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Factors that Impact the Efficiency of Cream Separator Machine for the Food Industry

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ABSTRACT

This study examines the variables that impact the effectiveness of cream separator machines in the dairy sector, with a specific emphasis on centrifugal force, temperature, and vibration. The process of cream separation, which is crucial in dairy production, has progressed from manual techniques to sophisticated mechanical centrifugal separators. The objective of this study is to optimize the performance of these machines, which is imperative due to the increasing need for low-fat skimmed milk. The study utilizes a disc centrifuge to examine the impact of centrifugal forces. The setup consists of more than 24 discs, which are used to measure the volume of fluid passing through the spaces between the discs and to determine the efficiency of separation. The experiments involved using flow rates of 600 ml/min, 1200 ml/min, and 1800 ml/min to alter the temperature from 7 °C to 15 °C, 25 °C, and 35 °C. The findings indicated that decreased temperatures significantly enhance the efficiency of skimming. The study also examines the impact of machine-induced vibration on the efficiency of separation. The study concludes that excessive vibration negatively impacts productivity, therefore, it is essential to incorporate vibration control into the design of separators. The key findings suggest that optimizing centrifugal force is crucial. Inadequate force leads to incomplete separation of fat, while higher flow rates decrease separation efficiency. Temperature regulation is equally crucial, and reducing temperatures enhances efficiency. Effective vibration control is essential for maintaining optimal separation quality. This study makes a valuable contribution to the advancement of cream separator machines by highlighting the importance of accurate management of centrifugal force, temperature, and vibration. This is crucial for enhancing productivity and meeting the requirements of the market. The findings offer valuable insights for the dairy industry, assisting in the development and functioning of advanced cream separators that provide enhanced performance and economic advantages for producers.

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1. Introduction

Cream separation, a crucial process in the dairy industry, has undergone significant advancements from its initial manual methods [1,2]. Historically, farmers would manually divide milk into cream and skimmed milk subsequent to the process of milking cows [3]. The dairy producers would keep some cream for butter production and skimmed milk, and sell the remaining amount to local markets [4]. Initially, the separation process occurred naturally, where cream would rise to the top and be manually removed, or through the use of container separators equipped with drainage nozzles [5-7].

Mechanical centrifugal separators have replaced manual methods, providing enhanced efficiency and consistency in cream separation. It is crucial to comprehend the primary factors that impact efficiency, including centrifugal force, temperature, and vibration [8,9]. The demand for low-fat skimmed milk in the market requires an efficient separation process. The density difference between milk fat ($p = 0.93$ g/cm^3) and skimmed milk ($p = 1.035$ g/cm^3) highlights the significance of mechanical separation methods [10,11]. Traditional natural de-creaming methods have limited industrial significance when compared to machine-based separation processes. This study aims to investigate methods for improving the efficiency of cream separator machines, specifically by examining the impact of centrifugal forces, temperature control, and vibration.

Cream separator machine advancements have been historically sluggish, mainly because the industry has been content with the performance of existing machines. Although certain enhancements have focused on increasing capacity by utilizing larger vessels and reducing turnaround times, the importance of efficiency in the separation process has frequently been neglected [12]. Mechanical mechanisms, such as high-speed rotating motors that generate vibrations, are crucial in addressing this efficiency challenge [13].

Centrifugal separators are widely used in the fats and oils industry for various purposes, including soap-oil separation, emulsion breaking, and milk skimming. The construction and separation sequence of machines may differ depending on the specific liquid being targeted and the type of machine being used. Certain separators have sediment-holding spaces that necessitate manual cleaning, while others have the ability to self-discharge [14].

Electric cream separators have clear advantages over manual ones. Electric separators rely on high-speed motors, typically operating at 5000 RPM or higher, to achieve consistent and efficient separation by ensuring uniform skimming and processing [15]. They manage a defined amount of material at a fixed rate, which is essential for efficient industrial manufacturing. In addition, electric separators offer advantages such as easier management, reduced noise, and lower maintenance requirements.

Manual cream separators have inconsistent skimming efficiency and processing delays due to reliance on manual rotation [16]. The operation is both cumbersome and unreliable, often resulting in spillage. Regular maintenance is required for manual machines due to their fragility, which includes tasks such as greasing, tightening bolts, and making alignment adjustments [17]. Electric separators have low maintenance requirements, typically involving greasing and periodic alignment checks. This study examines the important factors affecting cream separation efficiency, with the goal of advancing cream separator technology for the benefit of the dairy industry.

