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Ohmic Heating is an Alternative Preservation Technique-A Review

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Abstract- Ohmic heating offers an alternating to conventional heating because it simultaneously heats both phases by internal energy generated through electrical energy. In this process heating rate depends upon the electrical conductivity and field strength. By this method a product undergoes a minimum structural damage, retain its nutritional value. This technique gives excellent processed quality products in minimum operating time. Electrical conductivity of food products is linear with different temperature range. Energy during ohmic heating is dissipated directly into the foods. Ohmic heating can be utilized in different preprocessing and processing operations like blanching, evaporation, dehydration, fermentation, extraction, sterilization, pasteurization etc. Additionally research revealed that there is no protein denaturation at high temperature when heated with ohmic heating, also in the presence of starch, unusual conductivity behaviors found due to starch gelatinization.

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Abstract- Ohmic heating offers an alternating to conventional heating because it simultaneously heats both phases by internal energy generated through electrical energy. In this process heating rate depends upon the electrical conductivity and field strength. By this method a product undergoes a minimum structural damage, retain its nutritional value. This technique gives excellent processed quality products in minimum operating time. Electrical conductivity of food products is linear with different temperature range. Energy during ohmic heating is dissipated directly into the foods. Ohmic heating can be utilized in different preprocessing and processing operations like blanching, evaporation, dehydration, fermentation, extraction, sterilization, pasteurization etc. Additionally research revealed that there is no protein denaturation at high temperature when heated with ohmic heating, also in the presence of starch, unusual conductivity behaviors found due to starch gelatinization.

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I. Introduction

The rate of transfer of heat is low to the cold point in conventional aseptic processing, long processing times required but destruction of nutritional and sensory attributes, productivity is less and high cost of energy (Mitchell, 1989; Smith *et al.,* 1990). It is difficult to apply aseptic processing for high pH large particles viscous liquids. In conventional aseptic heating, it is not possible to sterilize particulate foods at temperatures much above 130ºC without serious overheating of the liquid phase (Parrot, 1992). Ohmic heating has been seen as a promising development to solve problems encountered in aseptic processing of low acid liquids containing particulates. Several authors have demonstrated that in ohmic heating, centre of the particle heats faster other than the liquid (de Alwis *et al.,* 1989; Sastry and Palaniappan, 1992). Ohmic heating offers an alternating because it simultaneously heats both phases by internal energy generation (Palaniappan and Sastry, 2002). The most favorable conditions where electrical conductivities of fluid and solid particle are equal mainly when do the processing of particulates foods (Wang and Sastry, 1993a). Heating rate depends upon the electrical conductivity and electric field strength and also directly proportional to that (Sastry and Palaniappan, 1992). By this method a product undergoes a minimum structural damage, retains its nutritional value and also gives excellent processed quality products in minimum operating time (Rahman, 1999). The critical property affecting energy generation is the electrical conductivity of the material (Palaniappan and Sastry, 1991).

Low acid foods with particulates can be continuous sterilized by ohmic heating.(Palaniappan and Sastry,2002). Residence Time Distribution (RTD) measurement is needed because of the difficulty in measurement of the particle internal temperature during continuous flow (Sastry and Cornelius, 2002). Some of the researcher had studied the RTD of food particle in holding tube (Dutta and Sastry, 1990a; Salengke and Sastry, 1995; Salengke and Sastry, 1996; Alhamdan and Sastry, 1997). To find out RTD of any particulate foods, ultrasonic method is widely used when processed through ohmic heating (Marcotte *et al.*, 2000). Ohmic heating technique widely used to blanching of vegetables (Mizarahi *et al.*, 1975), thawing of frozen foods (Naveh *et al.*, 1983). It can also be used for evaporation, dehydration, fermentation and extraction (Butz *et al*., 2002). Microbial inactivation is also carried out by ohmic heating process. The electrical pretreatments can reduce the intensity of using additional thermal methods to inactivate the microbes (Cho *et al*., 1996).

