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Analysis of Correlation of Induced Frequency and Cream Skimming Efficiency through Ultrasonic Technology

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ABSTRACT

Ultrasonic cream separator is a very new technology especially in the dairy industry. Ultrasonic separator machine is an eco-friendly technology that could boost the separation process and it could act as supplement to heat-based technology. However, ultrasonic separators are well developed in other industries such as sludge separation, emulsion breaking, de-oiling and sewage disposal. This technology has been implemented in the food industries recently too. The primary function of an ultrasonic cream separator machine is to separate the milk into two products i.e., cream, and skimmed milk. It is an instantaneous process which saves up workload, manpower, time, and cost. This machine intends to coagulate the fat particles with one another once a certain frequency is induced in the milk. Cream, which is lighter molecule will coagulate and float, whereas the heavier molecules of milk such as protein and minerals will sink. Upon separation, the fat molecules can be scooped out or separated through flushing from below. This machine is at a very agile stage that leads to inefficient cream skimming which leads to fluctuation of fat particles coagulation that leads to inefficient cream skimming. The intention of this study is to evaluate the factors that have a direct relationship with low performance of cream skimming via ultrasonic cream separation and come up with an ideal possible solution to enhance the process of cream separation.

1. Introduction

Ultrasonic separators are not new technology in competitive sectors such as petroleum industry [1] and cosmetics industry [2]. However, the efficiency of this technology is widely being implemented in food industries. This technology is heavily being implemented in food graded oil industries such as palm oil, coconut oil, and sunflower oil. This is to match the overwhelming demand from the market where supply cannot be matched. Improvements had to be made to increase the yield faster, cheaper, and more sustainable. Complying with the concerns, Ultrasonic cream

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separation is emphasized in dairy industry. Besides this, ultrasonic separation is also used to separate the microparticles and cells from suspending fluid through Acoustophoresis technology [3].

In ultrasonic cream separation, milk is exposed to ultrasonic waves, which create small bubbles in the milk. The bubbles grow and then collapse, creating high shear forces that cause the fat globules in the milk to agglomerate and rise to the surface, where they can be skimmed off to obtain cream. The process is non-thermal and does not involve the use of chemicals, making it an attractive alternative to traditional cream separation methods [4]. Ultrasonic cream separation has been studied extensively in recent years, and research has shown that the technique can be effective in separating cream from milk with high efficiency and minimal loss of milk components. The process has potential applications in the dairy industry, where it could be used to produce high-quality cream for use in various dairy products [5].

Besides cream separation, ultrasonic technology has been implemented in the dairy industry via other machines such as homogenizers. The composition of raw milk is slightly affected by this technology as the texture of the product is manipulated. However, there are benefits of this ultrasound technology where it improves gelation and syneresis during cheese production, reduces fermentation time or dairy products, and provide improvements depend on time, frequency and intensity of sonication [6].

A recent report released revealed that the global dairy industry has been experiencing constant growth over several decades despite economic downturns [7]. As the population of the world increases, the dairy demand increases together. The statistics in Figure 1 below indicate that the size of the industry is dependent on the functional aspects and efficiency of the processes in the industry among which 'cream separation' is central. Cream separation plays an integral if not critical role towards the sustainability of the industry using centrifugal force [8]. The production of diversified dairy by-products heavily depends on cream separator machines initially. Efficient cream separation would result in higher productivity and given the rising global population on an annual basis, industry players are required to optimize all processes, especially cream separation processes. Cream separator is also economical and effective for dairy processing as it is economical and able to operate efficiently at optimum circumstances [9].