2. Methodology

2.1 Research Design

The structure of the research is developed towards understanding the factors that influence the efficiency of cream separators depicted in Figure 1. For the analysis to be performed on assessing the effectiveness of cream separators based upon the objectives, following methodology as presented below was developed. The impact of three independent factors that are, impact of centrifugal, impact of temperature, and impact of vibration were discussed [18-20]. The methodology adopted for discussing the above-mentioned impacts is discussed below. The research design is hinged upon the three independent variables and their influence or impact against the dependent variable. The tests will be conducted using the following equation towards gauging the efficiency of cream separation:

$$E\,(\%) = (1-(f_s/\,f_w)) \times 100 \quad (1)$$

where, E is Separating Efficiency, f_s is Skim Milk Fat Content, and f_w is Whole Milk Fat Content.

The proportion of total fat from milk recovered in the cream is referred to in the separation efficiency calculation. The higher the fat content in milk, the higher the fat losses in skim milk, but lower in the skimming efficiency (SE), and vice versa. The relationship between the fat content in milk and fat losses in skimmed milk is directly proportional whereas inversely proportional to skimming efficiency. Lower fat content in skim milk is the greatest indicator of improved skimming efficiency [11].

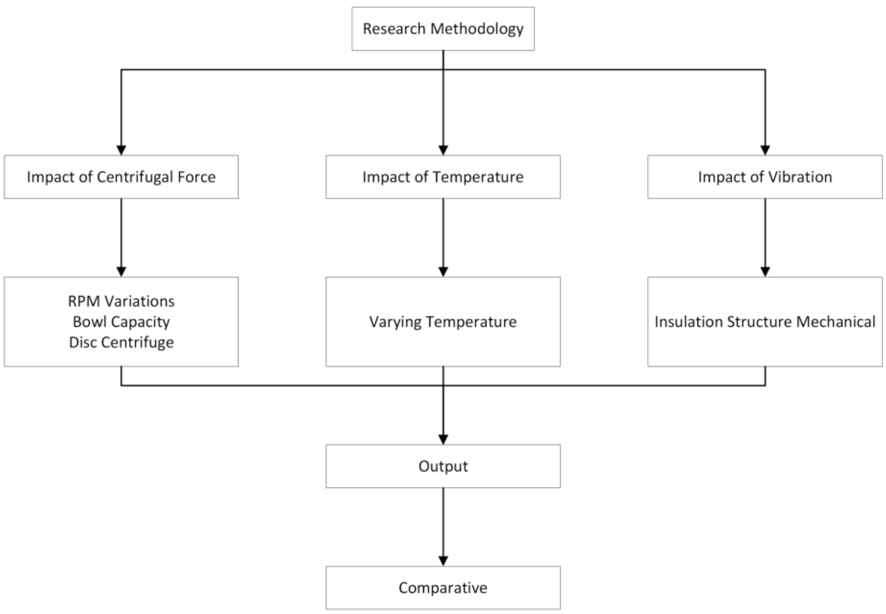

Fig. 1. Research design

2.2 Centrifugal Forces

We utilized a disc centrifuge in our experimental setup to study the effects of centrifugal forces on cream separators from the previous study [21]. Milk was added from the bottom, causing the separation of the fluid into cream and skim milk based on their respective densities. We utilized more than 24 discs, each containing apertures for milk passage. The fluid volume passing through the disc spaces during a specific time period determined the separation efficiency. The equipment comprised a disc centrifuge, milk analyzer, densitometer, stopwatch, thermometer, and test tube.

2.3 Temperature Variation

For this study, the low-end temperature selected was 7˚C thus reducing the overall cost of manipulating temperature for cream processing [22]. 35˚C was the temperature selected as a normal working temperature for cream separation. The variations in temperature that was applied were 7˚C, 15˚C, 25˚C and 35˚C while selected flow rates were 600 ml/min, 1200 ml/min and 1800 ml/min. Initially, temperature was maintained at a same temperature before being equilibrated by using water bath. At the initial stage, continuous centrifuge was used as the cream separator for 'fractionation' milk at various temperatures and feed rates. The milk was heated up in different temperatures and fed into the cream separator's feed [23]. The centrifuge in cream separator machine provides the output as skimmed milk and cream in each outlet. Skim milk and cream outlets were obtained and were labelled as Fractions 1 and 2 respectively. Higher proportion of heavier droplets was Fraction 1 while higher proportion of lighter droplets present in feed milk was Fraction 2. The first stage of separating milk at 7˚C and 15˚C was done at many batches.