II. Electrical Conductivity

Electrical conductivity is the main critical parameter for heating the food material by joule heating techniques (Palaniappan and Sastry, 1991). Several food materials electrical conductivity have been experimented by many scientist. Electrical conductivity of some liquid foods is measured at different temperature (Ruhlman *et al*., 2001). Electrical conductivity of different solid foods is also measured (Mitchell and de Alwis, 1989). Mostly food contains the some parts of salts and acids causes electric current pass through the food and generate heat inside it (Palaniappan and Sastry, 1991). With this result, increase the electrolytic content causing increase in the electrical conductivity. (Wang and Sastry, 1993a,b).This effect may be accomplished via the relatively slow soaking or marination process or the more rapid blanching process in salt solution. Diffusion of salt in pork and beef has been studied by many researchers (Wistreich *et al.,* 1960; Del Valle and Nickerson, 1976a,b; Dussap and Gros,1980). Some researcher had

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determined salt diffusivity in vegetable tissues (Drusas and Vagenas, 1988; Wang and Sastry, 1993b). Electrical conductivity of water chestnut increased with temperature and salt concentration. Relationship with temperature and salt concentration is found to be $R^2=0.98$. Electrical conductivity also changes with the change in the voltage and increase in the temperature as shown in Figure 1. By increasing the temperature, ohmic heating seems to be more effective (Sastry and Palaniappan, 1992). Figure 2 explain the linear increase in electrical conductivity with temperature (Palaniappan and Sastry, 1991; Castro *et al*., 2003). Figure 3 also supports the same statement for lean pork, which states that at higher temperature (above 100°C) tenderloin is more conductive than loin and shoulder (Sanjay *et al.,* 2007).

The heating rate of particle liquid mixture depends on conductivity of mixture and the volume of each phase (Sastry and Palaniappan, 1992b). The reason of this is, as particle content increases, the path of current through the fluid, forcing the total currents to flow through the particles. This will be caused in more energy generation within the particles and a greater particle heating rates. It is also concluded that the range of electrical conductivity of the food products should be in the range from 0.01 S/m to 10 S/m. Food products which is used should have pH more than 4.6 and solid particulates food have solid to liquid ratio 40:60 (Palaniappan and Sastry, 1991). Several researches have been done on electrical conductivity of fruits and concluded that electrical conductivity of pear (0.041 S/m) and apple (0.023 S/m) measured at 25°C (Mitchell and de Alwis, 1989). Electrical conductivity of fresh strawberry was measured at 25°C 0.05 S/m, and at 100°C 0.55 S/m (Castro and Sastry *et al*., 2003). It can be observed from Table 1 is that the conductivity of strawberry increased from 0.186 S/m at 25°C to about 0.982 S/m at 100°C . Electrical conductivity of different pork cuts observed that lean is highly conductive compare to fat (Shirsat *et al.,* 2004). The electrical conductivity of the individual components of the chicken chowmein over the process sterilization temperature range was measured at 27°C (2.1 S/m) and 140°C (6.8 S/m) (Tulsiyan *et al.,* 2007).

III. Starch Gelatinization

Conductivity of foods has been found affected by physical structures. Experiment was carried out on several foods, and result was reported that certain food component, such as fat or starch might cause unusual conductivity behaviors during ohmic heating (Halden *et al*., 1990). If food product containing starch then care should be taken during ohmic heating because it causes starch gelatinization. There is a slight change in the heating curves of potato (Halden *et al*., 1990). When applying this heating to particulate foods, conductivity was found to decrease with solids content and the particle size because it decreases the mobility of the ions (Palaniappan and Sastry, 1991b). Study on starch gelatinization is very important because there are many processes like extrusion, aseptic processing, sterilization etc., which are related to starch gelatinization. This change in a potato slice during ohmic heating was observed. The data explained that the major changes in electrical conductivity of the heated potato occurred at 40–50 °C and 75–80 °C. It is concluded that the starch gelatinization must be explained at higher temperature. A method was developed to get the degree of starch gelatinization by ohmic heating (Wang and Sastry, 1997).

IV. Effects on Physiochemical Property of Foods

Food products like cloudberry jam and goat milk were tested. All the chemical analysis were performed to find the total and volatile solids, ash, titratable acidity, ascorbic acid, total sugars, total fatty acids, total phenolic compounds and anthocyanins content, shown in Table 2 (Pereira *et al*., 2006). During ohmic heating moisture content of food products are also changes. From Table 3 the results of chemical analysis indicate that ohmic heating and conventional heating technology gives products with similar chemical properties. This is important because it allows the producers to replace the methods without major changes in their final products. Ohmic heating was also applied to the tomato paste. Tomato was exposed to ohmic heating with the voltage range from 6–14 V/cm. All data were taken at the temperature range from 26 to 96°C. This study showed a linear increase in conductivity values with increasing temperature. The value of "P" is always less than 0.05, which shows that the voltage gradient was statistically significant on the heating time. The variation in the pH noticed in the range of 4.20 to 4.51 (Hosain *et al*., 2012). Figure 4 explains the change in electrical conductivity when tomato is exposed to different voltage gradient and found to be statistically insignificant ($P > 0.05$).

