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Research Article

REDUCTION IN MILK SCALE FORMATION ON TUBULAR HEAT EXCHANGER SURFACE BY MAGNETIC TREATMENT

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ABSTRACT

An attempt was made to reduce the scale formation(fouling) on the tubular heat exchanger surface during heating of buffalo milk by magnetic treatment. The overall heat transfer coefficient of the heat exchanger during heating of buffalo milk separately pumped at different flow rates were calculated at different intervals of time to measure the extent of fouling and the same was compared with the control wherein no magnet was used. When compared with control, the percent increase in overall heat transfer co-efficient value at three different flow rates of 150, 250 and 350 L/h of magnetically treated buffalo milk was observed to be 10.30, 3.80 and 2.70%, respectively. It was concluded that magnetic treatment of milk improved the overall heat transfer efficiency of the tubular heat exchanger equipment which would lead to less maintenance and downtime for normal cleaning schedule, thereby offering scope for improving the scale of economy in the dairy plant.

Key words: Heat transfer coefficient, Magnetic treatment, Milk scale, Temperature

During heating of milk, a layer of solids called milk scale (also called fouling) is formed on the heat exchanger surface especially at temperature above 50°C. Factors responsible for the scale deposition on a heat exchanger surface during processing of milk and milk products include composition of milk, flow rate of milk, acidity of milk, ageing of milk, pre-heating temperature, air content in milk, nature of metal surface of the heat exchanger etc. (Burton, 1964).The scale provides resistance to heat flow to product and adversely affect the quality of the final product due to burning of milk solid sadhering to the hot surface. These scales are difficult to remove as it requires costly detergents (acids and alkalis), time and energy apart from overloading the effluent treatment plant (ETP). Reduction of fouling in heat exchangers, therefore, deserves special attention which could be done by physical means such as magnetic technology without using too much of chemicals.

The magnetic treatment method has been applied as a scale deposition controlling and/or preventing tool for several decades in the domestic and industrial water systems (Gabrielle *et al.*, 2000; Alimi *et al.*, 2007; Salman *et al.*, 2015). But not much work has been done on the effect of magnetic treatment to reduce fouling caused by milk during processing. The present study was undertaken to reduce the milk scale formation on the surface of tubular heat exchanger by magnetic treatment during heating of buffalo milk with the objective to improve the capacity utilization and economy of the dairy plant.

MATERIALS AND METHODS

A laboratory model tubular heat exchanger was fabricated from stainless steel tube of 1.56 m length and 12.5 mm diameter, and fitted in an oil bath. The oil bath temperature was kept constant at 150°C with thermostatically controlled electric heater. For measuring temperature of incoming and outgoing milk, a temperature recorder with resistance temperature sensing probes was used (Fig. 1). Milk (6% fat, 9% SNF and 0.17% titratable acidity in terms of lactic acid) entered the heat exchanger at 1.2 kg/cm^2 pressure and exited at a pressure of 1.0 kg/cm^2. To measure the different flow rates of milk, a rotameter was connected after the roto pump used for circulating milk through the tubular heat exchanger. A flow regulating valve placed before the flow meter was used to regulate milk flow rates. A set of permanent magnet (strength 2500 Gauss, approx.) clamped on the outer surface of the tube at the inlet of the heat exchanger was used in the present study.

Each trial was conducted with 10 liters of fresh whole buffalo milk obtained from the Experimental Dairy of National Dairy Research Institute, Karnal. The milk was standardized to 6% fat and 9% S.N.F, preheated to 42°C through a stainless steel jacketed vessel and taken in the balance tank for subsequent circulation. The experiment was conducted at three different milk flow rates of 150, 250 and 350 l/h. The temperature of outgoing milk was recorded after an interval of 10 min upto 60 min, separately for each flow rate. The total period of circulation was 60 min for each trial so as to achieve the final processing temperature. Milk from the balance tank was pumped by the circulating pump through the flow regulating valve, flow meter and the magnetic field placed at the inlet of the tubular heat exchanger. After every 10 min, temperature of milk at inlet and outlet were recorded for calculating overall heat transfer co-efficient values. Three trials were

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conducted for each milk flow rate. After each trial, the tubular heat exchanger was thoroughly cleaned to remove the deposited milk solids using the standard procedure with acid and alkali detergents.

Calculation of overall heat transfer coefficient: From the observed data of inlet and outlet temperature of milk and oil bath at a periodic interval of 10 min, the average log-mean temperature difference [(Δt)lm] and total amount of heat gained were calculated using the following formulae:

$$1/U = 1/(1/h_0 + x_1/k_1 + 1/h_i)$$

Where, h_0 = convective heat transfer co-efficient outside of the tube, x_1 = thickness of the tube wall, k_1 = thermal conductivity of the tube material, h_i = convective heat transfer co-efficient inside of the tube.

$$Q = UA\,(\Delta t)lm$$

Where, Q = the total amount of heat gained, kcal/h, U = overall heat transfer co-efficient, kcal/m^2-h-ºC, A = total area exposed to heat transfer, m^2.

RESULTS AND DISCUSSION

The change in U value was considered as a measure of rate of fouling on the inner surface of tubular heat exchanger. The variation in U value on account of fouling at different flow rates of control and treated milk with permanent magnets are presented in table 1 & 2, respectively.

