DEVELOPMENT AND PERFORMANCE EVALUATION OF UNIVERSAL DISPERSER FOR DAIRY PROCESSING OPERATIONS

THESIS SUBMITTED TO THE
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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF DEGREE OF

DOCTOR OF PHILOSOPHY
IN
DAIRY ENGINEERING

By

DATIR RUPESH PRABHUDAS
M. Tech. (Dairy Engineering)

DAIRY ENGINEERING SECTION
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This is to certify that the thesis entitled, **"DEVELOPMENT AND PERFORMANCE EVALUATION OF UNIVERSAL DISPERSER FOR DAIRY PROCESSING OPERATIONS"** submitted by **Mr. DATIR RUPESH PRABHUDAS (15-P-DE-02)** towards the partial fulfillment for the award of the degree of **DOCTOR OF PHILOSOPHY** in **DAIRY ENGINEERING** of the **ICAR-NATIONAL DAIRY RESEARCH INSTITUTE (Deemed University)**, Karnal (Haryana), India, is a bonafide research work carried out by him under my guidance and no part of the thesis has been submitted for any other degree or diploma.

(Dr. Menon Rekha Ravindra)
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Abstract

A universal disperser (product volume 3 L) was designed and developed in the form of a jacketed vessel enveloped by an outer insulation. Three multifunctional impellers, namely multivane churn impeller, pitched blade and saw tooth disc impellers were selected as attachments for the developed unit. An electric plate heater (2 kW) was integrated in the jacket volume of the developed unit along with the necessary control and indicators. The universal disperser was equipped with two motors for low speed and high speed operations and selected as per product characteristics. The developed unit was preliminarily tested for its performance using carboxyethylcellulose (CMC) solution as a test simulant. The developed unit was further investigated for different unit operations with three different dairy products viz., *Lassi*, Processed Cheese Spread and Recombined Milk. For *lassi* preparation, two independent parameters i.e. off-bottom clearance (OBC) (3, 6, 9 cm) and RPM (300, 400, 500) were selected and multivane churn impeller was identified as the better choice. The performance evaluation was adjudged in terms of the mixing index, mixing time, power consumption and overall sensorial acceptability. The process was optimized using Response Surface Methodology and it was recommended that *lassi* could be prepared at OBC of 4.84 cm at an impeller speed of 389 RPM. The overall acceptability was recorded 8.16±0.15 on 9-point hedonic scale while mixing time was 160±17.32 s. The power consumption was 34.21±0.70 W with a near unity mixing index. For the preparation of processed cheese spread, two independent parameters viz., temperature of processing (50, 65, 80 ^{o}C) and RPM (10000, 15000, 20000) were identified and the saw tooth impeller was selected for the operation. The output factors were evaluated in terms of mixing index, mixing time, power consumption, work of shear and overall sensorial acceptability. The product preparation was optimised at a temperature 80 ^{o}C and 19124 RPM. The mixing time was found to be 340±28.28 s and mixing index achieved was 0.974±0.003. Power consumption recorded was 292.88 ±2.28 W, while the work of shear (index of spreadibility) was measured and found to be 4.13±0.20 N.s. The overall acceptability was scored as 8.30±0.08 on 9-point hedonic scale. Similarly, the preparation of Recombined Milk (RM) was attempted with the saw tooth impeller using universal disperser. SMP, butter oil and water were used to formulate RM at different fat levels (1.5%, 3.0% and 4.5%) prepared at different processing conditions viz., temperature (20, 35, 50 ^{o}C) and RPM (10000, 15000, 20000) and mixing performance and product characteristics were evaluated as responses to optimise the process conditions to satisfactorily prepare recombined milk of desired fat content using the developed disperser. The study established that the developed universal disperser was versatile and could be successfully applied for different unit operations in the small and medium scale preparation of different dairy products.

सारांश

एक सार्वभौमिक डिस्पर्सर (उत्पाद की मात्रा 3 ली.) बाहरी इन्सुलेशन द्वारा कवर किए गए जैकेट वाले बर्तन के रूप में डिजाइन और विकसित किया गया था। विकसित इकाई के लिए संलग्नक के रूप में तीन बहुआयामी इम्पेलर, अर्थात् एंकर, पिच ब्लेड और सॉ टूथ डिस्क इम्पेलर चुने गए। एक इलेक्ट्रिक प्लेट हीटर (2 किलोवाट) आवश्यक नियंत्रण और संकेतक के साथ विकसित इकाई के जैकेट मात्रा में एकीकृत किया गया था। यूनिवर्सल डिस्पर्सर कम गति और उच्च गति के संचालन के लिए दो मोटर्स से सुसज्जित था और उत्पाद विशेषताओं के अनुसार चुना गया था। विकसित इकाई को टेस्ट सिमुलेंट के रूप में सीएमसी सोलुशन का उपयोग करते हुए उसके प्रदर्शन के लिए प्राथमिक रूप से परीक्षण किया गया था। विकसित इकाई को तीन अलग-अलग डेयरी उत्पादों अर्थात लस्सी, प्रोसेस्ड चीज़ स्प्रेड और रिकम्बाइनड मिल्क के साथ अलग-अलग यूनिट संचालन के लिए आगे की जांच की गई। लस्सी तैयार करने के लिए, दो स्वतंत्र मापदंडों यानी ओबीसी (3, 6, 9 सेमी) और आरपीएम (300, 400, 500) का चयन किया गया था और बेहतर विकल्प के रूप में एंकर इम्पेलर की पहचान की गई थी। मिश्रण मूल्यांकन, मिश्रण समय, बिजली की खपत और समग्र संवेदी स्वीकार्यता के संदर्भ में प्रदर्शन मूल्यांकन किया गया था। रिस्पांस सरफेस मेथोडोलॉजी का उपयोग करके प्रक्रिया को अनुकूलित किया गया था और यह सिफारिश की गई थी कि लस्सी को 4.84 सेमी के ओबीसी में 389 RPM की एक प्ररित करनेवाला गति से तैयार किया जा सकता है। समग्र स्वीकार्यता 8.16±0.15 दर्ज की गई जबकि मिश्रण समय 160±17.32 सेकेंड था। एक एकता मिश्रण सूचकांक के साथ बिजली की खपत 34.21±0.70 W थी। प्रोसेस्ड चीज़ स्प्रेड के लिए दो स्वतंत्र मापदंडों अर्थात, प्रसंस्करण के तापमान (50, 65, 80 ^{o}C) और RPM (10000, 15000, 20000) की पहचान की गई और ऑपरेशन के लिए सॉ टूथ डिस्क इम्पेलर का चयन किया गया। मिश्रण सूचकांक, मिश्रण समय, बिजली की खपत, वर्क ऑफ़ शियर और समग्र संवेदी स्वीकार्यता के संदर्भ में आउटपुट कारकों का मूल्यांकन किया गया था। उत्पाद की तैयारी को तापमान 80 ^{o}C और 19124 RPM पर अनुकूलित किया गया था। मिश्रण का समय 340±28.28 सेकेंड और मिक्सिंग इंडेक्स 0.974±0.003 था। दर्ज की गई। बिजली की खपत 292.88±2.28 W थी, जबकि वर्क ऑफ़ शियर (प्रसार का सूचकांक) मापा गया और 4.13±0.20 N.s. पाया गया। समग्र स्वीकार्यता को 9-पॉइंट हेडोनिक पैमाने पर 8.30±0.08 के रूप में स्कोर किया गया था। इसी तरह, रिकम्बाइनड मिल्क को तैयार करने का प्रयास यूनिवर्सल डिस्पेर्सर का उपयोग करते हुए सॉ टूथ डिस्क इम्पेलर इस्तेमाल किया। । एसएमपी, बटर ऑयल और पानी का उपयोग विभिन्न प्रसंस्करण स्थितियों अर्थात तापमान (20, 35, 50 ^{o}C) और RPM (10000, 15000, 20000) पर तैयार विभिन्न वसा स्तरों (1.5%, 3.0% और 4.5%) पर रिकम्बाइनड मिल्क बनाने के लिए किया गया। और मिश्रित प्रदर्शन और उत्पाद विशेषताओं का मूल्यांकन किया गया था ताकि प्रतिक्रिया के रूप में प्रक्रिया की स्थिति का अनुकूलन करने के लिए विकसित डिस्पेर्सर का उपयोग करके वांछित वसा सामग्री के रिकम्बाइनड मिल्क को तैयार किया जा सके। अध्ययन ने स्थापित किया कि विकसित सार्वभौमिक डिस्पर्सर बहुआयामी था और विभिन्न डेयरी उत्पादों के छोटे और मध्यम स्तर की तैयारी में विभिन्न इकाई संचालन के लिए सफलतापूर्वक लागू किया जा सकता है।

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%	Per cent
% L. A.	Per cent lactic acid
@	at the rate of
°C	degree centigrade
µm	micrometer
10K	10000
15K	15000
20K	20000
2-D	2-dimensional
3-D`	3-dimensional
AISI	American Iron and Steel Institute
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
AR Grade	Analytical grade
ASAE	American Society of Agricultural Engineers
ASTM	American Society for Testing and Materials
BIS	Bureau of Indian Standards
CCRD	Central composite randomized design
CI	Creaming index
cm	centimeter
CMC	Carboxymethyl cellulose
cP	centipoise
CPV	Conical process vat
DAS	Data acquisition system
DC	Direct current
EC	Electrical conductivity

ERT	Electrical resistance tomography
Fig.	Figure
FPS	Frame per second
FSSAI	Food Safety and Standards Authority of India
g	gram
H	hour
HCl	Hydrochloric acid
Hp	Horse power
HSM	High shear mixer
Hz	Hertz
ICAR	Indian Council of Agricultural Research
IS	Indian standards
kg	kilogram
LDPE	Low density polyethylene
m	Meter
MI	Mixing index
min	minute
MoC	Material of construction
MPa	megapascal
MPC	Milk protein concentrate
ms/cm	millisiemens/centimeter
N	newton
NaCl	Sodium chloride
NaOH	Sodium hydroxide
NDDB	National Dairy Development Board
NDRI	National Dairy Research Institute
N_{Re}	Reynolds number
OA	Overall acceptability

OBC	Off-bottom clearance
Pa	pascal
PB	Pitched blade
PCS	Processed cheese spread
PE	Polyethylene
PLIF	Planar laser-induced fluorescence
R^2	Coefficient of determination
RM	Recombined milk
rpm	Revolutions per minute
RSM	Response surface methodology
s	second
SD	Standard deviation
SMP	Skim milk powder
SNF	Solid-non-fat
SRS	Southern Regional Station
SS	Stainless steel
SSHE	Scraped surface heat exchanger
ST	Saw tooth impeller
TS	Total solid
UHT	Ultra heat treatment
V	Voltage
VADPs	Value added dairy products
W	watt

Introduction

1. INTRODUCTION

The annual milk production in India is about 176.3 million tonnes with a per capita availability of 375 g/day (NDDB, 2019). The Indian Dairy Industry is broadly divided into organised and unorganised sectors and small proportion of the milk produced in the country is processed through the organized sector. It is estimated that about 20 per cent of all the milk is delivered to some 400 dairy plants spread across the country. A major volume of the milk traverses through the unorganized sector comprising of local milkmen, cottage industry- level processors and vendors as well as domestic consumption at the point of production itself (Gadkari, 2017).