Figure 5 revealed that the increase in voltage, heating time to reach the specific temperature decreased and found statistically significant. The ohmic heating rates were 0.325, 0.647, 1.495 and 2.031°C/s at voltage gradients 6, 8, 10, 12 and 14 V/cm, respectively. Various other parameter of milk was tested and that was found that at 40°C electrical conductivity was increased and viscosity was decreased with increasing temperature. Pasteurized milk chemical composition and its pH were not influenced in electrical field (Assad *et al.,* 2013).

The results showed in Figure 6 that the viscosity of milk decreased with increasing temperature and this because the increase in temperature leads to lower milk fatty blocs responsible for the high viscosity of milk. The relationships between viscosity and temperature are first-order equations for all electrical fields. Milk density was reduced with increasing milk temperature as shown in Figure 7. This reduction is after the rising of milk temperature above 40^0C (Muhsin, 2012). The results also showed that the differences in the density between electrical fields were not significant at all temperatures.

V. Effect on Microbial Quality

The comparison of ohmic heating and conventional heating were carried out with respect to inactivation effect on viable aerobes and *Streptococus Thermophilus* 2646 in milk under same temperature exposure. The quality of milk in terms of degree of protein denaturation were also studied in both conventional and ohmic heating and found that microbial counts and calculated decimal reduction time (D value) resulting from ohmic heating was significantly lower than those resulting from conventional heating. It was also concluded that there was no difference in degree of protein denaturation during the two treatments. Ohmic heating had thermal and non thermal lethal effect on microorganism. (Huixian *et al.,* 2007).The initial counts of viable aerobes and the initial counts of *Streptococus Thermophilus* were almost the same. During treatments, when the set temperature achieved, the total microbial counts were reduced, which is greater in ohmic heating than those in conventional heating. Moreover, for both viable aerobes and *Streptococus Thermophilus*, microbial counts were significantly different ($P<0.05$) between the two treatments at each temperature (Kazuhiko *et al.,* 2007).

VI. Fouling Effect

Heating process of the food products like pasteurization, sterilization etc, is performed to inactivate or kill the microbes or protect the food products against any microbiological changes. But there is very fair possibility that the product may lower its quality. During heating process, heat transfer equipments undergo the effect of fouling. This fouling lowers heat transfer, efficiencies and production loss etc. Bansal, *et al.,* (2005) heated milk in ohmic heater and found that fouling was enhanced when the temperature of milk at the inlet was decreased. If the milk flow rate is increased by double then the fouling rate was observed to be minimal. The reason of the influence on overall fouling rate might be the extent of protein reactions, different deposition rates for denatured and aggregated proteins and fluid hydrodynamic forces. Skim milk fouling curve is shown in Figure 8. The effect of milk temperature at the inlet of the ohmic heater is shown in Figure 9. Low fouling has been noticed when a reduction in the inlet temperature and corresponding to the tank temperature (Bansal, *et al.,* 2005). During the supply of high current and stainless steel material electrode is used, rapid drop in power was recorded whereas the best results were obtained using graphite electrodes. The effect of the flow rate is shown in Figure10.

VII. Conclusion

Innovations in food processing techniques can significantly contribute to meeting the needs of the future with respect to quality, quantity and sustainability. Ohmic heating is one of the emerging technologies with enormous applications in the sector of food processing. Some of the possible applications are blanching, evaporation, dehydration, fermentation, extraction, sterilization, pasteurization and heating of foods to serving temperature. Research based on modeling on heating need to be done for complex foods, which may leads to the development of final packaging to the products. Fouling was increased when the temperature of milk reduced at the inlet and also doubles the milk flow rate. The reason of the influence on overall fouling rate might be the extent of protein reactions, different deposition rates for denatured and aggregated proteins and fluid hydrodynamic forces.

