 5% starch solution (Härröd 1986 b)

Equipment considerations

High-viscosity foods, often have a viscosity well above 10 000 cP or 0.1 Pa s, which is usually considered to be the practical limit for using the plate heat exchangers and tube heat exchangers, extensively used for low-viscosity foods and drinks. The equipment pre-dominantly used for continuous processing of more viscous and particulate foods is the scraped surface heat exchangers for heating and cooling with a cylindrical holding tube in between.

Tube flow

In the safety considerations for aseptic processing systems it is essential to understand the relationship between the fastest moving volume element or particle in the food and how this is related to the average volume velocity. In traditional laminar flow of Newtonian foods in a cylindrical holding tube the ratio between the fastest and the average velocity is 2:1 but in non-Newtonian fluid flow this ratio is substantially smaller as illustrated in Figure 2, where the n-values lower than unity stand for non-Newtonian foods.

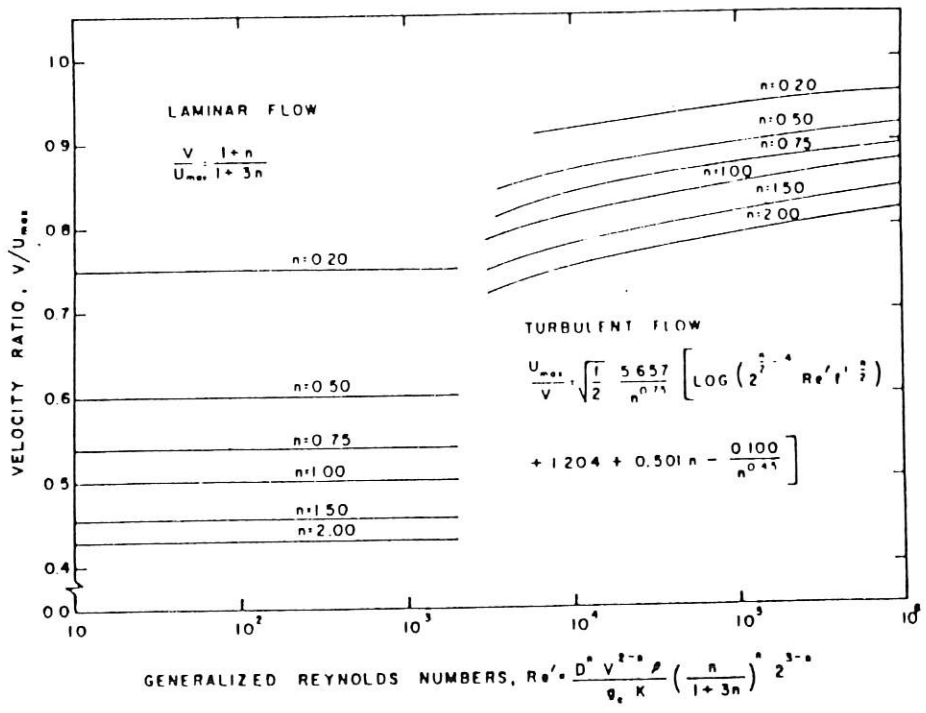

Figure 2

The ratio of the average velocity to the maximum velocity for laminar and turbulent tube flow (Palmer and Jones, 1976)

While understanding of the velocity of the fastest moving volume elements is important for the safety considerations, understanding of the velocity of the bulk average velocity is important for the assessment of the overall quality of the food. To avoid severe overprocessing of the foods the ratio between the fastest moving particle or volume fraction and the bulk average velocity should be as close to 1 as possible. This is usually called "plug or piston flow", which is often the desired type of flow in aseptic processing.

Scraped surface heat exchanger

The scraped surface heat exchanger consists of a concentric tube in which the inner rotor is equipped with scrapers preventing the material from building up at the heat transfer surface. The inner rotor also creates rotational flow and at sufficiently high rotation speeds, so-called Taylor vortex flow is prevailing. This flow condition means that vigorous mixing inside the scraped surface heat exchanger is created by small local vortices between the rotor and the stator.