The structure of the dairy industry is poised to change in the near future with more participation emerging in the organized sector which has been witnessing steady influx of investments, primarily among small and medium scale processors for increased capacity for value addition. This trend is driven by the growing realization of the market potential of value-added dairy products and changing consumption pattern in the market gradually spiking the demand for products such as cheese, dairy spreads, yoghurt, dairy beverages etc. The market viability of the dairy industry in India has, in recent times, seen entrants such as new entrepreneurs and startups invest in milk procurement and processing (Whitehead, 2018).

Demographics transformation, rising of middle class, rapid urbanization and change in eating habits of urban India have resulted into manifold surge in the demand for these value-added dairy products. In India, about fifty-five per cent of the milk produced is annually converted to various value-added dairy products (VADPs). Indian retail space emerged as most dynamic sector; witnesses a dramatic shift towards consumption of value-added products such as ice-cream, cheese, dairy beverages, UHT milk, functional milks, and whey products.

It is reported that the profitability in fluid milk space ranges from 4-5 per cent, whereas its value addition can boost the profitability in the space ranges from 12 to 18 per cent, attracting private participation in the industry (Anon., 2014). In addition to aiding in product diversification and market penetration, thus the switch to VADPs in the dairy processing space also favours profit augmentation, and the growth in recent times in this segment of the dairy industry has been a steady 20-25 per cent. The per cent growth rate for some dairy products like polypack milk, ghee, yoghurt, baby food, UHT milk, ice-cream, butter, dairy beverages, cheese, paneer and yoghurt has been determined as 16, 11, 28, 12, 32, 30, 17, 28, 22, 15 and 32 per cent, respectively (Shashidhar, 2016). Since the value-added dairy products belong to different process flow paths, prepared using different ingredients and processed with varied technologies, a large number of unit operations are involved in dairy processing, sometimes in the preparation of a single product. For example, preparation of a dairy beverage may combine operations such as clarification, separation, homogenization, blending, agitation, heating, dispersion, etc. (Motarjemi, *et al.*, 2014).

Organized processing calls for systematic mechanization and process control of the unit operations involved in dairy processing. The operations for fluid milk processing and packaging have been well defined and established with process lines and sophisticated equipment for pasteurization, cream separation, homogenization, packaging and storage of fluid milk. However, value added dairy products are an evolving sector and adequate attention and investment is necessary to raise the status of product category of value-added dairy products from a predominantly non-organised sector to emerge as a mature segment of the industry (Parekh, 2018). Over the past decades, there has been a consistent focus in this area in our country and process engineering facilities have been created in the dairy industry, either through domestic fabrication and commissioning or by import of processing units facilitated by dedicated consultants. This line of infrastructure development primarily caters to the large-scale processing facilities due to the capital investment involved.

Academic research has also been focused on mechanization of dairy processing operations and most reports are dedicated to the much-needed thrust area of process upgradation of traditional Indian dairy products. Pal and Raju (2007) and Talwar and Brar (2017) has extensively reviewed the mechanization taken place in the manufacturing of traditional Indian dairy products. Dodeja *et al.* (1992) developed a mechanized thin film scraped surface heat exchanger system at NDRI for the continuous manufacture of *khoa*. Kumar and Dodeja (2003) developed a continuous method of making burfi using three-stage TSSHE. Patel *et al.* (2006) developed a mechanized system for continuous *basundi* production. Workers at Indian Institute of Technology, Kharagpur developed a continuous chhana-making unit of 60 L/h of milk capacity (Sahu and Das, 2007). A continuous paneer-making system was developed at NDRI, Karnal by Agrawala *et al.* (2001). Chitranayak (2017) developed a microprocessor based pneumatic *paneer* press. Suryawanshi *et al.* (2019) developed a heat exchanger to control the matting temperature for automatic *paneer* press.

Choudhury *et al.* (2002) developed a mechanized unit for *rasogolla* preparation where kneading and ball formation can be done in a continuous manner. Dhotre and Bhadania (2016) developed and studied the performance of SSHE for continuous thermization of *shrikhand*. Karunanithy *et al.* (2007a, b & c) also tried to mechanize unit operations in *rasogolla* making for its continuous production. Recently Kumar (2016) developed a microcontroller based sub-baric thermal processor for manufacture of fried and soaked dairy products. Srinivasa (2017) developed a combined electric and LPG based heating system for *rasogolla* cooking.

In addition to large scale manufacturing plants and manufacturers of traditional Indian dairy products, the dairy processing space is also significantly occupied by small and medium scale processors and new entrants in the form of start-ups and business incubatees. Hence, there is a need to cater to the requirement to develop small volume processing machineries, which would aid the small – scale processors to economically and efficiently process the milk to value added products in a hygienic environment with consistent product quality. A versatile multifunctional equipments, that can be integrated across the process flow path of varied products and also adaptable to multiple unit operations may help such processing units which economize the capital investment in setting up and testing processing operations. A single equipment capable of delivering mechanical unit operations such as mixing, blending, dispersion, etc. across a wide range of rpm, in combination with heat transfer operations (heating and cooling) presents a versatile option for the small and medium scale unit involved in product development in the areas of dairy processing.

Keeping in view the above considerations, the present study was undertaken to develop a universal disperser with following objectives:

Objectives:

1. Design and fabrication of universal disperser for dairy processing operations
2. Evaluation and selection of suitable attachments for universal disperser
3. Performance evaluation of the developed universal disperser for performing different unit operations in dairy products processing

Review of Literature

2. REVIEW OF LITERATURE

The universal disperser, which forms the focus of this study is a multifunctional unit that is envisaged to perform different unit operations like mixing, blending, dispersion, stirring, agitation etc. during the preparation of various dairy products. This chapter reviews the literature reports related to the various aspects of mixing methodologies and equipment related to the dairy and food industry. The review also explores the technological aspects of the selected test products identified for the performance evaluation of the envisaged disperser, namely, dairy beverages (*lassi*), cheese spread and recombined milk.

2.1 Unit operations

The unit operations envisaged for the multifunctional disperser unit is summarised and explained in Table 2.1.

Table 2.1. Process description of common terms in mixing and agitation

Terminology	Process Description
Blending	The action of mixing and combining together of individual components through mechanisms of convective, diffusive and shear blending.
Mixing	It is the process which involve physical suspension, dissolving or dispersion of ingredients, achieved through mechanisms of macro, meso and micro mixing.
Dispersion	It is the process of breaking apart of solid particles into a bulk liquid using high shear forces and the subsequent mixing thereof by mechanisms of maximum circulation and minimum turbulence obtaining a rapid and homogeneous dispersion
Emulsification	The process involves dispersing of immiscible (or partially immiscible) liquid into another to obtain stable distribution of fine droplets in a continuous phase

De-agglomeration	The process of breaking inter-particular bonds and segregating the agglomerate into its fundamental particles by shearing and/or impaction.
Agitation	Process of evening out all gradients within a mixture matrix accomplished by transport processes of heat, mass and momentum transfer

2.1.1 Mixing Mechanism

Irrespective of the process involved, the basic mechanisms of mixing involve mass transport at the molecular, micro and macro levels due to the mechanical energy dissipated in to the fluid by the impeller. Das and Das (2019) identified the transport processes associated during the process as:

(i) Diffusion
(ii) Convection
(iii) Shearing

2.1.1.1 Diffusion

Diffusion refers to the micro-mixing mechanism at small scale operations and may be resultant of the movement of individual molecules through the mixture matrix due to a concentration difference (Doran, 2013). In solid mixing applications, diffusion may refer to the arbitrary dispersion of individual component through the porous media of the mix (Das and Das, 2019).

2.1.1.2 Convection

Convective mechanisms during mixing refers to macro scale operations due to bulk distribution within the mixture matrix. Inertial effects of the agitator and viscous resistance of the fluid significantly influence the convection process, which is governed by circulation times within the mixing tank (Lacey, 1954; Hogg, 2009).

2.1.1.3 Shearing

High speed shearing is applied to break large agglomerates to finer particulates which is then mixed in the product matrix through convective and diffusive mixing mechanisms and is an essential mechanism for producing stable emulsions and dispersions (Zhang *et al*., 2012).

2.2 Mechanical Mixing in the Food Processing Industry

The mixing of ingredients is an inevitable basic operation in the food process flow line (Cullen, 2009). The food ingredients include components in all three states of matter viz., solid, liquid, or gas. Depending on the product characteristics, the process flow chart may require that the ingredients be mixed/dissolved or dispersed to obtain either a homogenous uniform phase or a multiphase mixture. In order to meet consumer expectations and also retain the market, it is necessary for the food processing industry to deliver the product with constant properties and mechanical rather than manual methods of processing are inevitable to achieve the product objectives (Lindley, 1991a).

Primarily, the application of mechanical mixing operations in the food processing industry are devoted to disperse the components, eliminate gradients of concentration and improve heat and mass transfer (Rielly, 1994). Sometimes, the operations also contribute to texturization of the raw food and feed product in terms of new physical, rheological, and organoleptic properties (Coulson *et al*., 1979).

Various types of multiphase dispersions are common among processed foods, such as solid-liquid dispersion (e.g., soups, baked beans); liquid–liquid emulsions (e.g., mayonnaise, milk); solid-solid mixes (e.g., instant dry mix) and agglomerate dispersions (e.g., ice cream). The product characteristics and quality are significantly influenced by the mixing process. All these operations are carried out with the help of different types and variety of mixing equipment in the food industry (Paul *et al*., 2004). The selection of a particular design of equipment is primarily determined by the characteristics of the ingredients e.g., density and viscosity, as well as the phases being processed (Nienow *et al.*, 1997). The various mixing technologies employed in the food industry often overlap in its applicability and function and can be classified into several categories (Rielly *et al.*, 1994; Niranjan *et al*., 1994; Lindley, 1991a, b, c).

2.3 Type of Mixing Equipment

In the following paragraphs, several designs of mixing equipment currently in vogue in the food processing industry are discussed.

2.3.1 Ribbon or Tumble Blenders

These are simple mixers commonly used for free-flowing or non-cohesive mixtures, such as snack bars, spices and herbs, cereals and coffee (Fig. 2.1a). The blender is constructed as an enclosed vessel rotating about horizontal or inclined axis which causes the contents to tumble against each other (Niranjan *et al*.,1994). A tumble blender with double-cone rotating container shaped as a V-configuration has been reported for food applications (Moakher *et al*., 2000). Ribbon blender is reported as one of the most popular design of tumblers employed for food processing operations having U-shaped flat trough equipped with helical ribbon blades (inner or outer). This design achieves effective movement of material in axial as well as radial direction (Muzzio *et al*., 2008).

2.3.2 Single/Double Planetary Mixers

It has been reported that high-viscosity products such as syrups, candies, cheese, gels, pet food and dough are generally processed in the planetary mixers (Fig. 2.1b). The impellers are designed such that spin effect is obtained at two points, causing bulk movement within the processing vessel (Auger *et al*., 2013, 2015). Enhanced flow obtained is the advantage of this impeller design over anchor impeller. Both single and double planetary mixer configurations have been reported in literature.

