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EFFECT OF DIFFERENT MACHINE FACTORS ON MILK CONCENTRATION IN SCRAPED SURFACE HEAT EXCHANGER

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Abstract: Scraped surface heat exchangers are widely used for thermal processing of viscous food products. One of the important applications of scraped surface heat exchanger (SSHE) is in concentration of food products. For production of concentrated milk at small scale, SSHE is a very suitable equipment. Present work was undertaken to study the effect of various SSHE parameters for concentrating milk from 15 % to 25% total solids. Effect of number of blades (2, 4, 6), weight of blades (1.6, 1.75, 2.0 kg) and rotor speed (150, 175, 200 rpm) was investigated on milk concentration, evaporation rate and steam consumption. Response surface methodology was used to analyze the responses. Evaporation rate was in the range of 63.39 to 91.33 kg/h. Maximum milk concentration (26.9 %) was achieved using 1.6 kg blade weight and 6 number of blades. Thus the study was helpful in understanding effect of various machine parameters on milk concentration in SSHE.
Keywords: Scraped surface heat exchanger, milk, concentration, response surface methodology

INTRODUCTION

Scraped surface heat exchangers (SSHE) are frequently used for thermal processing of high-viscosity products. The main advantage is to prevent fouling of heat exchange surface by means of periodic scraping by blades [1]. In these heat exchangers, the product to be heated/ cooled flows axially in an annular section between a stationary outer cylinder and a powered coaxial rotor. The inner wall of the outer cylinder is periodically scraped by blades attached to the rotor, while the heating or cooling fluid circulates into the external jacket, which is generally equipped with flow baffles [2]. Scraped surface heat exchangers (SSHEs) have been particularly emphasized for processing liquid foods exhibiting non-newtonian rheological properties, containing suspended solids, or which tends to form fouling scales during thermal processing [3]. The SSHEs with hinged blades are basically of two types: liquid full SSHEs or votators and thin film SSHEs. For thermal treatments like pasteurization and sterilization, liquid full SSHE is most suitable. While for concentration processes thin film SSHE is widely used. Thin film scraped surface heat exchangers are basically of two types, firstly, wiped film type in which fixed gap exists between the rotating blades and heat

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transfer surface. Secondly, scraped thin film type having variable clearance between blades and heating surface.

Milk fouling, the unwanted formation of deposits on heat transfer surfaces during milk processing is one of the most important unsolved problem in the dairy industry [4],[5],[6]. And therefore for high viscous dairy products, SSHE are the most suitable heat exchanger. The optimization of SSHEs is not an easy task because of the high number of variables to tune, and there are still several lacks of knowledge concerning their application to high viscous foods. SSHE may present different geometrical designs and innovative solutions can be implemented to operate under specific conditions or to improve selected features of the exchanger, such as the heat transfer coefficient [7]. Literature survey indicates that effect of machine parameters like weight of blade and number of blade has not been looked into and which plays pivotal role in making film. The present work was conducted to study the effect of number of blades, rotor speed and weight of the blade on milk concentration (% TS), evaporation rate (kg/h) and steam consumption (kg/s).

MATERIAL AND METHODS

Experimental setup consisted of continuous three stages scraped surface heat exchanger (SSHE) system developed at Dairy Engineering Division, ICAR - National Dairy Research Institute, Karnal [8],[9],[10]. The machine has three steam jacketed insulated horizontal cylinders placed in a cascade arrangement. The scraper speeds and the steam pressures in the three stages can be controlled separately by VFD and PLC based control system. In the first stage SSHE, milk is concentrated from 15 to 25 percent TS. In the second stage it is concentrated to 50 percent and the third stage helps to achieve 65-70 TS product. In the present study, only the first stage SSHE was studied extensively for determining the factors affecting evaporation rate. Buffalo milk (6% fat and 9% SNF) was concentrated in first stage SSSHE by keeping constant milk flow rate (190-195 kg/h). The levels of different factors like number of blades, weight of blades and rotor speed is shown in table 1 and Central Composite Face Center Design was used (Table 2). Response surface method was used to analyze different responses and to develop regression equation using Stat Ease Design Expert software (v 8.0). Response surface module of Stat Ease Design Expert software has been found useful for analysis and optimization of multiple process parameters [11],[12].