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Table 1 : Electrical conductivity versus temperatures of different fruits (Sanjay Sarang, 2007)

Temperature (^{0}C)	Apple –Green	Apple –Red	Peach	Pear	Pineapple	Strawberry
25	0.067±0.020a	0.075±0.016a	0.170±0.018b	0.084±0.019a	0.037±0.014c	0.186±0.047b
40	0.144±0.024a	0.138±0.011a	0.307±0.022b	0.173±0.009c	0.141±0.034a	0.335±0.060b
60	0.251±0.042a	0.239±0.031a	0.541±0.043b	0.313±0.059c	0.245±0.052a	0.592±0.108b
80	0.352±0.049a	0.339±0.047a	0.738±0.064b	0.439±0.082c	0.348±0.067a	0.801±0.148b
100	0.425±0.054a	0.419±0.053	0.941±0.092b	0.541±0.098c	0.432±0.070a	0.982±0.176b
120	0.504±0.059a	0.499±0.052a	1.123±0.130b	0.607±0.080c	0.506±0.080a	1.143±0.178b
140	0.571±0.072a	0.577±0.050a	1.299±0.176b	0.642±0.088c	0.575±0.081a	1.276±0.180b

Table 2 : Results of chemical analysis performed in unprocessed, ohmically processed and conventionally processed goat milk (Pereira *et al*., 2006)

Tests performed	Conventional	Ohmic	Unprocessed
pH	6.59 ± 0.04	6.59 ± 0.05	6.61 ± 0.07
Total Acidity (% lactic acid)	0.134 ± 0.003	0.124 ± 0.004	0.132 ± 0.003
Total Solids (%)	14.7 ± 0.30	14.9±0.1	14.7±0.1
Ash (%)	1.3 ± 0.1	1.1 ± 0.1	1.0 ± 0.1
TFA (g 100 g-1 of milk fat)	88.2 ± 4.7	86.5 ± 7.0	89.5 ± 10.6

Table 3 : Results of chemical analysis performed in unprocessed, ohmically processed and conventionally processed cloudberry jams (Pereira *et al*., 2006)

Tests performed	Conventional	Ohmic	Unprocessed
pH	3.83±0.03	3.65±0.10	3.37±0.06
Total Acidity (g $_{\text{Citric acid}}$ 100 g^{-1} $_{\text{of product}}$)	6.18±0.08	6.01±0.01	6.34±0.08

Total Solids (%)	39.5±0.3	40.0±0.6	39.5±0.6
Ash (%)	0.23±0.01	0.23±0.02	0.21±0.01
Anthocyanins (mg_{C3G} $100g^{-1}$ $_{of\ product}$)	0.036±0.02	0.36±0.01	0.70±0.02
Total Phonlics (mg_{GAG} $100g^{-1}$ $_{of\ product}$)	149.4±7.4	150.9±1.8	144.5±3.6
Ascorbic Acid (mg 100 g^{-1} $_{of\ product}$)	2.88±0.08	2.76±0.08	3.08±0.10
Total Sugars (g_{sgf} $100g^{-1}$ $_{of\ product}$)	46.48±0.95	47.37±1.11	34±2.39

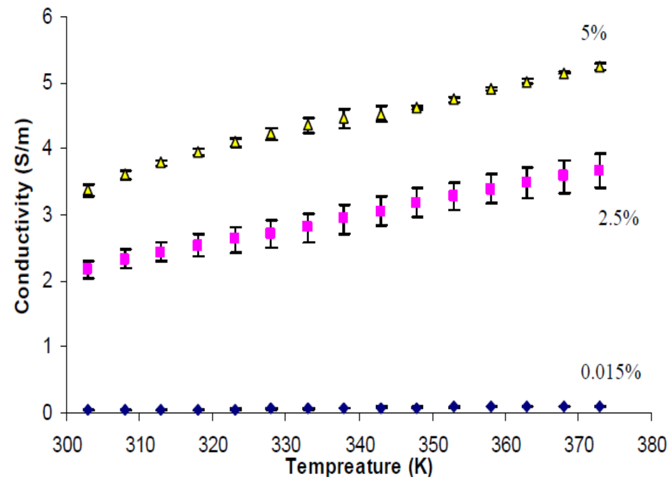

Figure 1 : Electrical conductivity variation with temperature, of water cheesenuts with .015%, 2.5%, 5% salt mass fractions