2.3.3 High-Viscosity Batch Multishaft Mixers

Multi shaft mixers (Fig. 2.1c) have been developed to process medium to high viscosity products like sweet syrups, pastes, beverages, peanut butter, sauces, and other spreads are generally prepared by these mixers. This kind of mixing system consists of two or more agitators fixed on a common header but working independently; the impeller designs integrated with high-shear devices such as disc-type disperser blade or a high-shear mixer rotor-stator head and low-speed anchor impeller (Wang *et al*., 2014).

2.3.4 Static Mixers

These mixers (Fig. 2.1d) are predominantly reported for continuous processing of products such as dairy beverages, mayonnaise, and chocolate. Static mixers do not have moving parts and the mixing action is achieved through insertions in the pipe flow, for example, through flow deviations with the help of plates, stuffing, or spiral designs, the food ingredients attain the desired degree of mixing (Ghanem *et al*., 2014).

2.3.5 High-Shear Mixers

High shear mixers (Fig. 2.1e) are very commonly reported in recent times for processing of structured materials like syrups and sauces, dispersion of emulsions etc. The mixer is generally constructed using high rotating rotor-stator impellers by producing the high shear required to disrupt and breakdown the liquid to fine drops. Both batch mode mixers and inline configuration of the unit have been reported (Rodgers and Cooke, 2012; Cooke *et al*., 2012).

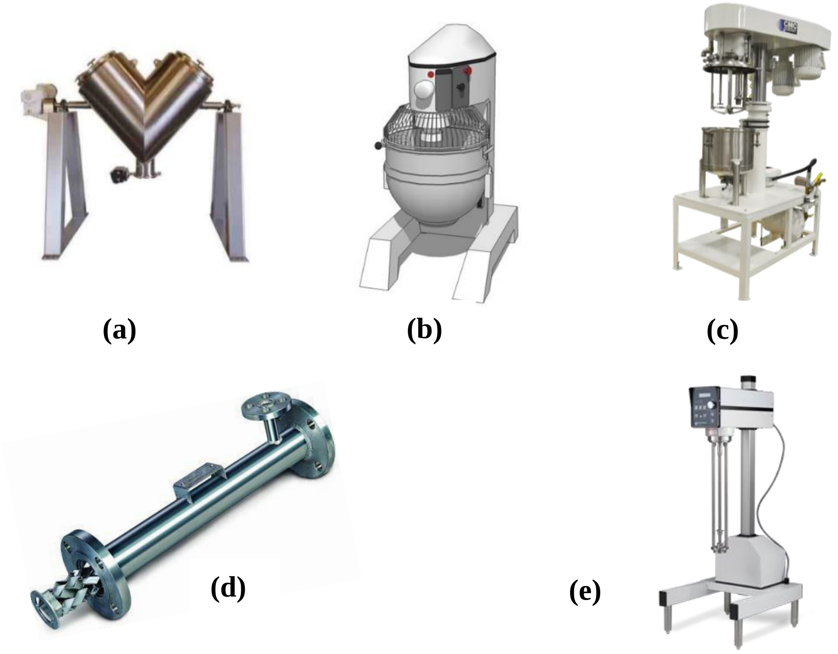


Fig. 2.1: Various mixing equipment in food industry (a) V-blender (b) Planetary mixer (c) Double shaft mixer (d) Static mixer (e) High shear mixer

(Anon., 2006, 2014, 2012, 2017a; Mercredi, 2013)

2.4 Mixing/Blending/Dispersion in Dairy Products Processing

The processing of milk and milk products encompass various unit operations such as stirring, atomization, homogenization and recombination (Walstra *et al.*, 2006). Dairy products include products of various classes of properties such as low viscous fluids like milk and whey, medium viscous products such as *ghee*, yoghurt, etc. and highly viscous products such as *khoa*, *channa*, cheese, etc. A dairy processing plant requires specialized equipment to achieve processing objectives including mixing of fluids and non-Newtonian fluids, emulsification and mixing of immiscible liquids, dispersion of one phase in another i.e. solids or gases into liquids and to blend and mix solid ingredients in a formulation. Various unit operations in dairy processing are devoted to mixing i.e. solid-liquid mixing, liquid-liquid mixing, gas-liquid mixing and solid-solid mixing. Dairy process flow path often requires the addition and processing of dry ingredients like skim milk powder, whey protein concentrate, whole milk powder, flours, stabilizers, thickeners, sweeteners, bioactive compounds, condiments, nuts, etc. while the liquid ingredients applied in dairy processing include water, color, flavour, fruit pulps, cream, butter oil, vegetable oil, antioxidants and extracts. Hence, specific and custom designed units for homogenization, blending, kneading, mixing and dispersion are widely employed in the dairy plant for processing the products.

2.4.1 Yoghurt

Yoghurt (set or stirred) is a popular fermented milk product having high solids content (about 20 per cent), generally classified as a medium to high viscosity product. The product process requires gentle agitation to ensure less hindrance to product texture and to preserve the viability of the live organisms in the product (Aryana and Olson, 2017). It has been recommended that a top mounted agitator at a speed of 20-60 rpm with large paddles would be most suitable for stirring of yoghurt and similar fermented products (Fuquay, 2007).

2.4.2 Processed Cheese

Processed cheese is a high viscous product produced by blending shredded natural cheeses of different types and degrees of maturity with emulsifying agents, and by heating the blend under a partial vacuum with constant agitation until a homogeneous mass is obtained. In addition to natural cheeses, other dairy and non-dairy ingredients may be included in the blend (Caric and Kalab, 1999). Fuquay (2007) suggested the agitator design of an anchor-type with scraped surface geometry, operating at an approximate speed of nearly 100 rpm during the manufacture of cheese spread.

2.4.3 Cream

Cream is the separated milk fat from the fluid milk stream and is widely used in dairy plants as a component during standardization of milk and in the preparation of fat rich dairy products such as butter, ice cream, ghee, etc. (De, 1980). The product is sensitive to agitation due to the potential problem of phase inversion and shear thickening (Walstra *et al.*, 2006; Shioya *et al*., 1981). It is therefore recommended that agitator systems designed for cream stirring should impart a gentle shear; typically, a paddle or pitch-blade impeller with rotation of 30-60 rpm have been reported in cream storage units and for mixing and blending cream based products (Fuquay, 2007).

2.4.4 Milk and Whey Concentrates

Dairy concentrates are manufactured by reducing the water content in the feed material by evaporation. Concentration of milk/whey is a commonly employed approach before drying operations for energy management and to ensure desirable powder characteristics (Anandharamakrishnan, 2017). Concentrated milk (sweetened or unsweetened) also find application in dairy processing as an ingredient in various products like ice cream, yoghurt and recombined milk products manufacture and to increase the solid content in dairy formulations (Chandan and Kilara, 2011). Agitation of dairy concentrates are reportedly achieved using pitch bladed agitators or marine propeller impellers at a speed of 200-400 rpm (Fuquay, 2007).

2.4.5 Powder Dispersion

Several milk products such as recombined milk, flavoured milk, yoghurt, dairy spreads, ice cream and dairy desserts require that the powder ingredients such as dairy powders, sugar, salts, stabilizers, emulsifiers, flavourings and other additives are often dispersed at varying concentrations. For effective dispersion, it is recommended that the powder is completely dissolved in the product matrix without any residual lumps or incorporation of air (Loit and Stenderup, 2018). Moreover, stabilizers like gaur gum, CMC and emulsifiers are often difficult to disperse satisfactorily. High-shear mixers are often recommended for these kinds of dispersion of powders. Rotor-stator type high shear mixers are used for the dispersion of these kind of applications and its speed of rotation vary from 10 to 50 m/s (Atiemo-Obeng and Calabrese, 2004; Rodgers and Trinh, 2016).

2.5 Mixing-Agitator Design for Dairy Products Processing

The process flow path in dairy processing includes varied applications of agitation and mixing where the degree of agitation is specific to each operation, necessary to obtain the desired result. Generally, all mixing systems are composed of three main components i.e., the drive assembly, a shaft and an impeller. However, the flow pattern set up in the product matrix and the effect of agitation achieved is primarily dependent upon the impeller design, number of blades, impeller blade angle, pumping direction and interaction of flow with the vessel wall (Kumaresan and Joshi, 2006). Hence, numerous designs of impellers have been reported and it is well established that one single design option cannot provide the optimum performance under the different process requirements in the manufacture of dairy products (Anon., 2017b). The common designs reported in literature involved in dairy products processing are summarized below.

2.5.1 Propeller Agitator

The agitator systems employed in dairy processing is classified on the basis of viscosity of the product. For low viscosity product processing having viscosity less than 100 cP, the most widely reported design includes propeller agitators. These are described as high-speed impellers which can operate in the range of 400-1750 rpm with a small agitator to tank diameter ratio of 0.2-0.3. The propeller is known to create an axial flow pattern that produce better mixing and good top to bottom agitation resulting in better particles suspension (Cronin and Fitzpatrick, 2011).

2.5.2 Turbine Agitator

Another design reported for applications related to low viscosity liquids are turbine agitators. These impellers have vessel to diameter ratio in between 0.2-0.5 (Hemrajani and Tatterson, 2004). The turbine agitator basically consists of a flat-blade design; the most commonly reported design being the disc-mounted six flat bladed impellers (Rushton turbine), that is commonly reported in fermenters (Shah, 2017). In the dairy industry, pitch-bladed turbines with a blade angle less than 90^{o} are often used applications such as yoghurt manufacture and lactose crystallization (Cronin and Fitzpatrick, 2011).

2.5.3 Paddle Agitator

To agitate medium viscosity liquids in the range of 50-1000 cP at low speed, typically in the range of 10-150 rpm in the dairy industry, paddle agitators with a larger impeller to tank diameter ratio in between 0.5 to 1 has been reported (Cronin and Fitzpatrick, 2011). They produce radial flow pattern which moves the contents of mixing tank to the sides of the vessel and used for dispersion of gases (Gooch, 2007).

2.5.4 High-Shear Agitator

High-shear mixers (HSM) are agitation systems that rotate at very high speeds in the range from 10000-20000 rpm. The mixers are often employed to break down particles, in applications such as in powder dispersion or emulsion formation. In fact, high-shear mixers are recommended as an excellent choice for emulsion making processes (O'Sullivan *et al*., 2018). The breakdown action requires the necessary creation of high shear force and its dissipation as surface energy. They produce intensive localized dissipation of energy near the mixing head. HSM units are therefore reported to consume much power than its counterpart i.e., conventional mechanically stirred vessels. HSMs have been applied mainly in energy exhaustive processes such as dispersion, homogenization, grinding, cell disruption, emulsification and dissolving in various food-manufacturing applications (Zhang *et al*., 2012).

Among the high shear impeller designs, saw tooth blades (Cowels impeller) that utilizes high speed single blade rotating impeller for effective dispersion, dissolution and de-agglomeration of materials has been widely employed in the process industry. The materials flow outward from the annular space (vanes) of the impeller at extremely high speed, impinges on the surrounding slower moving portion, creating intense hydraulic shear. The high shear mixing units are envisaged to handle very high viscosity product (> 50,000 cP) (Zhang, 2012).

