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FOULING OF HEAT EXCHANGERS BY DAIRY LIQUIDS

This bulletin includes technical information based on latest developments on products, systems, techniques etc. reported in journals, companies' leaflets and books and based on studies and experience. The technical information in different issues is on different areas of plant operation. It is hoped that the information contained herein will be useful to readers.

The theme of information in this issue is **Fouling of Heat Exchangers by Dairy Liquids**. It may be understood that the information given here is by no means complete.

In this issue:

1. INTRODUCTION

Heat treatment – pasteurization, ultra-high temperature (UHT) sterilization and evaporation – is perhaps the most important unit operation to dairy products processing. A particularly troublesome problem to such dairy industry is deposition of burnt milk solids on the hot surfaces of heat exchangers.

This fouling is unwanted for several reasons: it reduces heat transfer rates necessitating to increase heat transfer surface, which makes equipment costlier; increases pressure drop due to constricting flow passage, thereby increases pump horse power requirement; due to increasing fouling with operation time and hence decreasing capacity, the equipment needs to be shut down for cleaning, thus increasing down time and loss of production; makes cleaning difficult and increases cleaning costs; can be the source of bacterial contamination; increases load on effluent treatment plant, thus increasing effluent treatment and disposal costs.

It is, therefore, highly desirable to employ measures that can minimize fouling of dairy heat exchangers.

This issue of **Technews** provides some useful information on fouling of dairy equipment and recommendations to minimize fouling in order to reduce the overall costs. Information on effective cleaning of dairy plants is provided in Technews issues 48 (January-February 2004) and 49 (March-April 2004).

2. COMPOSITION OF FOULING

In milk heat treatment, depending on the degree of heating, two different types of deposits can be distinguished[(1)]:

Type A: Temperature 70°-90°C: Spongy, creamy white, wet, 60% protein, 30-40% ash.
Type B: Temperature 110-140°C: Compact, crystalline, glassy, 20% protein, 80% ash.

The composition and extent of fouling depends on the type of product and the temperature regime of treatment. Composition of deposits for different products heated at approximately 85°C is given in Table 1.

Table 1: Composition of deposit (% of total) of different milk products heated at about 85°C[2].

Component	Product					
	Whole milk	Skim - milk	Whey	Whey concentrate	Cream	Chocolate milk
Protein	58	44	63	45	56	54
Fat	26	0.4			22	11
Minerals	9	45	23	34	18	19
Calcium		16			7	
Phosphate		24			10	
Citrate		0.5	1	11		
Carbohydrate						16
Lactose		n.d.	13	4		
n.d. = not determined.						

3. FOULING MECHANISM

There are 3 stages in the fouling process during the heat treatment of liquid milk products[2]. The first stage involves the heat denaturation and aggregation of the whey proteins. At temperatures above 60°-65°C (whey proteins denaturate at 60°C) whey proteins unfold and aggregate with themselves or with the caseins and as a result adhere to the heating surface. The second fouling mechanism includes the precipitation of milk salts on the heating surface. This is due to the inverse solubility characteristics of tricalcium phosphate with increasing temperatures, and is influenced by the formation of the other types of deposits, especially protein. The third mechanism is the inclusion of other product components within the growing fouling layer. Only the second step in fouling causes a decrease in the heat transfer rate[3].

Thus in the heating zone above about 60°C, the initial deposits consist more of proteins than minerals. At higher temperature regions the reverse is the case. In deposits formation, milk constituents play major or minor roles as mentioned below[2].

Whey protein. Whey proteins absorb onto stainless steel even at room temperature, in bilayer, molecular level. This layer is difficult to remove. At temperatures above 60°C, the whey proteins denature. Some activated whey protein molecules may react with the bilayer molecules already deposited, and some of them may stick resulting in deposition. The amount of protein in the deposit increases with increasing whey protein concentration, but is not directly proportional to it[4].

Casein. The presence of casein in milk limits whey protein fouling to a great extent, due to the reaction of whey proteins with these micelles at high temperature. However, whey proteins may still foul the surface, e.g., as a bridging agent between the casein micelles and the heating surface, or as such when present in excess with respect to the level of casein.

Mineral. The second major contributor to fouling is mineral due to the inverse solubility of calcium phosphate with temperature. The precipitated calcium phosphate may deposit onto the casein micellar surface, and with time it will ultimately form a deposit on to the stainless steel surface.