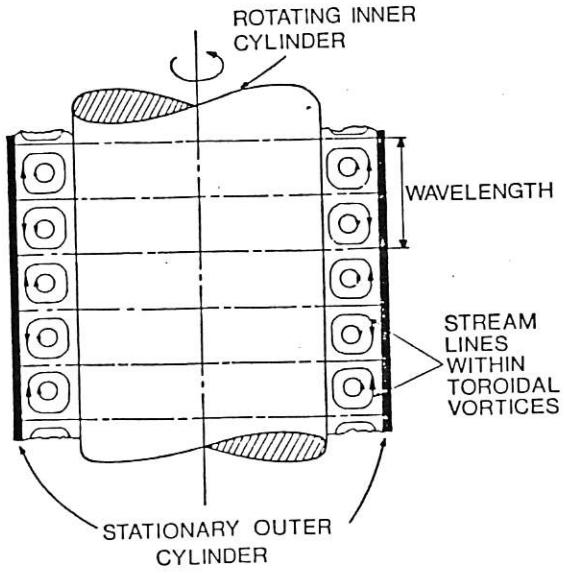

Figure 3

Flow system inside scraped surface heat exchanger in Taylor vortex flow region, (Härröd 1986 a).

The Taylor vortex flow condition in the scraped surface heat exchanger is fairly similar to plug or pistol flow, which is the desired operating condition in most cases. In addition to the rotational flow, other factors such as axial flow rate and of course the viscosity influence the position of the operating area for plug flow in scraped surface heat exchangers. In laminar flow conditions, channelling effects may develop with large temperature variations in the radial direction of the flow (Härröd, 1986 a).

Direct heating methods

There are also possibilities to heat foods directly by adding steam to the product (steam injection) or introducing the cold product into a steam atmosphere (steam infusion). Steam injection is frequently used in the

heating of viscous foods. Vigorous mixing of the steam and the food in turbulent flow is required in order to attain rapidly temperature uniformity. Due to the difficulties of controlling the final temperature, steam injection methods are often used for raising the temperature in part of the heating section only, where the temperature can be easily controlled, e.g. at 100°C. Steam infusion methods allow longer contact times between the food and the steam. Again, for viscous foods, contact times and residence times in the steam area are difficult to control. However, these methods should be considered, at least as part of the heating system as they involve simple and rapid heat transfer as well as low investment costs compared with scraped surface heat exchangers.

There are also other direct heating methods, such as electric resistance heating, where electric energy at a frequency of 50 or 60 Hz is applied to electrodes inserted into the stream of the liquid food. There is a Finnish system called Elecster employing this method for sterilization of ice-cream mixes and other low to medium viscosity products. Microwave heating methods have not yet been found to be commercially viable for heating of liquids.

FOODS WITH PARTICLES

Adding particles to the viscous food component means that the flow of the particles relative to the fluid food also has to be considered, as well as the heat transfer from the liquid to the particle and the heat conduction inside the particles to the centre of the food. Both the flow velocity of the fastest moving particles and the heat transfer time at the slowest point in the particle have to be controlled. This time determines the degree of sterility of the system. The quality assessment, however, depends on the integrated evaluation of the influence of time and temperature on all the different particles and the liquid. Sterility considerations are of course always of primary importance to quality consideration.

Flow of particles

In the flow of particles it is important to avoid separation of particles from the liquid flow. The gravitational forces caused by the differences in density between particle and fluid must be balanced by the drag forces

preventing settling or flotation of the particles. In some situations centrifugal forces will also act on the particles. When the gravitational forces and the drag forces are in balance the terminal settling velocity is attained. This is the axial flow rate that should be exceeded. However, for flow of single particles larger than 1 mm, the theoretical terminal settling velocity is seldom reached. For larger particles, the flow is often in the so called transition zone, where, due to gravity, there are more particles in the lower parts of the tube. If the axial flow velocity is further reduced particles will begin to settle at the bottom of the tube and a moving bed will develope on the bottom wall. This situation has to be avoided, as it leads to complete loss of control of the flow of the particles.

However, in the practical situation, many factors help to reduce the terminal settling velocity, and thus to maintain larger particles in suspension. One such factor is the deviation from sphericity of the particles, as shown in Figure 4.

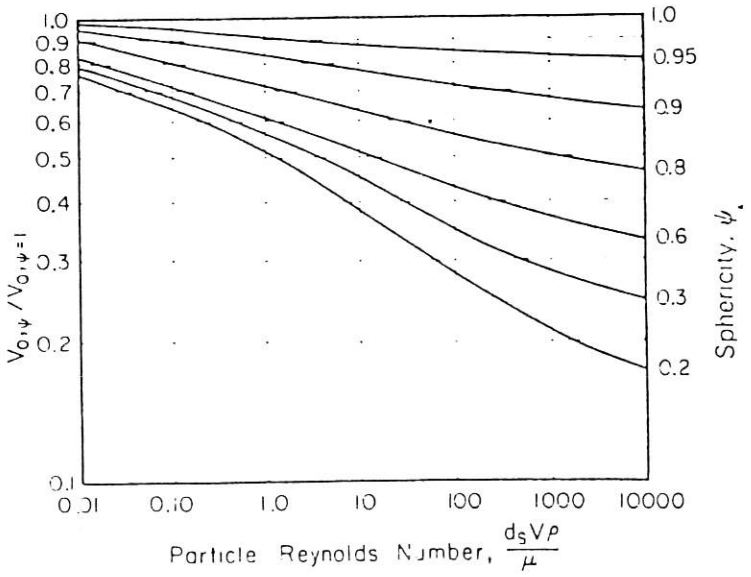

Figure 4

Reduction of terminal settling velocity with lower sphericity of solid particles for different particle Re-numbers. (Govier and Aziz, 1977).