Applications of HSMs in dairy and food industry have been reported by various authors. The mixing effect of high shear processing on cheese curd at different impeller speeds (750, 1500, and 3000 rpm) and times (2 and 4 min) was compared with conventional homogenization at different pressures (0, 25, 100 MPa) with respect to its effect on the texture of medium-fat cream cheese. It was observed that homogenization reduced the fat globules size and resulted in firm texture. Increasing the impeller speed and time of mixing resulted in a decrease size of curd particle with an increase in the cheese spreadibility (Ningtyas *et al*., 2018). O'Sullivan *et al*. (2018) reported on the preparation of fat-filled milk emulsions using high-shear mixing. Kowalski *et al*. (2011) discussed the application of high-speed mixers as multifunctional processing units for dissolving, dispersing, blending, emulsifying, mixing, stirring and de-agglomerating in food processing applications.

Scholz and Keck (2015) evaluated the properties of nanoemulsions and deduced that high speed mixing was more effective than high pressure homogenizers due to the limited size distribution and smaller particle size produced in the latter. Recent literature reports indicate the adoption of ultra-high shear mixers as an effective alternate to high pressure homogenizers. The disadvantages listed for homogenization include requirement for multiple passes of fluid, and high operating and maintenance costs, while ultra-high shear mixers are credited with increased process efficiency and improved overall throughput (Anon., 2019b).

2.5.5 High-Viscosity Agitator

High viscosity liquids (up to 100000 cP) are stirred using helical-ribbon type agitators and anchor impellers (Cronin and Fitzpatrick, 2011). These impellers sweep the whole wall surface of the tank and physically agitate most of the fluid batch. As a result, they can be used at much lower Reynolds number ($N_{Re} \leq 400$) (Bakker and Gates, 1995). High viscosity agitator are used in processing of high viscosity creams, purees and slurries, smoothies and beverages, etc.

2.6 Agitation/Mixing in Indigenous Dairy Products

Several attempts have been reported in the application of mixing and scraped surface equipment in the mechanization of unit operations for the preparation of indigenous dairy products. Each equipment is designed keeping in mind the specific requirement of the process/product and sometimes is custom designed to meet the needs of a specific product only.

The design and application of scraped surface heat exchangers for the heat desiccation of milk to *khoa* has been extensively reported by Dodeja *et al*. (1992). The design primarily consists of multi stage units of steam jacketed cylinders fitted with specially designed scraper blades that rotate within the cylindrical product space at low to medium rpm.

Patel (1985) reported on the use of a planetary mixer for the mixing of sugar with *chakka* for manufacturing *Shrikhand*. The process parameters were optimized as a shaft speed of 30-40 rpm and mixing time 30 min.

Khojare and Kumar (2003) used a Conical Process Vat (CPV) to prepare *burfi* from *khoa* using standardized process parameters. The CPV was equipped with a backward rake impeller operated at a shaft speed of 50-85 rpm and the time required for processing was reported to be 10-15 min.

Karunanithy (2007a, b, c), developed a kneader for mixing the *channa* dough required for ball making during *rasogolla* preparation. The equipment consisted of a kneading chamber fitted with a feed hopper and product outlet supported by a mechanical drive consisting of a rotor, reduction gearbox and motor.

Kumar and Das (2003) evaluated mechanized production of *sandesh* from cow milk and optimized the processing parameters viz. kneading and cooking of *chhana* and mixing of sugar mixture. Authors developed an extruder unit consisting of a single-vented -screw for cooking of *chhana* and sugar mixture.

A brief summary on the technical details of unit operations, dairy products ingredients and machine-product parameters reported is presented in Table 2.2.

2.7 Design Consideration for Mixing Equipment

The design of mixing/blending equipment is based on the mechanical and process requirements. Even though the process requirement remains an overriding influence on the design considerations, adequate mechanical design is also essential for efficient operation of the unit. Further, process requirements including the process environment, frequency and type of product directly impact mechanical design (Paul *et al*., 2004). The main design considerations to be taken into account for mixing vessels and equipment are discussed below.

2.7.1 Process Vessel

The process vessel is the tank wherein the actual operation was affected and therefore it is a very important factor in the design of a successful mixing system. Food industry does not prescribe any standard geometry and tanks of vertical/horizontal configuration; short or tall and cylindrical, square or rectangular geometry with flat, dished or conical base have been reported as the process vessel/mixing tank (Nienow *et al*., 1997).

Table 2.2: Technical details of unit operations, dairy products ingredients and machine-product parameters

Dairy Product	Ingredients	Unit operation	Type of device	Shaft Speed (RPM)	Process time (min)	Reference
Rasogolla	Channa, Maida, Additives	Kneading	Planetory Mixer	35-40	5-10	Karunanithy (2007a, b, c)
Sandesh	Channa, Sugar	Kneading	Planetory Mixer	60	5	Kumar & Das (2003)
Shrikhand	Chakka, Sugar	Mixing	Planetory Mixer	30-40	30	Patel (1985)
Burfi	Khoa, Sugar	Mixing	Backward Rake Impeller	50-85	10-15	Khojre and Kumar (2003)
	Khoa, Sugar, Cardamom	Mixing	Conical Process vat with anchor, turbine and helical spiral agitator	50	5-15 min	Gupta (2003)
Pedha	Khoa, Sugar	Mixing	Backward Rake Impeller	110-120	10-15	Narwade (2007)
Stirred Yoghurt		Stirring	Agitator with paddles	20-60		Fuquay *et al.* (2007)
Cream		Agitation	Pitch-blade/paddle impeller	30-60		Fuquay *et al.* (2007)
Powder dispersion	Water, powder	Dispersion	High shear			Fuquay *et al.* (2007)
Processed cheese	Cheese, emulsifier, stabilizer, additives	Blending	Anchor type scraped surface agitator	~100		Fuquay *et al.* (2007)

Even though baffles are widely recommended to avoid vortex formation to provide effective mixing (Pyle *et al*., 2012), tanks employed by the dairy industry are generally left un-baffled due to cleaning and hygiene concerns. Typically, to reduce the contamination while simultaneously facilitating the addition of ingredients, a lid with suitable opening is commonly employed in food processing tanks (Cullen, 2009). For small bench units and large industrial installations, vessel diameters may range from 0.1 m and up to 10 m, respectively. Typical ratios followed in the industry for the dimensions of process vessels is presented in Fig 2.2 and summarised in Table 2.3.

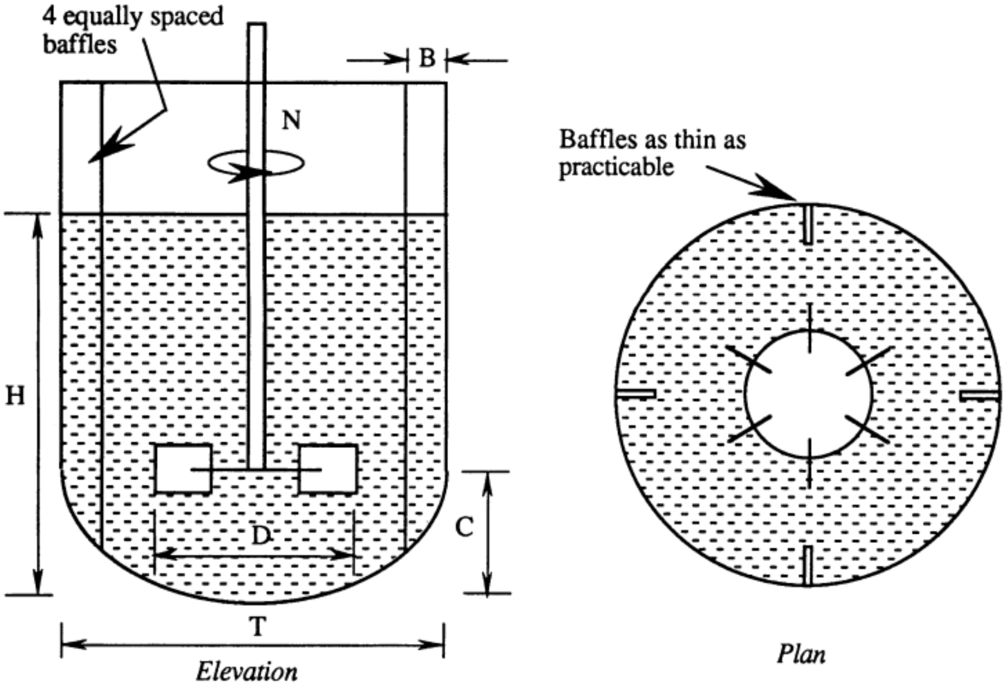


Fig. 2.2: Typical geometric consideration for agitated vessel

(Pyle *et al*., 2012)

2.7.2 Liquid Level in the Tank

As thumb rule, in most mixing applications, the ideal liquid level to tank diameter ratio is recommended as 0.8; ratios > 0.8 are reported to adversely impact proper axial mixing (Pyle *et al.*, 2012). In general, depending on the operation and type of product involved, ratios of

1.0 to 1.4 are widely adopted (Uhl and Essen, 1986). When the ratio exceeds 1.4, multiple impellers are suggested for effective performance.

Table 2.3: **Standard geometric ratios for stirred tanks** (Pyle *et al.*, 2012)

Geometric ratio	Typical range of values	Standard geometry
$\frac{H}{T}$	1-3	1
$\frac{D}{T}$	$\frac{1}{4}-\frac{2}{3}$	$\frac{1}{3}$
$\frac{C}{T}$	$\frac{1}{4}-\frac{1}{2}$	$\frac{1}{3}$
$\frac{C}{D}$	~1	1
$\frac{B}{T}$	$\frac{1}{12}-\frac{1}{10}$	$\frac{1}{10}$

H-Height of the liquid in tank, T-Diameter of the tank, D-Diameter of impeller, C-distance of the impeller from the bottom of the tank, B-Width of baffle

2.7.3 Baffles

Swirling or vortex formation is a common problem reported during processing of low-viscosity liquids in a vertical cylindrical tank with a centrally mounted impeller that diminishes mixing effectiveness significantly (Dickey, 2004). One of the commonly employed strategies to offset this problem is by employing baffles, described as thin vertical strips fitted to the walls of the vessel to prevent vortexing (Nienow *et al.*, 1997). Cullen (2009) stated that the use of baffles is more important in cylindrical tanks, since the flow regime in rectangular tanks can be treated as self-baffling. An important criterion in the effectiveness of baffling is its positioning within the tank. It is widely recommended that baffles sized to a width of 1/10th to 1/12th of the tank diameter should be mounted at 1/72th of the tank diameter off the wall of the tank. The standard practice is to employ four baffles at orthogonal axes and three baffles have also been reported to give satisfactory performance. To prevent solid build-up at stagnant points within the tank, it is suggested that the length of baffles should match the height of the tank, with a marginal space left at the bottom of the tank (Anon., 2019a).

2.7.4 Impellers

In addition to the standard considerations such as the flow regime developed and liquid height to tank diameter ratio that guide impeller selection (Machado and Kresta, 2015), for application in the food industry, more complex concerns related to the requirement to handle different process conditions such as viscosity changes or batch levels and ease of cleaning also become important (Cullen, 2009). Thus, specific process requirements are the overriding factors guiding the selection of impeller for intended applications (Nienow *et al*., 1997).