Table 1: Level of different factors

Number of blades	Rotor speed	Weight of each blade
2, 4, 6	150, 175, 200 rpm	1.60
2, 4, 6	150, 175, 200 rpm	1.75
2, 4, 6	150, 175, 200 rpm	2.0

Table 2: Central composite face centered design using response surface methodology

Run	Factor A	Factor B	Factor C
	Number of blade	Rotor speed(rpm)	Weight of blade (kg)
1	4	175	1.75
2	4	175	1.75
3	2	150	1.6
4	6	200	2
5	4	175	1.75
6	6	200	1.6
7	6	150	2
8	2	200	1.6
9	4	175	2
10	4	150	1.75
11	4	175	1.75
12	6	175	1.75
13	4	175	1.75
14	6	150	1.6
15	4	175	1.6
16	2	175	1.75
17	2	200	2
18	4	175	1.75
19	2	150	2
20	4	200	1.75

Measurement of different responses

Milk concentration was measured as percent total solids (% TS) using refractometer method (Erma, Japan, 0-32% TS range). Steam consumption was calculated by collection and taking weight steam condensate at two minutes interval. Evaporation rate was calculated using the following equation:

$$F = P + V \quad \text{Eq. 1}$$

Where,

F = Feed mass flow rate (kg/h)

P = Product mass flow rate (kg/h)

V = Evaporation rate (kg/h)

Results and Discussion

Effect of machine factors on evaporation rate

Evaporation rate increased with number of blades and rotor speed (Fig. 1). The evaporation rate for 1.60 kg weight of the blade varied from 74.62 to 89.4 kg/h, 63.39 to 91.33 kg/h for 1.75 kg weight of blade and 62.77 to 88.22 kg/h for 2 kg weight of the blade. Linear regression equation generated to predict the evaporation rate as affected by different factors (A: Number of blades, B: Rotor speed, C: Weight of blade) is as follows:

$$\text{Evaporation rate (kg/h)} = 57.719+2.66*A+0.196*B-13.763*C \quad \text{Eq. 2}$$

Effect of machine factors on milk concentration

Effect of different variables on the total solids in production of concentrated milk are represented in graphical forms (Fig 2). With an increase in scraper speed and number of blades, total solids of concentrated milk increased significantly. Total solids of concentrated milk was in the range of 20.8 to 25.9 % for 2 kg blade weight, 22.2 to 26.7 % for 1.75 kg blade weight and 22.9 to 26.9 % for 1.6 kg blade weight. It can be inferred that the total solids of concentrated milk can be increased by increasing the scraper speed and number of blades where as, increasing the blade weight resulted in decrease in final milk concentration in the first stage SSHE. Number of blades had significant ($p<0.05$) effect on final milk concentration. The linear model for total solids of concentrated milk was obtained through successive regression analysis. The non-significant lack of fit test indicated that the model is sufficiently accurate for predicting the total solids for any combination of the variables within the range evaluated. Adequate precision value (APV) was 7.498 which was appreciably higher than 4.00 suggesting that model can be used to navigate the design space. Linear regression equation generated to predict final milk concentration as affected by different factors (A: Number of blades, B: Rotor speed, C: Weight of blade) is as follows:

Total Solids (%) = 19.271 + 0.57*A + 0.042*B - 2.871*C Eq. 3

Effect of machine factors on steam consumption

It was observed that the steam consumption was minimum when scraper blades of SSHE was operated at low speed with two blades (Fig 3). When weight of the blade was considered at calculated center point (1.75 kg), steam consumption varied in the range of 0.03 to 0.035 kg/s. But at 2 kg blade Weight, steam consumption reduced to 0.025 - 0.03 kg/s. Number and weight of blades had significant effect ($p<0.05$) effect on steam consumption. Linear regression equation generated to predict the steam consumption as affected by different factors (A: Number of blades, B: Rotor speed, C: Weight of blade) is as follows:

Steam Consumption (kg/s) = $0.0683 + 1.167X10^{-3}*A + 2.11022 X 10^{-5}*B - 0.0208*C$ Eq. 4

The adequate precision which measures the signal to-noise ratio was found to be 11.99 which was appreciably higher than 4.00 for total solids for high precision ability. It was found that model can be used to navigate the design space.

Conclusions

It can be inferred that higher evaporation rate can be achieved by increasing the scraper speed and number of blades. While higher weight of blades resulted in decrease in final milk concentration. Evaporation rate was in the range of 63.39 to 91.33 kg/h. Maximum milk concentration (26.9 %) was achieved using 1.6 kg blade weight and 6 number of blades. Due to higher evaporation rate, steam consumption was also higher in case of more number of blades and higher scraper speed. Thus for design and operation of SSHE for milk concentration all the three machine parameters viz number of blades, weight of blades and rotor speed are important.

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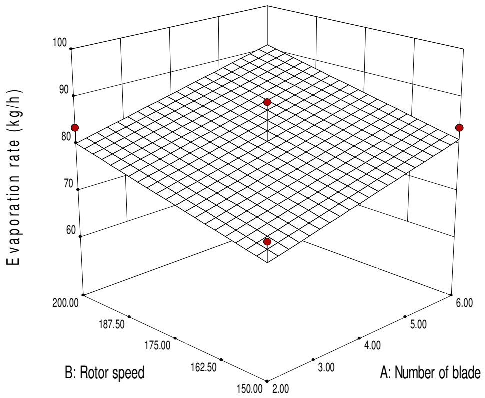
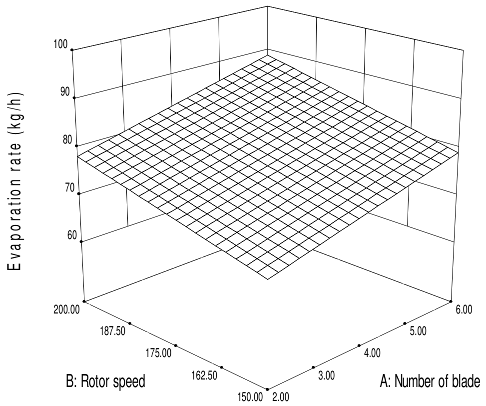
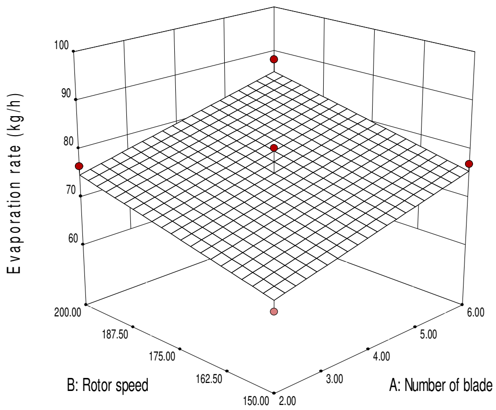