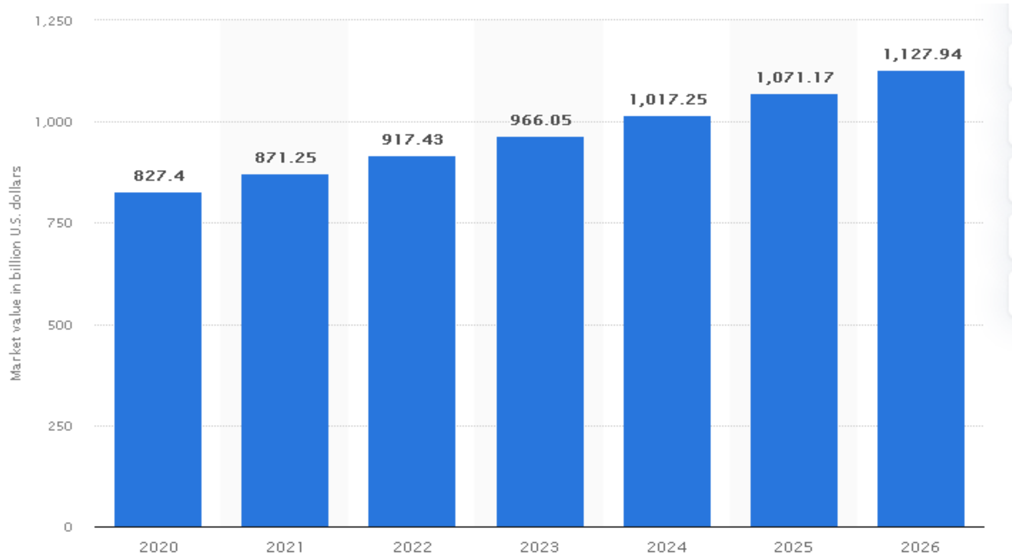

Fig. 1. Dairy Market Value 2020 – 2026 [7]

Among the primary issues with the traditional manual cream separator is the fact that they require frequent maintenance due to high fragility (higher external forces). Ultrasonics cream separator is believed to be an intense dairy processing method to process huge volume in a shorter time with lower overhead costs. However, these separators are facing challenges to adopt with the fluctuation of raw milk quality and induced frequency for coagulation. The different size of fat molecules of milk reacts with different transduced frequencies of transducers. The transducers create wave where the fat particles will attach to the wave line [10]. The declined coagulation efficiency leads to escaped fats to skim milk. This is cream skimming inefficiency and leads to economic loss of the organization or hosts. Therefore, understanding that narrow knowledge gaps on ultrasonic cream separation in the current market will be essential to the entire dairy industry and the companies involved in the processing of whole milk through tests and analysis.

2. Literature Review

The latest in cream separation technology introduced in circa 2015 by Australian researchers is the use of ultrasonic waves to separate cream from whole milk [11]. In general, the current separation techniques involve using 1 MHz & 2 MHz transducers placed on direct opposite sides to achieve maximum impact. Based on Figure 2 below, coarse emulsion in milk is converted to fine emulsion using ultrasonic probe sonicator. This application mostly being practiced in homogenizer to break down the fat particles into finer molecules.

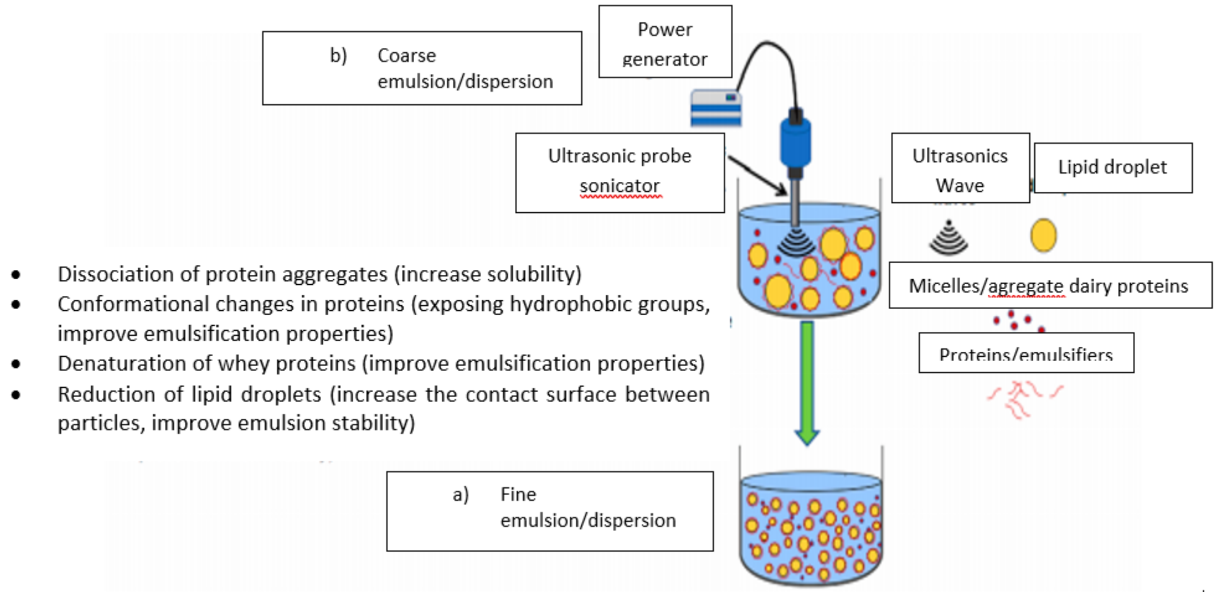

Fig. 2. Ultrasonic cream separation [12]