Irrespective of the design, an impeller is constructed as characteristic blades attached to a central hub that is spun using a driver shaft, the action results in movement of material to be mixed (Paul *et al*., 2004). Thus, the flow of energy through the system involves conversion of the line electrical energy through the motor and drive shaft to mechanical energy dissipated through the impeller to the food material setting up fluid motion in either axial, radial or mixed patterns, and/or power delivered for creation of new surfaces for break down and dispersion of ingredients and gas bubbles; impeller converts electrical energy into fluid motion (Hemrajani and Tatterson, 2004). Common impeller designs reported in food applications include propellers, anchors, turbines, helical ribbons, paddles, helical screws; small-diameter impellers at moderate power input are capable to generate flow in all parts of the tank in low-viscosity liquids (Pyle *et al*., 2012).

Table 2.4: Flow regimes generated by common impeller designs

Flow type	**Impeller Designs**
Radial	Flat Paddle, Disc Turbine
Axial	Marine Propeller
Radial and Axial mixed flow	Pitched Blade Turbine, Hydrofoil

For highly viscous products, the choice of impellers employed include anchors, screw and helical ribbon impeller; effective mixing is achieved in such products due to their close clearance between the wall and the blades that sweep through large volume of tanks (Ameur *et al*., 2018). A guidance chart for selection of impellers for various product viscosities is presented in Fig. 2.3.

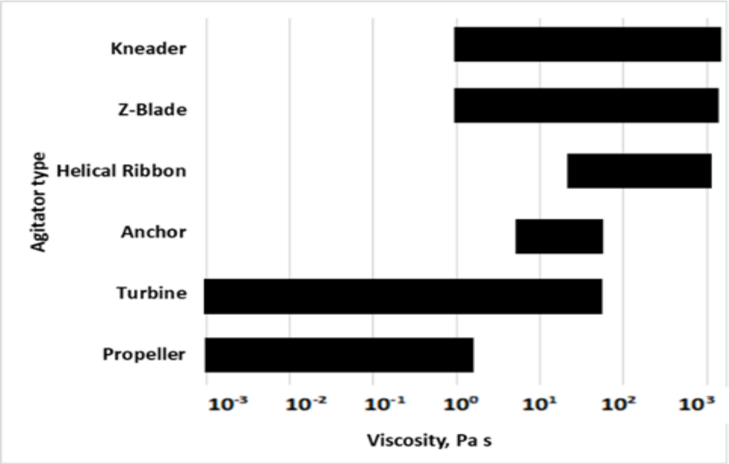
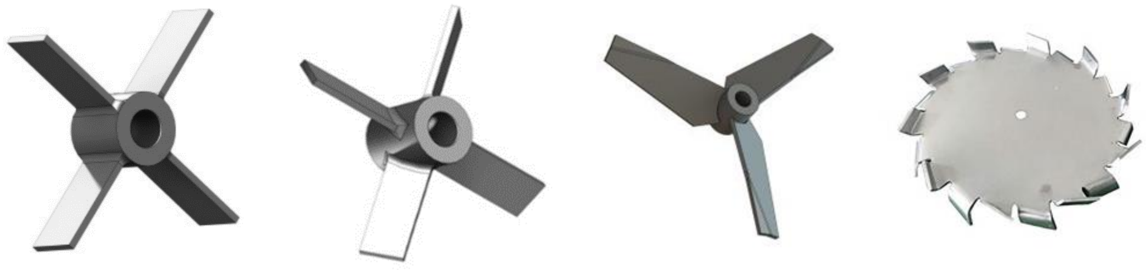


Fig. 2.3: Mixer selection chart for fluid processing

(Pyle *et al*.,2012)

2.7.4.1 Straight Blade Impeller

This impeller design (Fig 2.4a), which constitutes of 2, 4 or 6 straight blades projecting from the central hub, produce radial flow with the thrust generated during mixing, projecting the mixture in the process vessel straight out towards the walls of the container (Loeschen, 2019). Straight blades are best suited for intense mixing such as dispersion and emulsion, but not preferred for solid suspension.



a: Straight Blade impeller

b: Pitched blade impeller

c: Hydrofoil impeller

d: High shear impeller

Fig. 2.4: Common impeller designs employed in food processing

2.7.4.2 Pitched Blade Impeller

Pitched-blade turbine impeller (Fig. 2.4b) is one of the most common and versatile mixing impellers. These impellers have four blades and mounted at 45^{o} angle with the width of blade sized to about one-fifth of the impeller diameter (Lee, 2006). The impeller pumps the fluid in downward motion which requires clockwise rotation (Cullen, 2009). The blades are reportedly easy to manufacture and are found to be effective for a wide range of mixing applications.

2.7.4.3 Hydrofoil Impeller

Hydrofoil impeller (Fig. 2.4c) are typically constructed with its blades mounted almost parallel with the bottom of the tank such that the rotation of the impeller tends to push the mixture downward. However, due to the steep angle of impeller, their usefulness for high viscosity mixing and dispersion is found to be limited (Loeschen, 2019). Hydrofoil impellers are found effective for the bulk blending of liquids and the suspension of solids in liquids due to a low power number and the strong axial flow that result in a motion across the bottom of the tank and good circulation and top to bottom mixing (Cullen, 2009).

2.7.4.4 High Shear Impeller (HSI)

A high shear producing saw-tooth impeller (Fig. 2.4d) consists of a disk with serrations around its circumference and is known to create a reasonably high intensity of turbulence in the vicinity of impeller. HSI are operated at high speeds and are used for the addition of a second phase in dispersing pigments, grinding and making emulsions. These dispersing impellers are low pumping and therefore are often used along with axial flow impellers for providing both high shear and homogenous distribution (Paul *et al*., 2004).

2.7.4.5 Anchor Impeller

Anchor impeller are intended for high viscosity applications (5,000-50,000 cP). Its rotation provides radial flow and improved heat transfer (Shastri and Borkar, 2015). It reduces the heat transfer fouling with optional wall scrapers (Frank, 2004). It is reported that processing industries prefer anchor impellers for mixing of viscous and polymer solution (Hoyt and Sellin, 2005).

2.7.5 Mixer Shaft

The mixer shaft in food applications is often top mounted and houses the impeller at one end and functions for the transmission of mechanical energy from the motor to the impeller blades. Thus, in addition to providing necessary support to the impeller assembly, the shaft is also subjected to axial and bending stress due to the loads and torque it is subjected to while in operation (Dickey and Fasano, 2004). Therefore, sufficient mechanical strength is the first design criterion for a mixer shaft, dictating the shaft diameter, and the stresses (bending moment, torque and shear stress) in the shaft are designed to be kept well below the yield point to avoid fatigue failure and shaft bend (Paul *et al*., 2004).

The maximum torque on the mixer shaft is calculated as follows.

$$\tau = \frac{P}{2\pi N} \qquad \text{…(2.1)}$$

Where,

τ = torque, Nm
P= motor power, W
N= rotational speed, rpm

In addition to the mechanical strength, other overriding factors taken in to consideration for the mixer shaft, include sanitary and economic considerations regarding the material of construction. The length of the shaft is defined by the size of the mixing blade. The general recommendation stipulates that the shaft should be long enough so that the blade is immersed beneath surface of the mixture by a factor equal to twice the diameter of the impeller (Loeschen, 2019). On the other hand, a too short shaft is prone to cause vortexing in the mix.

2.7.6 Motor Selection

Electric motors are the most common choice for motive force for mixing equipment, primarily specified in terms of power and speed (RPM) and available in different capacities. Air and hydraulic motors are used for some applications where chance of ignition is a major problem (Dickey and Fasano, 2004). Electric motors can be classified based on size, power source, enclosure and application (Paul *et al*., 2004).

2.7.7 Tanks and Mixer Supports

The support structure is an integral part of the mechanical design process. The design of the support is based on the three primary loads viz., vertical loads, (equipment weight and pressure forces), torque and bending moment. Dynamic loads can cause disturbing of the mixer and support structure (Paul *et al*., 2004). To improve the stability of mixer in operation, it is recommended that enough support stiffness should be provided while designing the system (Cullen, 2009).

2.7.8 Other Mechanical Design Considerations

Other components of the mixing unit include properly designed speed reduction gears, antifriction bearings and mechanical seals. The selection of the gear reducer must ensure adequate reduction from the motor speed so as to minimize power, torque and bending. The output shaft and bearings for the drive must be sufficient to handle the torque (Loeschen, 2019). Further, blade thickness for impeller must consider bending load calculations.

2.8 Mixing Effectiveness

Mixing effectiveness is usually quantified in terms of mixing time, defined as the time required from the start of blending operation to the time when specific degree of uniformity in the concentration is achieved. Nienow *et al*. (1997) defined mixing time as the time required for achieving a certain degree of homogeneity for a tracer introduced in a stirred vessel. Mixing time is also reported as a measure of analyzing the performance and the flow behavior of a stirred vessel. Two types of mixing times are quoted; the bulk mixing time, reported widely for macro-mixed systems, is defined as the time required to get all points in the vessel uniformly distributed, while the local mixing time is described as the measure of the quickness with which a component is dispersed in a specific region within the vessel and is more influenced by local turbulence (Ascanio, 2015).

Following are the techniques that are widely used in determination of mixing time by various researchers:

2.8.1 Colorimetry

Colorimetry is the most common technique employed for measuring mixing times in stirred vessels (Kraume and Zehner, 2001). It is a non-intrusive technique used to quantify the mixing time and also aids in visualizing the flow patterns (Lamberto *et al.*, 1996; Ascanio *et al.*, 2004; Ascanio *et al.*, 2002; Alvarez *et al.*, 2002). The methodology usually involves the injection of a coloured liquid tracer followed by recording and observation of the flow of the tracer in the fluid contained in stirred vessel.

Hoogendoorn and Hartog (1967) measured the mixing time for several impellers designs including anchor, inclined blade paddles, helical screw, helical ribbon and flat blade turbine using a discoloration technique and found that the turbine and anchor mixers were unsatisfactory for viscous mixing. In spite of this observation, anchor impellers are popularly employed in food, paint, cosmetic and pharmaceutical industries (Nagata *et al*., 1975; Kaminoyama *et al*., 1990).

Norwood and Metzner (1960) was amongst the early reports on the use of an acid-base neutralization reaction, which was a variant of the colorimetric technique by using the colour indicator for pH change, as a means for measuring mixing time in baffled stirred tanks. Hari-Prajitno *et al*. (1998) applied the acid-base neutralization technique for measuring mixing time for dual and triple coaxial impeller configurations in the turbulent regime. Other reports have also indicated this method as a standard technique for monitoring mixing time (Hirata and Ito, 1988; Pandit *et al.*, 1989; Takahashi *et al.*,1994, 2006, 2012; Wang and Zhong, 1996; Espinosa-Solares *et al.*, 2001; Foucault *et al.*, 2006; Iranshahi *et al.*, 2007; Aizawa *et al.*, 2009)

Fradette *et al.* (2007) applied image analysis technique to study mixing and record mixing time. Video grabs of a colour change process during mixing were captured and the image was suitably processed for data interpretation by means of a threshold value each for the Red, Green and Blue (RGB) components in the mix.