As compared to control, higher U values in case of circulation of magnetically treated milk indicated that the magnets exerted a beneficial effect during the heating of milk by minimizing the scale formation on the inner surface of the tubular heat exchanger. Bansal and Chen (2009) reported that factors such as milk composition, operating conditions, heat exchanger characteristics, presence of microorganisms in milk and location of fouling influenced greatly the fouling of heat exchanger surface by milk. Shaoo *et al.* (2005) noticed that uniform fouling deposit occurred throughout the length of heat exchanger due to constant heat exchanger wall temperature. With time, the fouling deposit and Biot No. increased towards the outlet of heat exchanger and the fouling deposit stabilized after 105 min. Effect of whey protein fouling on heat transfer performance and pressure drop in heat exchanger was reported by Emad *et al.* (2013). The authors opined that study of fouling by electro-magnetic means, adding additives, treating heat exchanger surface and changing of heat exchanger configuration might help to understand the chemistry of fouling of milk fluids. Ansari *et al.* (2012) developed a mathematical model for a triple tube heat exchanger using hydrodynamic heat balance concept to predict both the fouling behavior and bulk milk temperature along the length of heat

Table 1
Effect of circulation of buffalo milk through tubular heat exchanger on the overall heat transfer coefficient*

Sl No.	Flow rates l/h	Time for recycle min	Temperature of incoming milk(t_1)°C	Temperature of outgoing milk(t_2)°C	Difference (Δt_1)°C	Difference (t_2)°C	Log Mean temperature Difference (Δt) LMTD	Overall heat transfer coefficient(U) (Kcal/m^2.hr. °C)	
1	150	10	62.0	71.0	88.0	79.0	83.4191	307.566	272.025
		20	74.0	81.5	76.0	68.5	72.1851	296.194	
		30	82.0	88.5	68.0	61.5	64.6956	286.416	
		40	84.0	90.0	66.0	60.0	62.9524	271.707	
		50	88.0	93.0	62.0	57.0	59.4649	239.739	
		60	88.2	93.0	61.8	57.0	59.3676	230.526	
2	250	10	61.5	70.5	88.5	79.5	83.9196	509.554	481.437
		20	70.0	78.0	80.0	72.0	75.9298	500.598	
		30	75.5	82.8	74.5	67.2	70.7873	489.980	
		40	80.0	86.6	70.0	63.4	66.6455	470.526	
		50	83.0	89.2	67.0	60.8	63.8498	461.364	
		60	86.7	92.5	63.3	57.5	60.3535	456.601	
3	350	10	60.0	68.0	90.0	82.0	85.5379	619.219	574.965
		20	68.0	75.0	82.5	75.0	78.4479	593.547	
		30	76.0	82.1	74.0	67.9	70.9063	572.248	
		40	80.0	85.7	70.0	64.3	67.1097	564.974	
		50	85.0	90.2	65.0	59.8	62.3639	554.639	
		60	89.0	93.8	61.0	56.2	58.5672	545.162	

$\Delta t_1 = (T - t_1)$°C; $\Delta t_2 = (T - t_2)$°C; *(Δt) LMTD = $(\Delta t_1 - \Delta t_2) / \ln(\Delta t_1 / \Delta t_2)$
*Results are averages of three replicates

Table 2
Magnetic treatment of buffalo whole milk with circulation for different flow rates*

Sl No.	Flow rates l/h	Time for recycle min	Temperature of incoming milk(t_1)°C	Temperature of outgoing milk(t_2)°C	Difference (Δt_1)°C	Difference (t_2)°C	Log Mean temperature Difference (Δt) LMTD	Overall heat transfer coefficient (Kcal/m^2.hr. °C)	
1	150	10	63.0	72.0	87.0	78.0	82.4181	311.3504	300.042
		20	72.0	80.0	78.0	70.0	73.9278	308.5401	
		30	82.0	88.8	68.0	61.2	64.5403	300.4052	
		40	89.0	95.0	61.0	85.0	57.9482	295.2166	
		50	88.8	94.8	61.2	55.2	58.1484	294.2002	
		60	89.1	95.0	60.9	55.0	57.8999	290.5384	
2	250	10	62.0	71.0	88.0	79.0	83..4196	512.6181	499.738
		20	71.5	79.5	78.5	70.5	74.4283	510.6969	
		30	74.8	82.4	75.2	67.6	71.3325	506.2178	
		40	79.8	86.8	70.2	63.2	66.6387	499.0945	
		50	83.2	89.8	66.8	60.2	63.4427	494.2806	
		60	87.0	93.0	63.0	57.0	59.9499	475.5258	
3	350	10	60.0	68.0	90.0	82.0	85.9379	619.2190	590.531
		20	72.0	78.8	78.0	71.2	74.4451	606.7504	
		30	81.0	86.8	69.0	63.2	66.0575	584.0430	
		40	87.0	92.3	63.0	57.7	60.3111	584.5436	
		50	87.7	92.9	62.3	57.1	59.6622	579.7531	
		60	89.0	94.0	61.0	56.0	58.4643	568.8768	

$\Delta t_1 = (T-t_1)$°C; $\Delta t, = (T-t_2)$°C; *(Δt) LMTD= $(\Delta t_1 - \Delta t_2) / \ln (\Delta t_1 / \Delta t_2)$
*Results are averages of three replicates

exchanger with time. The authors reported that an equivalent value of fouling deposit of 0.84 and 0.61 mm for the inside and middle tube, respectively and final fouling thickness and bulk milk temperature at the end of simulation to be about 0.05 mm and at 148°C, respectively.

A direct relationship between the milk flow rate and the overall heat transfer coefficient was discernible. At higher milk flow rate, greater increase in overall heat transfer coefficient was noticed. Apart from the effect of magnetic treatment, turbulence created by the higher milk flow rate might be responsible for the decrease in the formation of milk scale on the heat transfer equipment surface.

CONCLUSION

It is concluded that magnetic treatment of milk with permanent magnets reduces milk scale formation on the surface of the heat transfer equipment, thereby helping in the minimization of the periodic cleaning and overall maintenance of heat exchanger which in turn would improve the scale of economy of the dairy plants.

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