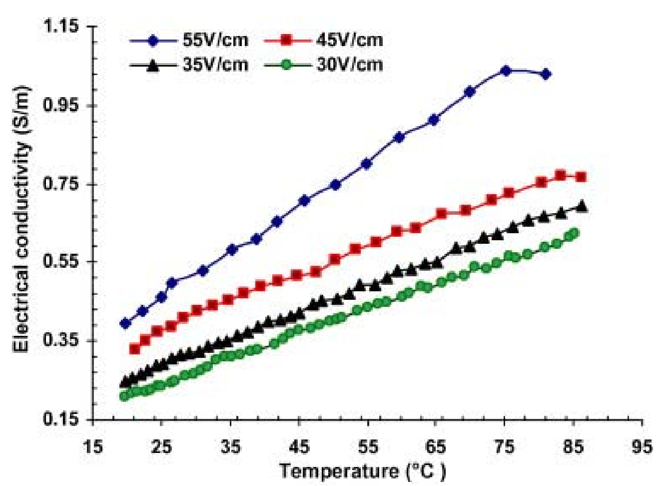

Figure 2 : Electrical conductivity changes with change in voltage

Global Journal of Science Frontier Research (E) Volume XIV Issue IV Version I Year 2014

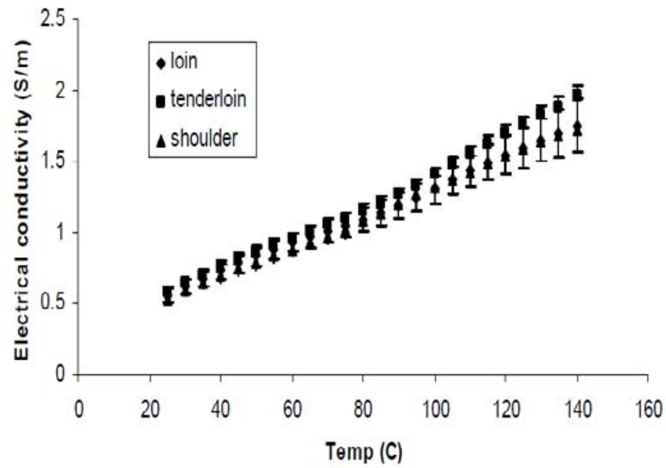

Figure 3 : Electrical conductivity of different pork cuts increases linearly with temperature

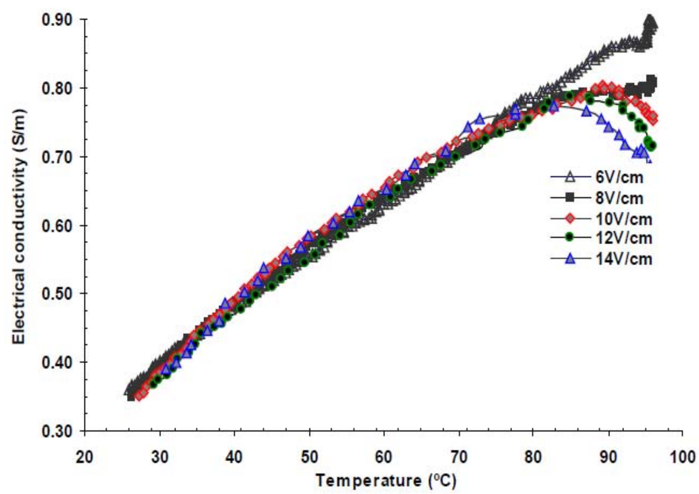

Figure 4 : Electrical conductivity of tomato versus temperature (Hosain Darvishi et. al ,2012)

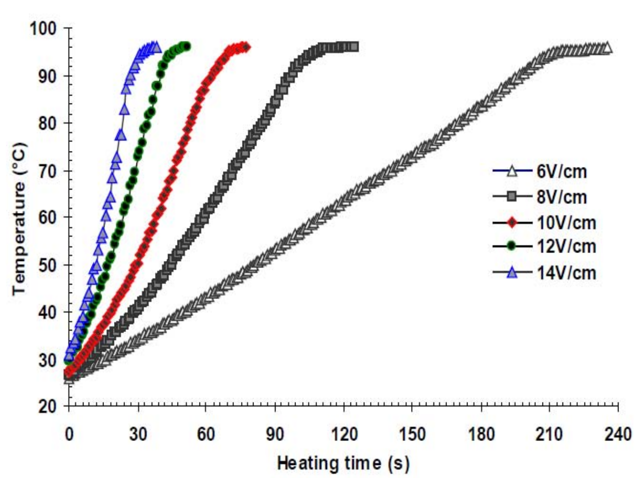

Figure 5 : Temperature and heating time curves of tomato samples at voltage gradient (Hosain Darvishi *et. al.*,2012)