2.8.2 Electrical Resistance Tomography

Electrical Resistance Tomography (ERT) is reported as a non-intrusive and non-invasive technique which uses electrical resistance to determine mixing time. The technique is recommended for continuous phases that are conductive intermixed with other phases having different values of conductivity. The setup generally consists of electrodes, the data acquisition system (DAS) and a user interface (ITS, 2017). The electrodes are connected in series around the circumference of vessel to avoid disturbance to the flow of liquid. The ERT measurement procedure involves measuring the resultant potential difference between the electrodes.

2.8.3 Planar Laser-Induced Fluorescence

Planar laser-induced fluorescence (PLIF) is described as a non-intrusive Eulerian technique that provides instantaneous mapping of concentration contours in fluid mixes.

Arratia and Muzzio (2004) discussed the application of this technique to map the 3-D concentration of a dye as it traverses in a stirred vessel equipped with three coaxial impellers. Hu *et al*. (2010) extended the PLIF method to study the reactive process in an un-baffled stirred tank by visualizing the process in which two liquids mixed and reacted with each other.

2.8.4 Thermography

Thermographic principle states that when light is incident on liquid crystal, it is selectively scattered and this can form the basis for temperature measurements (Rao and Xu, 2012). Liquid crystal are unique in its molecular structure, rendering it to behave as a crystal between these two phases; a threshold temperature classifies the material in to an amorphous solid form and a pure liquid beyond the upper limit of temperature. Lee *et al*. (1997a) and Lee and Yianneskis (1997b) reported the application of liquid crystal for the measurement of mixing time in a stirred vessel using the thermographic principle.

2.8.5 Conductometry and pH

Mapping of electrical conductivity and pH is widely applied as a technique for determination of mixing time in various mixing experiments. The general methodology involves the placement of respective probes for conductivity and pH at different points in the stirred vessel and measurement of the electrical conductivity of the mixer solution is recorded over the time. The conductivity values thus obtained are then calibrated and transformed to concentration data versus time. Satisfactory mixing is deemed to be achieved if the concentration index, calculated using the following expression reached the pre-set threshold value (~ 10% of the final concentration).

$$C_i = \frac{C_{(t)} - C_{(0)}}{C_{(\infty)} - C_{(0)}} \qquad \ldots(2.2)$$

Where,

$C_{(0)}$=initial tracer concentration, %
$C_{(\infty)}$ =final tracer concentration, %
$C_{(t)}$ =tracer concentration at a certain time, %

Nagata (1975) discussed a method based on local measurements of pH for the determination of mixing times in stirred vessels. Poulsen and Iversen (1997) devised a system based on the signal of two pH sensors placed in the bottom and top a stirred reactor to calculate the mixing time.

2.9 Power Consumption in Mixing Equipment

The performance of mixing equipment is often adjudged by the following indicators, mixing time required to achieve desired degree of homogeneity or any other process objective, the power consumed and the uniformity attained in mixed product (Das, 2008). The amount of power drawn is a paramount variable in chemical and bioprocess systems and is defined as the amount of energy required over a specific duration in order to create necessary mobility of the fluid particle within a container using either mechanical or pneumatic agitation (Ascanio *et al*., 2004).

Mixing is a power intensive operation and obviously the overall economics of the process is significantly influenced by the amount of power drawn during mixing; thus, it is important to regulate energy expenses improving the efficiency of the mixing system (Bader, 1987). The amount of energy drawn and delivered also influence the flow profile, circulation time and heat and mass transfer during the mixing process and become an important consideration in process design and scale up (Charles, 1985).

Various techniques, based on the principles of calorimeters, wattmeter, ammeters, dynamometers, torque meters and strain gauges have been developed and reported to measure the power draw of fluid during agitation (Ascanio *et al*., 2004) and are briefly reviewed below.

2.9.1 Electrical Measurements

Electric motors with associated gearbox and seals remain the main stay of mechanical drive for mixing units and the measurement of the electrical power drawn using watt meters and ammeters is the conventional approach to record the power consumed in mixing equipment (Brown, 1977). Motors operating on either direct or alternating current have been reported and depending on the type of motor, the power is computed. In case of DC motors, the energy is calculated as a product of the supplied voltage and the current intensity.

2.9.2 Calorimetric Measurements

Calorimetric measurements involve the computation of energy consumed as a function of temperature differences and is monitored using a series of thermistors placed in the vessel.

The number and position of thermistors is a consideration affecting the computation. Multiple thermistors are engaged and the average of the temperatures registered by thermistors is considered as process temperature at any time. Usually, the losses due to friction in bearings and other mechanical devices is neglected in the method (Ascanio *et al*., 2004).

Oosterhuis and Kossen (1981) applied the calorimetric approach to calculate the power consumed to produce the fluid movement using an energy balance. The power was calculated using following equation:

$$P = V\rho C_p \frac{dT}{dt} \tag{2.3}$$

Where,

P= power, W
V is the bioreactor volume,
ρ is the fluid density
Cp is the specific heat ($kJkg^{-1}K^{-1}$)
dT is the variation on temperature (K)
dt is the time increment.

Bourne *et al*. (1981a, b, c) reported a calorimetric technique involving the measurement of the temperature difference between the bulk liquid and the jacket wall as a function of time using a heat flow calorimeter. The power used to cause liquid mixing was obtained assuming that the power dissipated by the agitator was entirely used for heating the fluid within the vessel.

2.9.3 Dynamometers

Dynamometers work on the principle of the Newton's third law (Holland and Chapman, 1966). The system for power measurement in mixing assemblies using this method is based on the assumption that the mechanical force of agitator is equivalent to the resistance of the liquid contained in the tank, which in turn produces the torque upon the impeller and is transmitted to the motor through the shaft. This torque results in the free rotation of the process vessel in same direction of that of the impeller, which is recorded as transmitted force to a calibrated platform through a mechanical coupling (Brown, 1977). From these measurements, the power draw is computed using the relation

$$P = FB\omega \tag{2.4}$$

Where,

P is the power draw, W
F is the force applied, N
B is the lever arm, m
ω is the angular velocity, s^{-1}

The angular velocity is:

$$\omega = 2\pi N \tag{2.5}$$

where N is the stirring speed (s^{-1}).

2.9.4 Torque Meters

Torque meters are versatile instruments popularly used in the industry and research laboratories to monitor force, velocity, torque, pressure, flow and weight in a system (Himmelstein, 1994) and can be employed to monitor power consumption in mixing systems. Serrano and Galindo (1997) used torque meters to quantify the mixing in high viscosity fluids achieved by a number of impellers configurations. Similarly, other authors reported the use of torque meters to measure the total power input to the fluid by the agitation system (Shamlou and Edwards, 1985; Smith, 1987; Bohme and Stenger, 1988; Abrardi, 1990).

2.9.5 Strain Gauges

Strain gauges have been employed for quantifying power drawn in a multi-impeller model (Brown, 1977). The working principle involves the measurement of the strain on the shaft under a known stress by installing the strain gauge on the agitator shaft. Kuboi and Nienow (1982) reported the first use of strain gauges to measure the power drawn in systems with two impellers; the power drawn by the composite impeller unit and single impeller in isolation were conducted and a detailed description of the measurement system is presented in Kuboi *et al*. (1983).

2.10 Overview of Dairy Products Selected for Evaluation

2.10.1 *Lassi*

In India, about 7 per cent of the total annual milk production is utilized for making *dahi* for direct consumption (Rasane and Singh, 2017). Traditional fermented products such as *dahi*, *lassi*, buttermilk, etc. occupy an important place in the diet of an Indian as it serves as an important source of protein. These fermented milks have persisted over centuries and their scale of production range from domestic level small scale to industrial large-scale production. Fermented milks are popular because of great organoleptic properties such as the characteristic flavour, refreshing taste and therapeutic benefits like easy digestibility and supplementation of gut microflora. Process technology of fermented dairy products involves the use of suitable starter cultures; recent process interventions include the adoption of automatic processes and modern equipment.

Lassi is among the very important and most popular fermented milk products that finds its origin in the Indian subcontinent (Mathur, 1991). *Lassi* (in its sweet or salty variant) is described as a cultured milk and characterized as a refreshing, delicious and nutritious, thirst-quenching beverage with a creamy consistency, sweetish rich aroma and mild to acidic flavor, and often associated with beneficial value to the consumer. Aneja *et al*. (2003) described *lassi* as the ultimate probiotic; a natural means of promoting the proper intestinal flora. Technologically, it is defined as a bacterial fermented milk beverage, prepared from heat treated milk followed by sweetening with sugar.

2.10.1.1 Effect of Process Conditions on *Lassi*

De (1980) described the procedure for preparation of *lassi*. Pasteurized skim milk containing 9-10 per cent solids was cooled and added with 1 per cent *dahi* starter culture followed by incubation at 20-21 °C, until the acidity reached a value of 0.80 to 0.85% LA. The fermented curd was then broken up and mixed to a uniform consistency with required amount of water, sugar and flavour. The final product was reported to consist of 0.8 per cent fat, 3.8 per cent total solids, 1.3 per cent protein, 1.2 per cent lactose, 0.4 per cent ash and o.44 per cent lactic acid.

Gupta *et al*. (1983) also detailed a similar procedure for preparation of *lassi*. The curd was broken with agitator and required amount of water, sugar, salt and flavouring agent were added. The authors described that the finished product could be sipped with a straw from bottles and consisted of 14 to 16 per cent SNF, 3.5 to 4.0 per cent fat and lactic acid of about 0.75 to 0.85.

Bhandari (1985) reported the effect of some processing variables on acidity and flavour development in *lassi*, prepared from skim milk standardized to 9 per cent SNF by a continuous agitation method at a speed of 140 rpm. The results revealed that higher temperature and increased inoculum levels favoured rapid acid development. Satisfactory *lassi* with pleasant acidic flavour was obtained at 20 °C after 12 h of refrigerated storage. The experimental samples reported 5 and 18 per cent whey separation in *lassi* prepared at 22 ^{o}C and 30 ^{o}C, respectively, while no whey separation occurred in control sample of unbroken curd.

Mathur (1991) reported that the *lassi* can be prepared by stirring *dahi* with the addition of 10 to 20 per cent water and desired level of sugar and salt. Homogenization of the product was suggested to improve its body and texture.

Aneja (1994) upgraded the conventional process for *lassi* preparation using a multipurpose vat. Milk standardized to 3.8 per cent fat and 9 per cent SNF was subjected to pasteurization, homogenization and inoculated with 1 per cent *dahi* culture before incubation at 31°C for 10-12 h. The bulk product mix of 2200 kg *dahi*, 300 kg sugar and 100 L water were mixed mechanically in the vat and the obtained *lassi* was ultra-high temperature processed at 120 °C, cooled and packed aseptically in 200 mL cartons and stored for extended periods at room temperature.

Chandan and Hedric (1983) stated that *lassi* could be prepared from the set curd stirred using a mechanical agitator and adding required amount of sugar, water, salt and flavourings. It was further recommended that fruit juice, along with sugar and salt at 50 ^{o}C could be gently incorporated in preferred amounts. Gupta and Kulkarni (1983) also discussed mechanical agitation for breaking the curd for preparation of *lassi*.

2.10.2 Cheese Spread

In India, cheese and cheese-based products are gaining popularity because of changing food habits and life styles of people (Guinee *et al*., 2004). Cheese is a unique dairy product in the sense that the product undergoes several processing stages before reaching the consumer. The readily controllable quality characteristics, versatility and relatively good keeping quality of cheese contributes to its wide acceptability (Caric *et al*., 1985).