Fat and lactose. Fat does not play a role in the process of fouling. On heating whole milk the whey proteins associate with the fat globule membrane components and hence whey protein covered fat globules may become entrapped in the whey protein deposits.

Since lactose is water soluble, it is normally not a constituent of fouling. However, at high temperatures, higher than 100°C, if caramelization or maillard reactions take place, lactose may contribute to a deposit, usually very spongy layers of deposit.

4. EFFECT OF PROCESS PARAMETERS ON FOULING

Temperature[2,5]**.** Pasteurization and sterilization equipment usually consist of a regenerative pre-heating section followed by a heating section, a holding section and then a cooling section. Table 2 gives composition of deposit at different temperature ranges.

Table 2: Composition of the deposit in the different sections of a plate heat exchanger after a UHT-treatment of whole milk[5]

Section	Temperature °C	Composition		
		Protein	Minerals	Fat
Regeneration up	60-120	47	41	2.5
Heater	120-138	14	74	2
Regeneration down	138-80	14	74	2

In sections where temperature remains below 70°C no deposit forms. Heating and holding sections are particularly prone to fouling because temperatures vary from 70°C to 140°C, the temperature range where the heat denaturation of whey proteins and precipitation of calcium phosphate occur. Between 70 and 110°C the amount of deposit formed increases more or less steadily with the temperature. This deposit is of type A. Both minerals and proteins participate in deposit formation. In the presence of calcium ions, the sticking probability of the denatured whey protein to the surface increases. Any temperature increase promotes fouling. Deposits formed at temperatures higher than 110°C are essentially composed of minerals. Between 110 and 120°C the amount of deposit decreases and reaches a minimum around 120°C.

In the heating section of the UHT plant where temperature of milk is raised from, say, 120°C to 138°C or higher, the deposit corresponds to type B. It increases with temperature. It is hard, dense, compact and cracked. In the regenerative cooling of UHT plant where milk is cooled from sterilization temperature to about 80°C, fouling is low and decreases very rapidly. During UHT processing, when pasteurized milk is homogenized at 138°C instead of at 65°C, the amount of fouling increases considerably on the surfaces located after the homogenizer. The deposits of homogenized milk contain less fat.

While high wall temperature promotes fouling, high bulk temperature is also important in fouling.

Flow rate[2,6]**.** Increasing flow rate decreases both the amount and the extent of fouling in heat exchangers. Fouling particularly decreases in the transition flow region, probably due to both an increase in the wall shear stress and in an increase in the turbulance level, which provides a higher mixing intensity in the bulk of the fluid, and in turbulent flow. Tubular heat exchangers often operate in the transition flow regime, while plate heat exchangers often operate in turbulent flow regime.

The heat exchanger geometry also influences the fouling, as it affects the mixing intensity. For this reason, tubular heat exchangers are more prone to fouling than a plate heat exchanger. In plate heat exchangers, the one with plate geometry that provides a higher mixing intensity, such as herringbone plates compared to straight corrugated plates, are less prone to fouling.

Air entrained with milk. Dissolved air in milk or air leaks in the system causes increase in fouling[6]. The air produces foam and when this foam becomes air locked in the heat processing line, much deposition takes place.

Initial temperature differential between the heating medium and milk[6]. One of the important factors affecting the fouling rate is the temperature difference between the heating medium and milk. Lower temperature differentials result in less denaturation of protein and crystallization of minerals thereby less fouling takes place.

It appears that the temperature differential is the first requisite for fouling, flow rate is only a factor which could modify the status of the denaturated protein material, whether it would adhere to the metal surface or be carried in suspension by the flow.

Milk pH[2,6]. The product pH influences the deposit formation. A decrease in pH of the heated product results in an increase in deposition rate and in deposit amount. When the pH decreases to the level of isoelectric point of whey proteins, they no longer repel each other and tend to aggregate. On the other hand, at low pH the solubility of the milk salts is high and the crystallization of calcium phosphate is at a minimum. As a consequence at low pH very weakly adhering spongy deposits are found, consisting mainly of protein and entrapped liquid. Raising the pH has the effect of a higher salt content of the layers because the reduced solubility is responsible for the enhanced crystallization during heat treatment.

Preheating of product[2,5]**.** Preheated milk product results in less fouling on subsequent heat treatment. This is because the deposit formation is influenced by the heat denaturation of whey proteins. Since much of the whey proteins get denaturated in preheating process, in subsequent heat treatment less deposition takes place. Similarly, with the preheating step the milk salts already precipitate to some extent in the pre-heater and as a result less mineral deposit is found in the high temperature zone of the equipment.