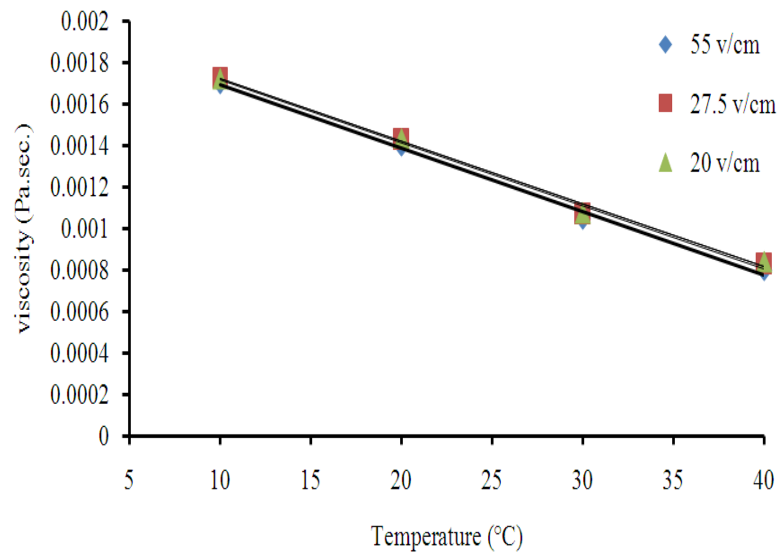

Figure 6 : Viscosity vs. temperature of milk at electrical field pasteurization (Assad Rehman Saeed Al –Hilphy, 2013)

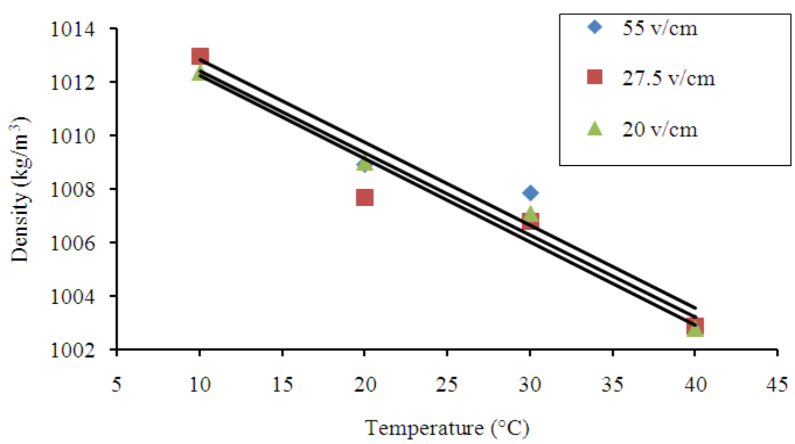

Figure 7 : Density vs. Temperature of pasteurized milk by electrical field (Assad Rehman Saeed Al –Hilphy, 2013)