At high particles concentrations, particle-to-particle interference and wall-to-particle interference will also lower the terminal settling velocity and thus help maintain particles in suspension.

It should be noted that for both geometrical and flow reasons there will be a higher concentration of particles in the central line of the tube flow. The particle concentration will also influence the flow profile of the fluid.

Equipment considerations

Recent experimental studies have shown that particles in a cylindrical holding tube sometimes travel at speeds slightly greater than the average bulk velocity (Nesaratnam & Gaze, 1987).

In flow of particles in scraped surface heat exchangers, Taylor votex flow should be aimed at. Recently, Defrise and Taeymans (1987) showed that at high rotational speeds and with high-viscosity liquids, the ratio of the mean residence time of the particles to the mean residence time of the liquid is 0.8-0.9 to 1 (Table 2). This indicates that there is some axial mixing of particles in the SSHE, but that the flow of the particles during these conditions is close to plug flow.

Table 2.

Mean residence time for the solids compared with the average residence time under different processing conditions (Defrise and Taeymans, 1987)

TABLEAU III

Temps de séjour moyen réduit pour la phase solide, pour différentes conditions opératoires

CMC 0,75 % Concentration particulaire 5 %				CMC 0,75 % Concentration particulaire 20 %				CMC 1,75 % Concentration particulaire 5 %			
Débit L/h	Vitesse de rotation tr/min			Débit L/h	Vitesse de rotation tr/min			Débit L/h	Vitesse de rotation tr/min		
	150	250	400		150	250	400		150	250	400
100	0,62	0,80	0,62	100	- - - -	0,89	0,86	100	0,97	- - - -	0,87
170	0,45	0,72		170	- - - -	0,77		170	1,17		
250	- - - -	0,82	0,79	250	- - - -	- - - -	0,88	250	1,08	- - - -	0,97

An important equipment consideration is the selection of pumping equipment for transport of the particle containing foods through the system. Monopumps and lobe-rotor pumps are often used. These can handle fairly large particles, but there is always a risk of mechanical damage to sensitive particulate foods. A special problem is associated with the pump for the sterile product between the thermal processing equipment and the packaging system. This pump needs to be sterilized in the pre-sterilization sequence of the aseptic system. This means that it has to withstand temperatures around 120^{o}C for some time.

At the same time the sterile pump will have to operate properly and maintain sterility at the low temperatures of the cooled product during production. These are stringent requirements, which are difficult to meet with many pumps.

Particle heat transfer

In considering the safety of the aseptic processes we also need to understand the heat transfer inside particles. In most aseptic processing systems the conservative approach is taken that the residence time of the particles in the scraped surface heat exchanger used for heating and cooling is disregarded in the calculation of sterilization values. The holding time for the particles in the holding tube will be long, due to the slowness of heat conduction from the surface to the centre of particles. Overprocessing of particles will also occur, due to the traditional approach of laminar Newtonian flow of the fluid. This has already been discussed above.

With these conservative approaches severe overprocessing of particles may occur and the advantages of high temperature short time sterilization and the possibilities of improved quality of food through aseptic processing are lost. The quality may even be inferior to that achieved by good traditional canning, where there is less risk of quality defects due to mechanical damage.

In recent studies, the influence of the heat transfer during heating and cooling in the scraped surface heat exchangers has been included in the calculation of the sterilization value. Hegg and Karlsson (1987) demonstrate the effect of different temperatures in the holding tubes both when it comes to the actual length of the holding tubes and how these influence the cook values of the liquid and the particle. The cook value is an indicator of product quality, and the lower value the better.

Table 3.

Length of holding tubes and calculated cook values for particles and liquid for different sterilization temperatures in an aseptic SSHE processing system (Hegg and Karlsson, 1987)

	120°C	125°C	130°C	135°C	140°C
Holding time	10x	4x	2x	1.5x	x
C value (particle)	115	77	65	65	72
C value (liquid)	120	85	80	86	100

Table 3 shows that the optimum/lowest cook values of both particles and liquids are reached around a temperature of 130°C, indicating that there is no need to use higher temperatures in aseptic processing of particulates with a diameter of 6 mm.