Cheese spread, is the fastest growing segment among cheese-based product in India. Processed cheese spread is produced by comminuting and mixing natural cheese of different ages and degree of maturity into a homogenous plastic mass, in presence of one or more of the permissible emulsifiers (IS: 2785, 1964) and other dairy and non-dairy ingredient. It is then heated and mixed continuously to form a product with prolonged shelf life (Hladka *et al*., 2014). The main ingredients of processed cheese spread are fat, milk protein, water, emulsifiers, stabilizer and salt; each ingredient contributes to the characterized physical behavior to the final product (Lee and Klostermeyer, 2001). The emulsifiers such as tri-sodium citrate, sodium phosphate, or potassium tartrate reduce the tendency for tiny fat globules in the cheese to coalesce and pool on the surface of the molten cheese (Dalaly, 1967). Cheese spread has manifold advantages over traditional cheese including prolonged shelf life, resistance to separation when cooked and economic advantages of value addition.

2.10.2.1 Effect of Processing Conditions on Cheese Spread

Both cooking temperature and mixing conditions affect the functional properties of process cheese spread. It has been observed that fat globule size distribution is influenced by the mixing speed and temperature during manufacture (Rayan *et al*.,1980; Glenn *et al*., 2003; Lee *et al*., 2003). When cooking time and temperature is held constant, high mixing speed results in a large number of small, evenly distributed fat globules, as compared with a low mixing speed (Lee *et al*., 2003). During the cooling of processed cheese after manufacture, these small and homogenous fat globules further strengthen the protein matrix by acting as fillers (Aguilera and Kessler, 1989; Fox *et al*., 2000).

However, increasing the mixing speed beyond certain limits is expected to enhance fat and protein interactions to an extent that the casein molecules coagulate into a "pudding-like" state. This phenomenon is generally referred to as "over creaming" and is indicated by an increase in mean viscosity and reduction in meltability (Berger *et al*., 1998).

Swenson *et al*. (2000) reported that increase in cooking time resulted in softer and more meltable cheeses, and vice versa. Glenn *et al*. (2003) demonstrated that processed cheese formulated with 75 per cent young Cheddar cheese and 14 per cent medium Cheddar cheese showed a reduction in melt characteristics of the processed cheese when the mixing speed was increased from 50 to 150 rpm at constant temperature.

2.10.3 Recombined Milk

As per FSSAI, recombined milk refers to the homogenised product prepared from milk fat, non-fat milk solids and water; added and mixed and homogenized well to achieve the desired fat and total solids content. The recombined milk may be pasteurised to show negative phosphatase test. Stabilizers and emulsifiers are sometime added to facilitate emulsification of the fat and to improve storage stability (Tetrapak, 2015).

Recombined milk is used as an alternate when access to fresh domestic milk is limited due to production and/or transportation issues. Blending of recombined milk with fresh milk is also reported to meet occasional and seasonal shortages of fresh milk (Shew, 1972; Hadland *et al*., 1974; Hammond *et al*., 1979). It has been established that up to 60 per cent recombined milk can be blended into fresh milk without affecting the quality of milk, when the recombined milk is made from low heat skim milk powder and unsalted butter (Sanderson, 1970).

2.10.3.1 Effect of Processing Conditions on Recombined Milk

Milk powder, anhydrous milk fat and potable water are the primary ingredients in recombined milk. The wettability of the milk powder was found to be dependent on the dissolution temperature (Bylund, 1995). It was established that as the temperature increased from 10 to 50 °C, the wettability progressively increased; further increase of temperature from 50 and 100 °C, yielded the opposite effect.

It is recommended that during recombination, milk fat should not be added until the powder hydration period is complete, otherwise this lead to processing problems and impaired product quality. Different systems have been reported for melting of milk fat before its addition and dispersion. Immersion heating at 80 ^{o}C for 2 - 3 h has been reported for canned milk fat, while storage of milk fat containers at 45 - 50 ^{o}C for 24 h or rapid heating through steaming is also reported (Kneifel, 2003). Depending on the mixing equipment, the molten fat is either continuously pumped or added in discrete lots into the mixing vessel. High shear agitation is the commonly recommended method suggested for satisfactory emulsification and stable dispersion of milk fat in recombined milks.

Based on the review, it was concluded that there is no custom designed equipment available which can facilitate multiple functions like mixing, stirring, homogenization, emulsification, dispersion, blending, size reduction, de-agglomeration in dairy product processing operations. Therefore, it was proposed to fabricate a universal disperser which will enable to perform multiple functions in dairy product processing operations.

Materials and Methods

3. MATERIALS AND METHODS

The present work was aimed at development and performance evaluation of Universal Disperser for dairy processing operations that is designed to be versatile in terms of different unit operations viz., heating, cooling, homogenization, mixing, stirring, agitation, emulsification, size reduction and deagglomeration etc. This chapter deals with materials, methods, design and fabrication of module, development techniques, experimental procedures and methodologies employed during research work. Analytical grade chemicals and standard glassware were used for the trials and analysis in this work.

The research work was mainly divided into two components, (i) the development of the mechanical unit and (ii) performance testing of the developed unit including the optimization of process parameters for the selected products.

3.1 Design and Development of Universal Disperser

Various design equations, models and techniques were studied and applied for development of the Universal Disperser. The developed unit was planned with the following components:

1. Heating cum process vessel
2. Low speed motor
3. High speed motor
4. Impellers
5. Support framework and accessories

3.2 Design Consideration of the Various Components of The Universal Disperser

3.2.1 The Process Vessel

The process vessel of the Universal Disperser was designed based on the principles of a batch mode mixing tank with facility for heat exchange through an external jacket. The unit was envisaged as a co-axial concentric cylinder comprising of an inner cylindrical vessel, jacket vessel, insulated outer cylinder and heating elements and controllers. Water was selected as the heating / cooling medium in the jacket space; heated to the desired temperature through a plate heater of suitable specifications placed in the jacket. The regulation of the temperature of the water in the jacket during heating applications would be achieved using suitable thermostatic controls so as to heat the water to the set temperature within range of ±1℃. For cooling applications, externally chilled water could be added in the jacket space.

The various components of process vessel were designed and selected as described below.

3.2.1.1 Design of Inner Cylinder

The dimensions of processing vessel were computed considering a working capacity of 3 L of the product. The standard design ratios practiced for the agitated vessel were taken into consideration while dimensioning the vessel. It was assumed that a free board of 40 per cent would be provided to avoid the spillage during high speed processing, thus 60 per cent of the cylinder volume would be the product volume. The ratio for vessel height: diameter was considered as 1:1. The dimensioning of vessel was calculated using equation (3.1); based on the volume of the cylinder:

$$V = \pi r^2 h \tag{3.1}$$

Where,

V= Volume of process vessel, m^3

r = Radius of vessel, m

h = Height of vessel, m.

The bottom of the inner cylinder vessel was kept slightly dish-shaped to eliminate localized stresses in the cylinder wall and to achieve effective mixing of the product through sanitary principles of design (EHEDG, 1992). For easy and complete draining out of the vessel contents after the processing, an outlet with regulating valve (faucet type) was provided at the centre of the vessel.

3.2.1.2 Design of Jacket Vessel

Taking into consideration the ease of machining and other practical considerations during fabrication, a jacket clearance of 5 cm was assumed. An additional clearance of 3 cm was provided to the height of outer vessel to accommodate outlet for product vessel and its fitting arrangements at the bottom of the vessel. The dimensioning of outer vessel was calculated using equation (3.1):

$$\text{Volume of the outer vessel} = \pi r^2 h$$

The jacket volume was computed as the difference in the volume between the jacket and inner cylinder. It was also seen that the volume was sufficient to accommodate adequate quantity of water for effective transfer during the processing applications intended.

3.2.2 Rating of Heater Coil

The capacity of heater coil was determined by considering total heat load that would be incurred in heating of the product. The heat load was computed as follows by using Eqn. (3.2):

$$Q = mCp\Delta T \tag{3.2}$$

Where,

Q = Heat Load, kJ
m = Mass of water, kg
Cp = Specific of water, kJ/kg℃
ΔT = Temperature difference between initial and set temperature of water
The wattage of heater coil was then calculated as using Eqn. (3.3),

$$Power = \frac{Heatload}{Time} \tag{3.3}$$

3.2.3 Design of Critical Insulation Thickness

Critical thickness of insulation was determined by the following Eqn. (3.4)

$$r_c = \frac{k_i}{h_o} \tag{3.4}$$

Where,

k_i =Thermal conductivity of insulating material, W/m^{2}k

h_o = heat transfer coefficient of outside surface, W/m^{2}K.

3.2.4 Design of Cylindrical Shell Thickness

Cylindrical shell thickness was calculated by using guidelines of para UG-27 of ASME Section VIII, Division 1, 2011 edition code book using Eqn. (3.5).

$$t = \frac{P * R}{2\,SE - 0.6\,P} \tag{3.5}$$

Where,

t = Sheet thickness in corroded condition, m
P = Design pressure, MPa
R = Inside diameter in corroded condition, m
S = Maximum allowable stress at design temperature, MPa
E= Joint Efficiency (fraction)

3.3 Design of Impellers

A thorough review of the unit operations involved in the preparation of the selected dairy products, along with the characteristic flow pattern generated and features of the available designs of impellers was considered. Based on the requirement, three different impellers were selected to facilitate the mixing, dispersion, agitation and other unit operations for the selected products. Dimensioning of each impeller was performed as per standard design practice; the ratio of impeller diameter to vessel diameter was kept between 1/4 to 2/3.

3.3.1 Pitched Blade Impeller

The pitched blade is one of the versatile and most common impeller suitable for axial movement of the product. The pitched blade impeller for the disperser was constructed with four blades and mounted at 45^{o} angle to generate the necessary axial thrust to the fluid being processed. The material of construction was selected as SS316.

3.3.2 Saw Tooth Impeller (High Shear Impeller)

Energy demanding processes such as dispersion, dissolution, homogenization, grinding and emulsification in food processing has seen the adoption of high shear mixers (Zhang *et al*., 2012). In the present study, a saw tooth impeller was selected for energy demanding processes during the preparation of recombined milk and processed cheese spread manufacturing to breakdown the particles into smaller size and to help in formation of stable emulsion. The diameter of the impeller was calculated on the basis of standard geometric equations.

3.3.3 Multivane Churn Impeller

A multivane churn impeller designed on the basis of traditional curd churn and fabricated for churning applications for viscous fluids such as curd. Standard geometric equations and ratios were considered while dimensioning the impeller.

3.4 Motor Selection

Based on the need of unit operations encountered during the processing of different dairy products, it was decided to fit the Universal Disperser with two different motors of varying operation, a low speed motor for processes requiring gentle agitation and a high speed motor to mount the high shear impeller. The horse power of motor was calculated on the basis of power required to mix the production and for applications requiring a higher speed of rotation. Theoretical power requirement was determined by using product properties like viscosity, diameter of impeller, speed of rotation and power number of impeller (Eqn. 3.6). The highest possible values for the parameters that may came across while processing of the product were used in the computation.

$$P= N_p \rho N^3 D^5 \tag{3.6}$$

Where,

P = Impeller power, W

Np= Power number

N = Rotation speed of impeller, rpm

D = Diameter of impeller, m

ρ = Density of product, kg/m^3

3.5 Design of Support Framework

Adequate support was designed in the form of a stand to mount the motor. The stand was designed with a flanged clamp to mount the motor; the easy sliding of the clamp along the vertical rod of the stand was considered to facilitate adjustable height of the mounted motor.