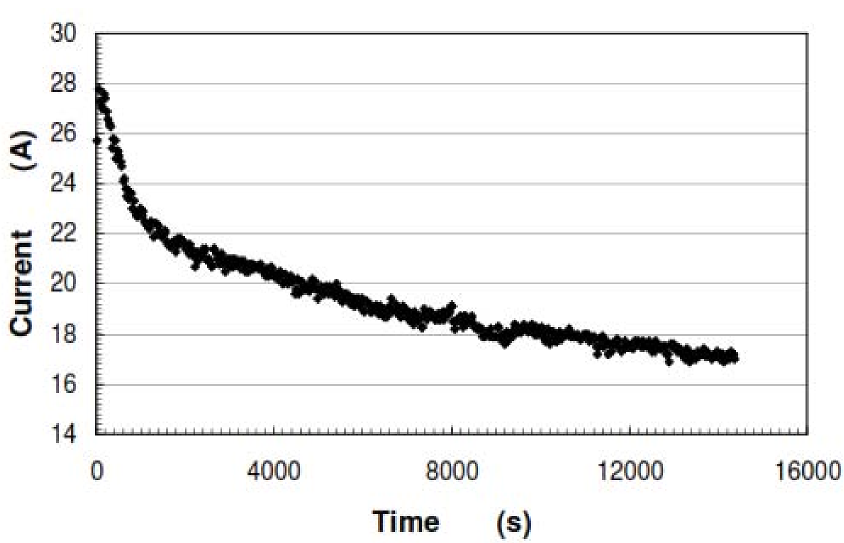

Figure 8 : Typical skim milk (5 wt %) fouling curve in the ohmic heater

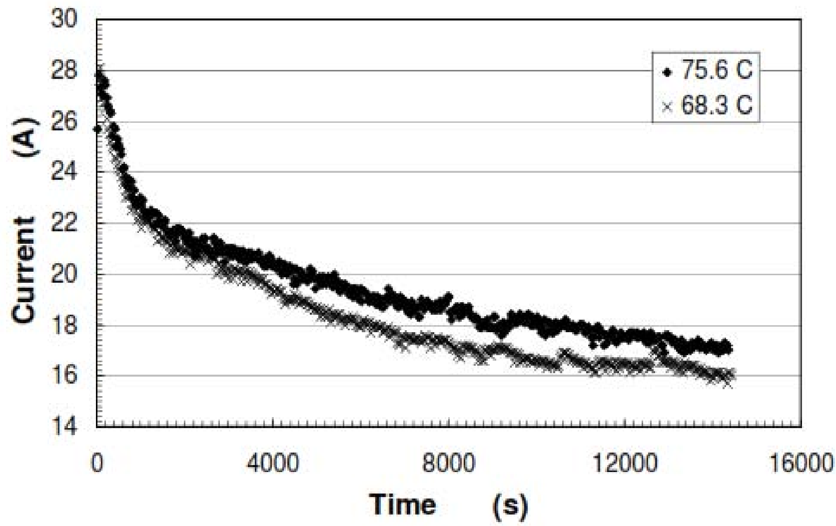

Figure 9 : Effect of milk inlet temperature on fouling

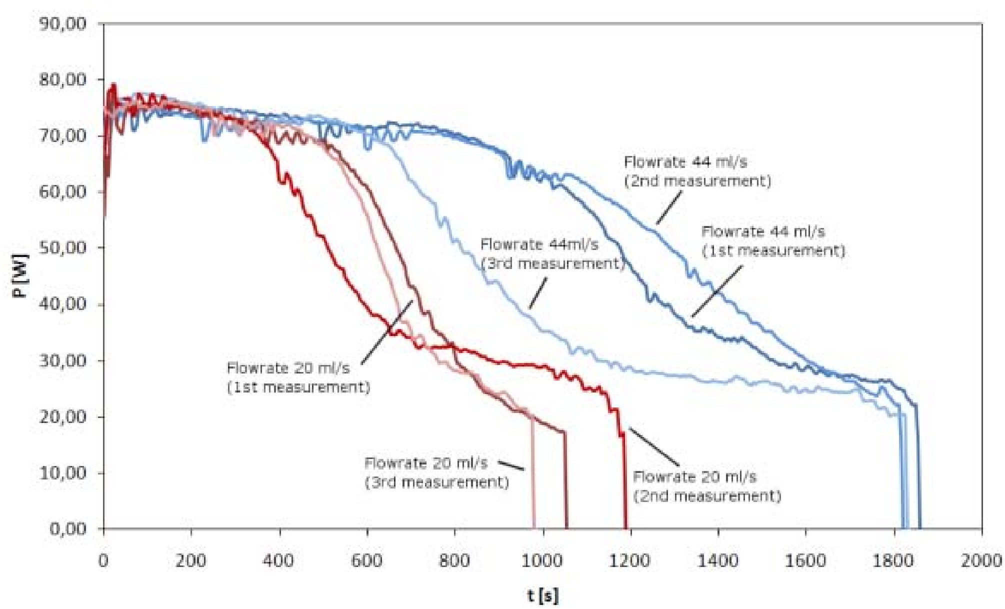

Figure 10 : Dependence of flow rate on milk fouling during direct ohmic heating

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