2.4 Vibration

To study the effect of vibration on cream separator efficiency, first 4% of milk was separated at 30˚C [24]. Machine was adjusted in such a manner that it may cause vibration while running. This was done by raising or lowering the bowl or placing the machine at rough surface [25]. The results of cream and skim milk separation due to vibration were jotted down. It was found that excessive vibration reduces separation output significantly and as such it is critical to reduce vibration within the construct of the separation machines.

3. Results

3.1 Impact of Centrifugal Force

Investigate the correlation between centrifugal forces and cream separation efficiency [9,15]. The mechanical analysis of this operation resembles a sedimentation process driven by gravity force. The net force causing the separation of two phases with different densities is a combination of the centrifugal force from the heavier liquid portion (or solid), the buoyancy force, and the drag force.

$$\rho_s V_s R v^2 - \rho_L V_s R V^2 - \frac{C_A v^2 \rho_L S}{2\rho_s V_s} = \rho_s V_s \frac{dV}{d\theta} \quad (2)$$

where s is the solid (or heavy phase – skim milk, in this case), L is the liquid (or light phase – fat globules, in this case), ρ is the density, V is the volume, R is the radius at some point in the centrifuge, ω is the angular velocity of the centrifuge, C_A is the drag coefficient, S is the particle area normal to the flow direction and q is the time [26].

When the milk enters the centrifuge, the heavy particles will be pushed to the exterior and light particles to the interior of the centre [21]. The velocity of the centrifuge will generate centrifugation which separates cream from milk. Separation of light molecules increase due to the centrifugal force and the acceleration will decrease due to the increase of the drag force. When the acceleration is null the velocity will have the maximum value (terminal velocity). Equalizing the last equation to zero and assuming laminar flow will give the following equation for the terminal velocity of the particles (in milk centrifugation, the fat globules) being separated:

$$V_t = \frac{(\rho_S - \rho_L) D_S^2 R \overline{\omega}^2}{18 \mu_L} \tag{3}$$

This is the general equation for calculating the radial velocity a particle (vt). However, when light particles flow over the heavy fluid, the viscosity is not the light phase viscosity but the heavy phase viscosity. Solving this equation for Ds, and substituting vt for r/(V/Q) (r is the distance that the fat globule must dislocate in order to be separated from the heavy phase – in this case, the radius of the holes in the discs; V is the volume of the centrifuge and Q is the flow rate, and thus V/Q is the residence time), the critical diameter of particles for separation can be determined by:

$$D_{s,Critical} = \sqrt{\frac{18 \mu_L}{(\rho_S - \rho_L) R \overline{\omega}^2} \frac{r}{V/Q}} \tag{4}$$

The critical diameter signifies that half of the particles with this diameter will migrate to the heavy phase and the other half to the light phase. Thus, fat globules with higher diameters than $D_{s,crit}$ will be separated. Based on this value the proportion of fat to be separated from the milk can be predicted if data of the fat globule's diameter distribution are also available.

3.2 Impact of Temperature

The milk that underwent the initial separation stage without the use of separating cones resulted in the formation of two milk streams: outlet 1 and outlet 2 (Figure 2). The cream concentration exhibited a direct correlation with the milk temperature prior to being fed into the cream separator machine [27]. The lighter molecules, known as cream, gain kinetic energy during the heating process of the milk. This increased energy allows the centrifugal force to more effectively separate the fats from the whole milk [28]. The lighter molecules begin to circulate in their orbit, propelled by the centrifugal force. Heating milk causes an increase in the kinetic energy of its molecules, especially the lighter cream molecules (fat globules). As the temperature increases, the molecules become more active, which enhances the centrifugal force in the cream separator [29]. This increased force effectively pushes the molecules towards the center, making it easier to separate them from the heavier milk components. Milk exhibits higher viscosity at lower temperatures, specifically at 7 ˚C.