Heat exchange surface finishing[2,6]**.** Under identical conditions of processing rough surfaces attract and hold slightly more deposits than smooth surfaces. This is due to entrapment of deposits in the crates and the greater area exposed in the rougher surfaces.

Boiling vs. heating. Fouling is much more rapid when milk is being heated in contrast to when it is being boiled at the same temperature. Due to this effect, fouling can begin at the entrance of the tube of an evaporator where boiling has not yet begun. It could then spread to the remainder of the tube.

5. EFFECT OF PRODUCT TYPE ON FOULING

Different dairy products result in different types of fouling and its composition on heat treatment. The effect of some major dairy products on fouling is presented here briefly.

Milk. Fouling of milk on heat transfer surfaces have been classified into two types: Type A and Type B, as mentioned earlier.

It is, therefore, seen that the type of fouling depends on the degree of heating. There is difference in the type of fouling by whole milk and skim milk also. In the whole milk deposits, fat is detectable although to a minor extent. Compared to other dairy fluids, milk has much lower tendency to form deposits under identical heating conditions. The reason is that the denaturing and aggregating whey protein prefer to react with much larger surface of the casein micelles present in milk than with that of the heating surface[2].

Reconstituted milk causes less fouling than fresh milk[4].

Cream. The fouling behaviour of cream resembles that of whole milk. Though fat is by far the major component of high fat cream, the amount of deposit in the cream is only of minor importance. It can be assumed that fat is rather indifferent in the fouling process and is entrapped by protein. Protein and ash are the main components, their level varying with the heating conditions as shown in Table 3.

Table 3: The influence of temperature on the cream deposits[2]

Composition of deposits (% of total solids)	**Temperature °C**	
	85-93	**121-136**
Protein	56.0.	15.0
Fat	22.0	10.0
Ash	18.0	71.0
Calcium	6.8	23.8
Phosphorus	3.2	13.0

Whey[2]**.** Since whey contains whey proteins, calcium phosphate and lactose, the fouling by whey on heat transfer surfaces involves protein aggregation, salt precipitation and entrapment of product mainly lactose. Typically, whey fouling includes a first mineral layer with on top a spongy deposit of aggregated protein including entrapped products. In the temperature range of 70-90 ^{o}C, the composition of fouling generally comprises 60-80% protein, 10-20% minerals and about 10% lactose.

6. MEASURES FOR REDUCTION OF FOULING

Some measures would result less fouling. These are outlined below:

1) The milk should be low in acidity.
2) Pre-heated milk above 65^{o}C causes less fouling in subsequent heating sections. Therefore, where possible, such as in ultra-high-temperature (UHT) plant and in evaporators, additional holders may be installed in the regions of the plant where the heat denaturation of whey protein (especially β-lactoglobulin) is at maximum.
3) Too high milk temperature should be avoided. Check if the milk flow rate is decreased or the heating medium temperature/ flow rate is increased, and take necessary action. The evaporation temperature in evaporator should be as low as possible. The milk entering the evaporator should be at least equal to, if not higher than, the evaporation temperature, so that the evaporation starts immediately.
4) Too high temperature difference between heating medium and milk should be avoided. It should be better to increase the heat transfer area to achieve a given thermal load; it would lengthen production time and decrease cleaning frequency and cost. The optimum temperature difference can be estimated through a temperature difference – cost analysis.

5) Where possible, heat exchangers should be operated in turbulent flow regime. This can be done by proper plant design by choosing appropriate duct diameter and optimum flow rate conditions. In evaporators, tube surfaces should be completely wetted hence milk flow rate should be high. At the same time, the feed milk should be uniformly distributed over the tube surface.
6) Homogenization of milk should not be done at very high temperatures such as 138^{o}C.
7) Air leaks into the heat exchanger should be avoided.
8) Heat exchange surface should be thoroughly cleaned and sterilized before operating it with milk.
9) Milk should be adequately filtered before permitting it on to heat exchanger surfaces.
10) Where legally permitted, such as in evaporated milks, very small quantities of phosphate salts could be used in milk. Most effective is sodium pyrophosphate(7). Other salts effective in decreasing order are disodium hydrogen phosphate, sodium tripolyphosphate and sodium hexametphosphate. The effect of phosphate in decreasing fouling is more with whole milk than skim milk.

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