For particle heat transfer calculations, the surface heat transfer coefficient must be known. According to classical engineering theory the heat transfer coefficient can be determined according to Nu = 2, when there is no relative movement between the particles and the liquid. However, studies have shown that the experimental evaluated heat transfer coefficients often exceed the values predicted by Nu=2. This is probably due to the movement of particles relative to the fluid and also some rotation of the particles.

Separate flow systems

It is clear from the presentation above, that the possibilities to control the flow and the heat transfer to the particles in scraped surface heat exchanger systems and to achieve high quality products from such a system are limited. Systems involving separated flow of the liquid and the particles offer a method to overcome some of these limitations. In the APV Jupiter system, this is achieved by processing the particles in a rotating double cone with both direct steam heating and heating through the jacket. The liquid part of the product is processed in traditional heat exchangers. The sterile liquid is used to transfer the solid particles to the

filling stations through a series of aseptic valves. The system is quite complicated from a mechanical point of view. A drawback that has been mentioned is the long trahsport time needed inside the equipment, which means that the quality improvements may not be sufficiently large. The first installed semi-full scale production unit for soups is not in operation any more.

Another interesting development has recently been presented by the APV Company. It involves using electric resistance heating to heat directly solid particles in foods transported in a liquid medium inside a tube to which electrodes connected to a 50 Hz power source are applied.