The increased viscosity of the milk results in a slower flow, facilitating the separation process as the cream is given more time to be expelled by the centrifugal force. Conversely, when the temperature is elevated, for instance, at 35 ˚C, the milk's viscosity diminishes, resulting in a faster flow and a decrease in the effectiveness of the separation process due to the reduced duration for the cream molecules to be influenced by centrifugal force. Therefore, the cream concentration obtained from milk at 7 ˚C is greater than that obtained from milk at 35 ˚C due to the increased viscosity at lower temperatures, which facilitates a more complete separation of cream from the milk [27,29]. Excessive heating can harm the fat globules by causing them to disintegrate or merge into bigger clusters. This can impede the separation process and have a negative impact on the overall quantity and quality of the cream. The temperature of the milk has a significant impact on the efficiency of cream separation in a centrifugal separator [30]. Lower temperatures are more favorable as they result in higher cream concentration and viscosity, leading to better separation.

(a) (b)

Fig. 2. (a) Diagram of milk is heated up in different desired temperatures and (b) Diagram of different yield of cream and skimmed milk obtained

3.3 Impact of Vibration

Table 1 displays the average test results for cream and skim milk, as depicted in Figure 3. The vibration of the bowl has been found to have a substantial impact on the fat content. In cream, the fat content can range from 2% to 16%, while in skim milk, it can range from 0.01% to 0.3%. The separator can sustain significant damage if subjected to excessive vibration, which is the maximum threshold for safe operation without endangering the operator. The presence of vibration in a cream separator bowl can be attributed to factors such as an unstable foundation, incorrect leveling, insufficient lubrication, or inconsistent operating speeds [31]. These factors have the potential to disrupt the stable functioning of the centrifugal separation process. The disturbance causes fluctuations in the centrifugal force and induced turbulence, resulting in variations in the distribution of fat between the cream and skim milk. The presence of these instabilities hinders the organized separation of fat and skim milk layers, resulting in the retention of some fat in the skim milk and diminishing the purity of the cream.

The measured fat content in skim milk (ranging from 0.01% to 0.3%) reflects the degree of this inefficiency. The fat content in cream is extremely responsive to vibration, with documented values varying between 2% and 16%. This emphasizes that even slight vibrations can have a substantial impact on the efficiency of fat separation. Elevated levels of vibration additionally present a hazard to the structural soundness of the separator, potentially resulting in mechanical malfunctions and jeopardizing the safety of operators. In order to minimize the effects of vibration, it is crucial to establish a stable base, achieve accurate alignment, provide sufficient lubrication, and maintain consistent operating velocities. These measures contribute to the preservation of centrifugal force stability and the reduction of turbulence, thereby improving separation efficiency and extending the machine's operational lifespan. Minimizing vibration is essential for preserving the production of high-quality cream, optimizing the separation process, and protecting both the equipment and operators.

Fig. 3. Diagram of Cream Separator with Leakage of the System due to Excessive Vibration within Parts

Table 1
Unsteadiness of the bowl on percentage of fat in cream and skim milk

Sample No.	Temp of whole milk (°F)	Acidity of whole milk	% of fat in whole milk	Percentage of Fat			
				Cream		Skim Milk	
				Steady	Unsteady	Steady	Unsteady
1.	85	0.20	3.9	38.8	24.0	0.010	0.030
2.	85	0.20	3.9	29.0	27.0	0.015	0.025
3.	85	0.20	3.9	32.0	18.0	0.020	0.040
4.	78	0.20	3.9	25.0	21.2	0.025	0.050

4. Conclusions

In this paper, we have discussed the impacts of centrifugal forces, temperature, and vibration on cream separator efficiency. Centrifugal force concludes that, the minimum diameter for non-homogenized milk is around 0.7 mm. Values for critical diameter would be higher than this then it would indicate that not all the fat will be separated. It is proved from Eq. (2) that increasing the flow rate increases the critical diameter which results in less fat being separated from the milk. Temperature impact concludes, how decreasing the temperature of raw milk before feeding it to the cream separator will directly decrease the rate skimming efficiency Vibration impact results, the temperature of milk makes a difference of from 1% to 5% of cream at average skimming temperature, greater variation being caused in extreme cases. The amount of flush water used with average skimming temperatures will make a difference of from 1% to 3%.

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