According to studies, high-frequency sound waves (ultrasonic) above 400kHz can separate food materials in multicomponent mixtures [13]. The study also indicates that ultrasonic separation enhances separation processes. The recent developments revolving around the application of ultrasonic sound waves have been introduced in the food processing spectrum with emphasis on particle separation [14]. It is also used to separate the particles under a static wave field, to separate solid particles from emulsified content (separation of solid particles of canola oil, palm oil separation, and other saturated oils). Cream separation using ultrasonic waves is currently still at an agile state of development. The application of the static or standing waves to the system causes fat globules to coagulate at regions of high pressure. Then the coagulated fat droplets will rise to the surface much faster due to the buoyancy than the individual globules its selves. The operation of coagulating milk fats will be very much faster compared to the conventional method which they depend on gravity through sedimentation process and cream separator [13].

High-frequency ultrasound (400 kHz to 3MHz) has been proven in recent studies to improve milk fat separation in small-scale devices capable of treating a few millilitres of samples. The evaluation conducted by Greenvall *et al.,* [15] and Juliano *et al.,* [16] the effect of ultrasonic standing waves on the creaming of milk fat in a recombined coarse milk emulsion in a 6-L reactor, as well as the effect of various frequencies and transducer designs in direct contact with the fluid. Runs were carried out using one or two transducers in vertical (parallel or perpendicular) and horizontal (at the reactor base) positions at 400 kHz, 1 MHz, and/or 2 MHz. They discovered that creaming following treatment was most efficient at 400 kHz in single and double vertical transducer designs.

Acoustic cavitation occurs when ultrasonic waves are applied to a liquid, causing bubbles to grow and then collapse because of the alternating high- and low-pressure waves. High-intensity shear forces and turbulence are generated during this process, which can cause physical and chemical changes in the liquid, such as the agglomeration of fat globules in milk during ultrasonic cream separation [17]. The application of ultrasonic waves to milk causes acoustic cavitation, which creates small bubbles throughout the liquid in the case of ultrasonic cream separation. As these bubbles expand and contract, shear forces are generated, causing fat globules in the milk to agglomerate and rise to the surface, where they can be skimmed off to obtain cream.

3. Methodology

3.1 Testing of Milk

Before beginning of experiment, milk is procured with trustable source where the fluctuation of quality is minimum. Several tests for the milk were done before beginning the experiment with transducers. The procured milk undergoes the Solid and Fats (S&F) analysis must be more than 13%, Ethanol Test must have no coagulation and Methyl Blue Reduction Test (MBRT) must be more than 5 hours. This standard is due to the economic factor of the dairy business module. Compromising to this quality results to decline of quality of the milk [18]. If the milk quality passes, the experiment will be further continued.

3.2 Experiment Setup

For determining the effect of ultrasonic waves, submersible plate transducers with nominal frequencies of 400Hz, 1000Hz, 2000Hz, and 3000Hz were selected for separation. The dimensions of these transducers were identical having dimensions of 160 x 160 x 30 mm with an active area of 100 x 100 mm. A rectangular reaction vessel was deployed. The role of reflector was played by the plates themselves. These two Sonosys transducers were located opposite to each other as shown in Figure 3 below. The collection of samples was performed from the top and bottom of separation vessel with the help of a 10 ml serological pipette. For extracting thin layer from the surface of container, extra care was taken. An approximately 20 mL sample was collected from top and bottom. With the help of Rose-Gottlieb method [19], contents of fats were analysed, for determining the concentration of fat in milk before ultrasound processing, and upper and lower part after ultrasound applications. 2 mL of 25% ammonia solution with 10 mL of ethanol was dissolved in 10 mL of sample. By aiding help from subsequent extractions of diethyl ether and petroleum ether in a spherical mask having been pre-weighed, the fat of milk was then extracted.