a. Weight of blade 1.6 kg

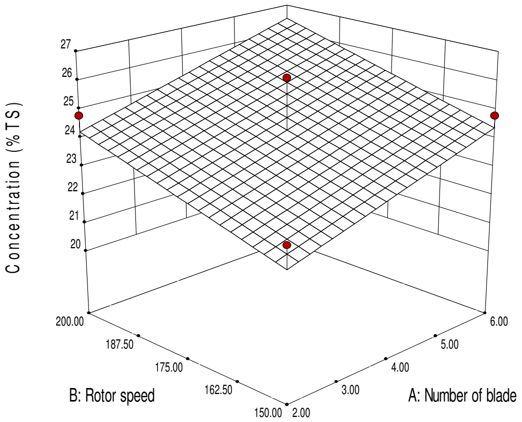


b. Weight of blade 1.75 kg



c. Weight of blade 2.0 kg

Fig. 1: Effect of different factors on evaporation rate



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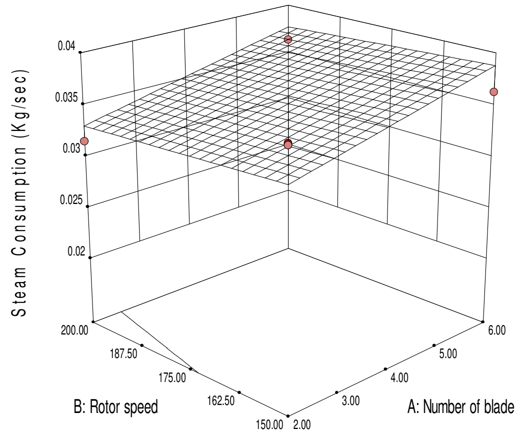

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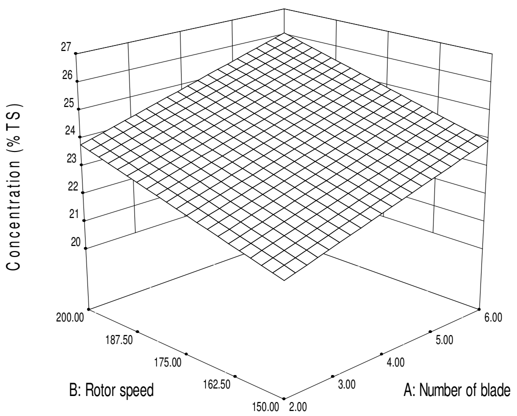
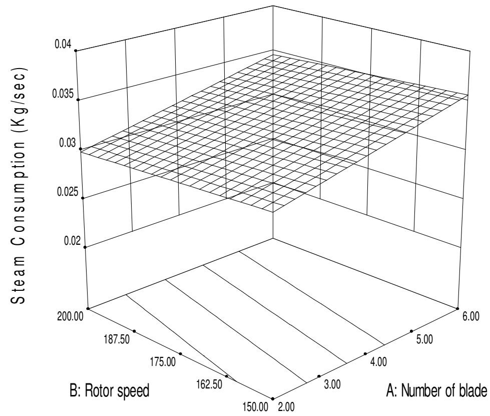
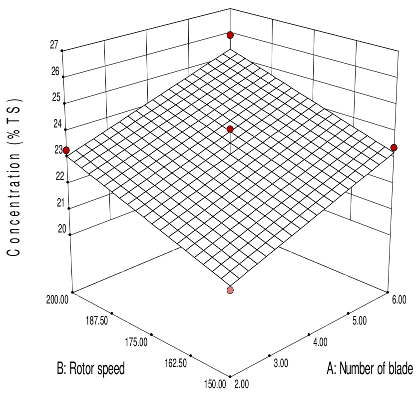


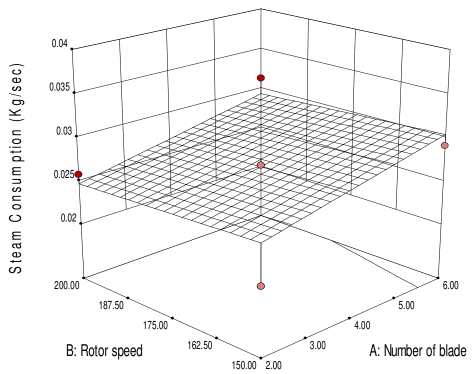
b. Weight of blade 1.75 kg



b. Weight of blade 1.75 kg



c. Weight of blade 2.0 kg



c. Weight of blade 2.0 kg

Fig. 2 Effect of different factors on milk concentration

Fig. 3 Effect of different factors on Steam consumption