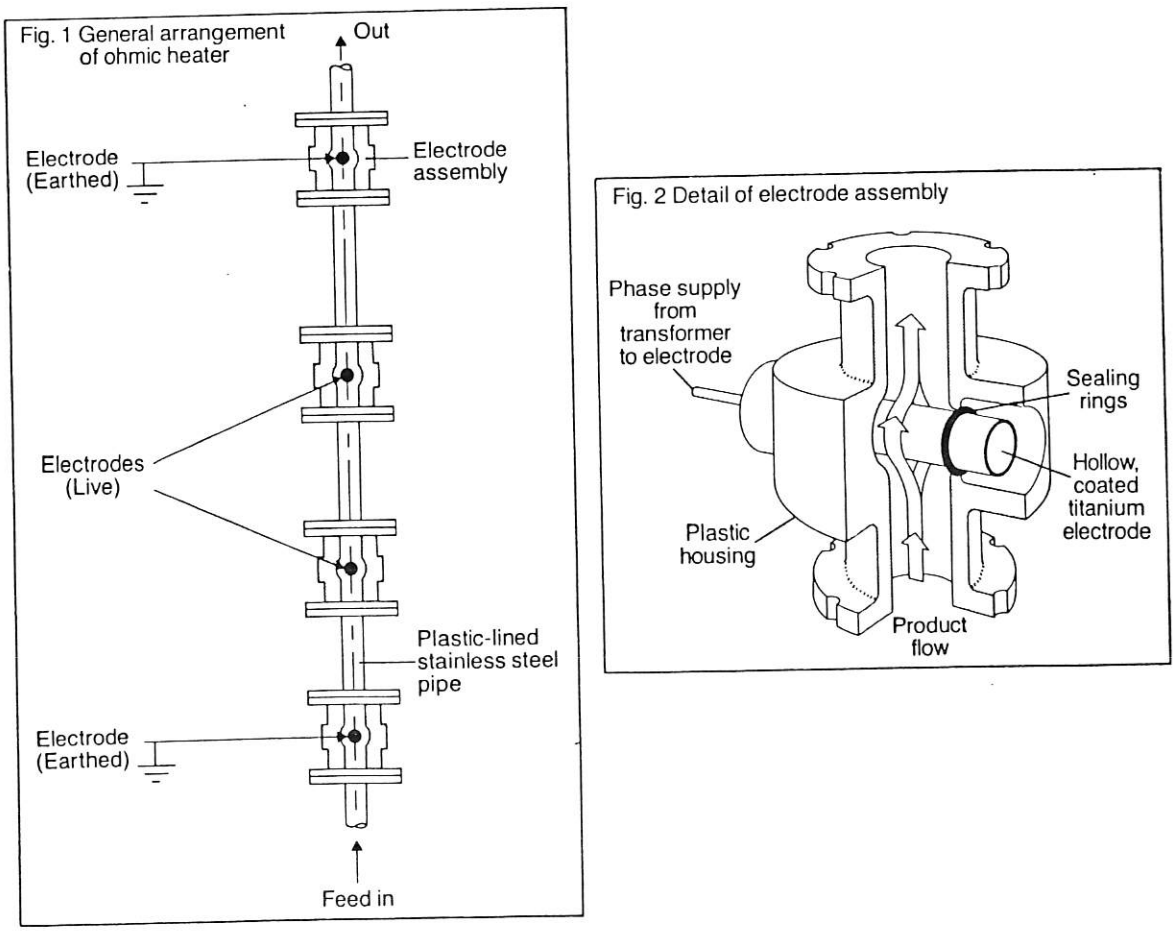

Figure 5 Ohmic heater

By this so called Ohmic heating method, the slowness of the heat transfer in the solid particles can be overcome and rapid heating achieved. However, for uniform heating precise control of the conductivity of both the solid and the liquid part of the food is important. This method is not yet used commercially.

ECONOMIC ASPECTS

There have been very few studies, where the economics of aseptic processing systems have been compared to similar techniques such as sterilization in regular cans or glasses. Some of these have shown, however, that the largest cost in such systems is the packaging cost. This is often one or two orders of magnitudes higher than the cost of labour, maintenance and even capital.

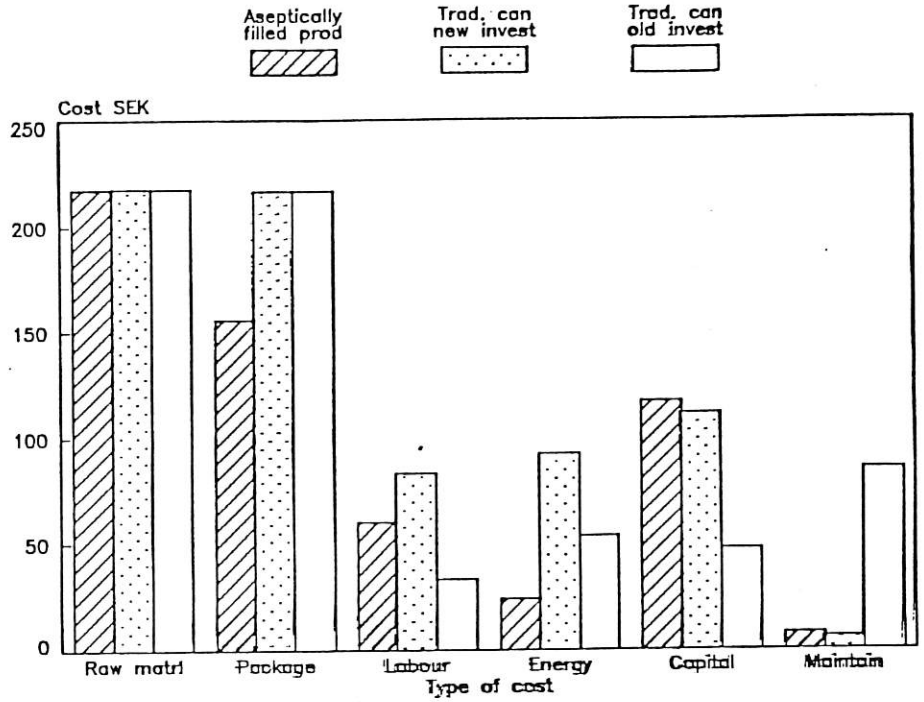

Figure 6

Comparison of different costs for traditional retort and aseptic processing systems (Eklund, 1985)

The packaging costs in aseptic systems are often cited as being approximately half of the cost of glass and tin plate, but with more advanced barrier properties of the package, the price difference is today often very small. Comparisons between systems are difficult to make and the results are often contradictory. Calculations have to be made for the same kind of the product and for comparable investments, e g by adding a new product to an existing line or investing in a completely new processing system.

It is important to understand that the processing of viscous and particle-containing food is technically very different from the aseptic processing of low-viscosity foods. This also has economic consequences. One important economic aspect is that scraped surface heat exchangers are

normally only available in sizes up to a production of approximately 500 kg/hour. The need for economy of scale is therefore not as pronounced as for other heat exchanger systems. A typical full scale processing unit for viscous foods contains a number of scraped surface heat exchangers, at considerable investment costs. I therefore believe we will see continued development of separate flow systems and combination systems, in which steam injection and traditional heat exchangers are combined to provide the best process economy.

SUMMARY

In this presentation I have tried to show the often considerable differences between processing of low viscousity foods such as milk and other drinks, and processing of high-viscosity, particle-containing foods. Their flow properties are very different, leading to large differences in equipment design, processing principles and process control. Control of the flow and the heat transfer of the particles further complicates the design and operation of the processing and packaging systems. The development of new methods involving separate flow systems and systems with direct heating equipment will continue.

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