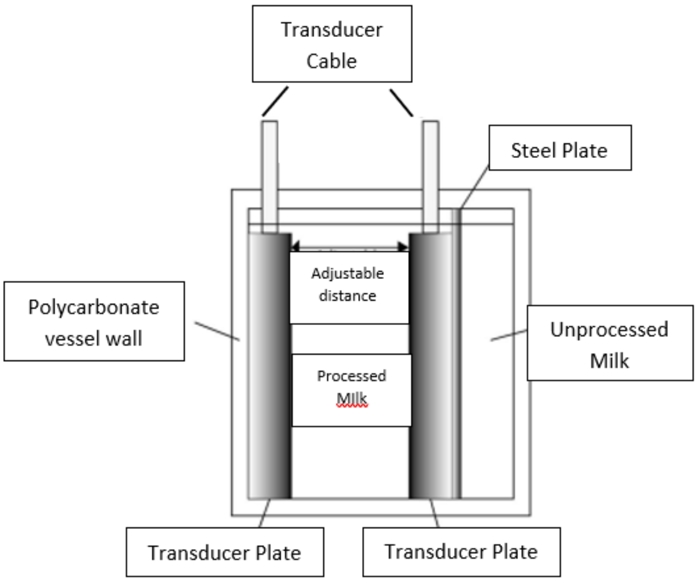

Fig. 3. Schematic of the experimental set-up (batch mode operation)

With the range having from 5% to 100% nominal power, Sonosys control unit could be controlled digitally for manipulating nominal power input. Unless stated otherwise, transducers were being operated at 100% nominal power (for 1 and 2 MHz, 330 and 290 W respectively). By using a power meter, electrical power was shown. To determine energy released in the form of heat in the processed milk, it was done calorimetrically with the help of temperature measurements using Eq. (1).

$$Q = mCp\Delta\mathrm{T}/\mathrm{t}, \tag{1}$$

where heat energy, Q, milk's specific heat capacity, *Cp,* mass, m, temperature change, $\Delta\mathrm{T}$, and time, s.

The loss in energy which happened due to two reasons which were, absorption of loss heat by reactor walls and absorption of loss heat to surroundings by convection were not accumulated in this study, which may result in an error of >5% in the real measurements. With the help of needle hydrophone (model HNC-1000, Onda Corp., Sunnyvale, USA), sound pressure levels were obtained. For obtaining the maximum pressure in vessel, hydrophone was positioned at different positions throughout the container. For this experiment 4 different frequency variables were fixed. They are 400 Hz, 1 MHz, 2 MHz, and 3 MHz. The results were analysed then using statistical analysis.

4. Results and Data

For this research, the data is tabulated after the experiment is conducted. The data are then analysed using descriptive analysis, tabulation of data in table and graph projection and Analysis of Variance (ANOVA). Previous research was done contractually as there were other methods supporting their assessment included the measurement of fat content, backscattering, particle size distribution, and microscopy of samples taken at the bottom and top of the reactor [20]. This research emphasizes primely on the efficiency of cream separation using ultrasonic frequencies. The statistical analysis in this research emphasizes on clearer understanding on correlation of different induced frequency and skimming efficiency. The expected result is to estimate the best induced frequency for efficient cream separation.

5. Descriptive

The Table 1 and Figure 4 below show the effects of ultrasonic waves frequency on cream separator efficiency. Based on the line chart, the lower the ultrasonic waves frequency results in better cream separator efficiency. Four settings are used in the experiment which are 400kHz, 1MHz, 2MHz and 3MHz. When the ultrasonic waves frequency is adjusted at 400kHz, the average efficiency is 84.55%. On the other hand, when waves frequency set at 3MHz, the efficiency drops significantly to 71.99%.

Table 1
Efficiency of Cream Skimming

					95% Confidence Interval for Mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
400	72	84.5522%	1.56250%	0.18414%	84.1850%	84.9194%	81.56%	88.16%
1000	72	81.6481%	1.72363%	0.20313%	81.2431%	82.0531%	78.34%	85.30%
2000	72	76.7565%	1.53738%	0.18118%	76.3953%	77.1178%	73.57%	79.96%
3000	72	71.9900%	1.51667%	0.17874%	71.6336%	72.3464%	68.87%	75.70%
Total	288	78.7367%	5.05040%	0.29760%	78.1510%	79.3225%	68.87%	88.16%

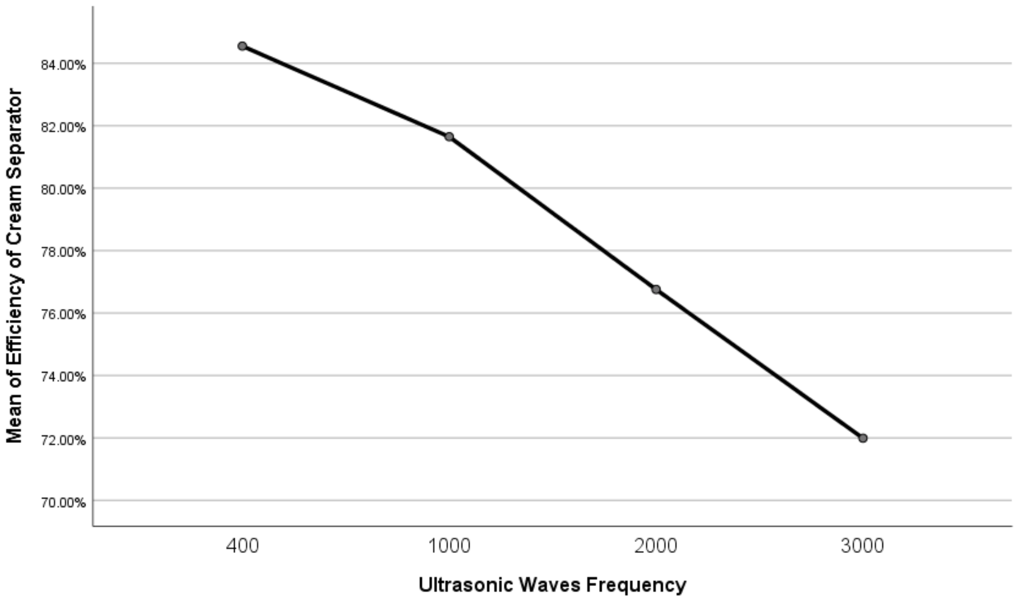

Fig. 4. Graph projection of correlation between mean of efficiency of cream separator and ultrasonics wave frequency

Table 2 below shows the ANOVA table of assessing the contribution of ultrasonic waves frequency on cream separator efficiency.

Table 2
ANOVA test for efficiency of cream separator

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6604.980	3	2201.660	874.009	0.000
Within Groups	715.406	284	2.519		
Total	7320.387	287			

The hypothesis tests are

i. **Null hypothesis**: Ultrasonic waves frequency does not contribute significantly to affecting cream separator efficiency.
ii. **Alternative hypothesis**: Ultrasonic waves frequency contributes significantly to affecting cream separator efficiency.

Based on the ANOVA test above, the p-value of the test is 0.000, much lower than the standard threshold of 0.05. Hence, we have sufficient evidence to reject the null hypothesis. Therefore, we conclude that ultrasonic waves frequency contributes significantly to affecting cream separator efficiency.

6. Conclusion

The data were analysed from the experiment above. The extracted cream justifies the yield of the ultrasonic cream separation technology. Further justification is tabulated in the Table 3 below.

Table 3
Justification of significance of ultrasonic waves frequency

Factor	Significance	Remarks
Ultrasonic waves frequency	Significant	The P-value of the coefficient test is 0.000, which is much lower than the significance threshold of 0.05. Hence, we have sufficient evidence to prove that Ultrasonic Waves Frequency is significant in affecting the efficiency of cream skimming.

In conclusion, ultrasonic cream separation is no doubt the most advanced technology till date for cream separation. Ultrasound has demonstrated its abilities in the food business in preservation, extraction, and processing. Ultrasonic waves show their abilities to increase effectiveness and diminish the time expected for various processing operations that has guaranteed a dynamic future. It turns out to be even more remarkable when utilized in combination with other procedures for the preservation of food. It has several advantages over other prior or conventional advancements and helps adapt up or defeat their weaknesses when coupled along with them. Conclusively, the right frequency of the transducers along with good quality of whole milk will give the best fat extraction from whole milk.

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