3.6 Preparation of Fabrication Drawing for the Universal Disperser

On the completion of the design calculations and finalization of specification of the required components for the Universal Disperser, fabrication drawings were prepared using AutoCAD software in the form of the different 2-D front view, top view, and cutaway section of the unit and elevated to 3-D sketch of the complete unit as expected post assembly. Once the fabrication drawings were prepared, and the various bought out items required for the designed unit were procured, the fabrication and assembling of Universal Disperser was carried with the assistance of M/s Milk Tech Engineers, Ganganagar, Bengaluru.

3.7 Performance Evaluation of the Developed Mechanical Unit

After the fabrication and assembling of the developed unit, the preliminary testing of the developed unit was carried out using an engineered test fluid. After testing the same, the disperser was evaluated for the preparation of the selected dairy products.

3.8 Testing of the Developed Unit

The Universal Disperser was initially tested with simulant fluid i.e. carboxymethylcellulose (CMC) solution, which is widely used to simulate the test fluids in performance evaluation of mixer (Brown *et al.,* 2004). The advantages listed for this approach include its readily availability, low cost, non-toxicity and easy modification of solution viscosity as well as the relative insensitivity of its viscosity to extrinsic factors such as temperature. Ghannam and Esmail (1997) stated that the rheology of a CMC solution was not greatly affected by minor alterations in the amount of solute that was possible to dissolve. Compatibility for repeat cycle usage and extended shelf life are other factors considered for choosing CMC as a test simulant.

3.8.1. Preparation of CMC Solution

The CMC solution was prepared by adding 2 per cent CMC solution in distilled water, preheated to 40 ^{o}C. Powdered CMC (Brand : HiMedia Pvt Ltd, Mumbai) was slowly added to the water bath with constant stirring. After complete dispersion, the solution was left undisturbed overnight so as to ensure complete hydration of CMC in the water. The pale yellow solution was obtained after the above preparation steps.

The preliminary testing of the disperser performance using CMC solution was carried out as described below.

3.8.2 Acid-Base Decolorization Method

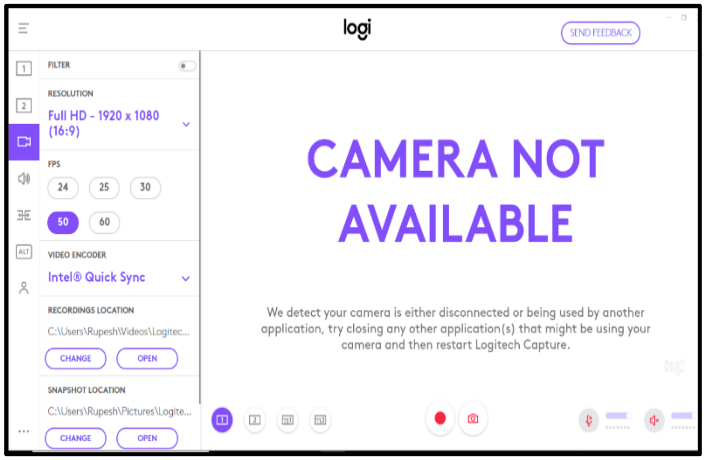
Experimental Method

Mixing effectiveness of the developed disperser was evaluated using the CMC solution as a simulant fluid using the decolorization method suggested by Delaplace *et al.,* (2004) and reported by various authors to determine the performance of mixers and impellers. In this method, sodium hydroxide and hydrochloric acid are used to alter/neutralize the pH of the solution and their neutralization effect is detected using phenolphthalein indicator.

Twenty milliliters of 1N NaOH was taken in a beaker and a few drops of phenolphthalein indicator was added till the solution turned pink in appearance. This alkaline solution was then added to the prepared simulant fluid i.e. CMC solution in a transparent container. The selected impeller (to be tested) attached to the mechanical drive was manually placed inside the container with the simulant fluid and the drive was started. Gradually, the pink colored alkaline solution was observed to completely disperse in the CMC. When the complete simulant fluid was uniformly colorized (ascertained by visual observation), the impeller was stopped.

At this stage, twenty milliliters of 1N HCL was filled in a syringe and carefully introduced at the base of the vessel. The mechanical unit was set to the given rpm before being switched on so that the circulation current ensures gradual dispersion of the introduced HCL within the contents of the container, setting off the neutralization reaction with the NaOH already present in the container. This was visually observed as a gradual disappearance of the pink colour of the CMC solution. When the last trace of the pink hue in the mix was completely decolorized, the machine was switched off.

The whole procedure was recorded using a digital video recorder (Make – Logitech) as depicted in Fig. 3.1 and Fig. 3.2. The video file was imported to the processing software (VirtualDub V. 1.10.4, Avery Lee©) and analysed using a frame – by – frame breakup of the video grab (Fig. 3.3) to objectively locate the precise end point of the neutralization, representing the completion of the mixing process.



RESOLUTION
Full HD - 1920 x 1080 (16:9)

FPS
24 25 30 50 60

VIDEO ENCODER
Intel® Quick Sync

RECORDINGS LOCATION
C:\Users\Rupesh\Videos\Logitec...

SNAPSHOT LOCATION
C:\Users\Rupesh\Pictures\Logite...

CAMERA NOT AVAILABLE

We detect your camera is either disconnected or being used by another application, try closing any other application(s) that might be using your camera and then restart Logitech Capture.

Fig 3.1: Video recording software

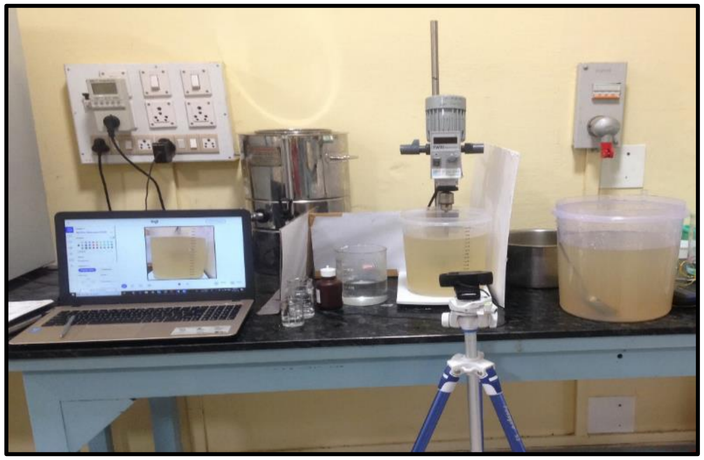


Fig. 3.2: Experimental setup of acid-base decolorization method

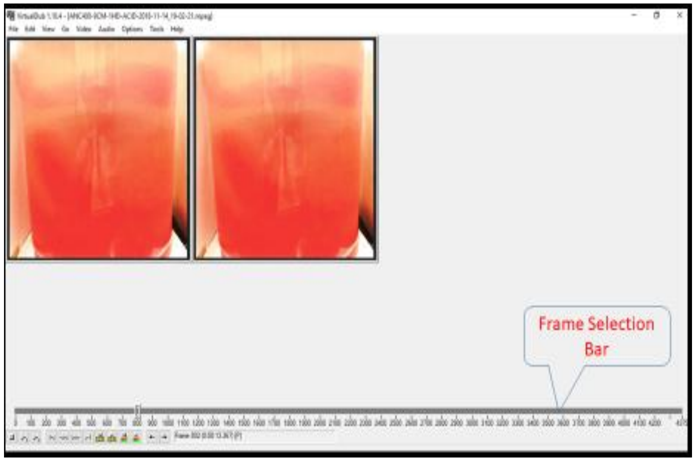


Fig. 3.3: Virtual Dub software

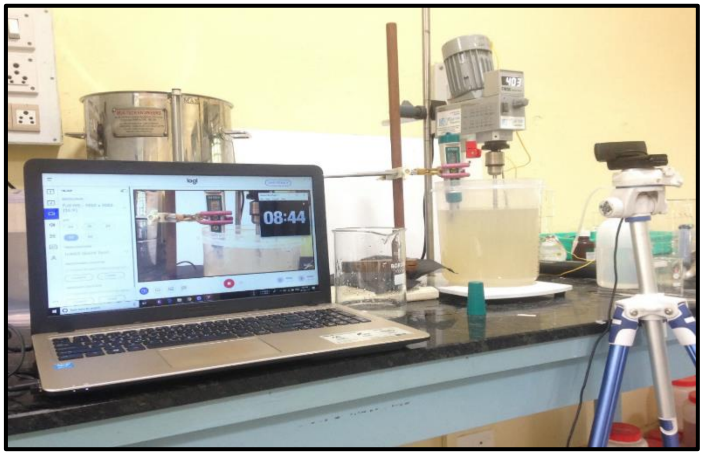


Fig. 3.4: Experimental setup of electrical conductivity method

3.8.3 Electrical Conductivity Method

The use of electrical conductivity as an indicator of mixing performance has been described by Bouwmans *et al.* (1997) and Magelli *et al*. (2013). In this method, a conductivity probe was used as a detector to assess the mixing effectiveness of the unit.

Pre-calculated amount of salt (0.1 per cent, w/w) was added to and mixed thoroughly in a representative sample (20 ml) of the simulant fluid (2% CMC solution). This was then carefully filled into a syringe and introduced at the bottom of vessel. Electrical conductivity meter (Make: ExSTik II, Model: Extech, E.C. range 0-20 ms) was supported by a clamp on a stand (Fig. 3.4) and positioned at the surface (4 cm deep) of the CMC solution to measure the change in electrical conductivity. The impeller of the unit was started at the prefixed speed and other process parameters (Table 3.1). The electrical conductivity was monitored by online recording.

The mixing performance of the three different impellers *viz*., Pitched Blade, Saw Tooth and Multivane churn impeller, at different speeds and placed at varying off-bottom clearance levels were adjudged using the color decolorization method and electrical conductivity method. Thus, the experimental design for this test included 27 runs for 3 types of impellers × 3 impeller speed × 3 levels of off-bottom clearance. The different levels of the process parameters applied for testing the developed disperser using the simulant fluid is tabulated in Table 3.1.

Table 3.1. Process conditions for testing of the disperser using CMC solution

Process Parameter	**Level (s) during testing**
Temperature, ^{o}C	a) 37
Off-bottom clearance, cm	a) 3 b) 6 c) 9
Speed of impeller, rpm	a) 300 b) 400 c) 500
Liquid height, cm	a) 18
Type of impeller	a) Pitched Blade b) Saw Tooth c) Multivane Churn Impeller

3.8.4. Performance Evaluation of the Developed Universal Disperser

Three products viz., *Lassi,* processed cheese spread and recombined milk were selected to evaluate the performance of the Universal Disperser. The above products were selected considering the different unit operations involved in its preparation as well the scope of these products in its adoption by small and medium scale processing units.

3.9 Method of Preparation of *Lassi*

3.9.1 Standardization of Milk

Fresh cow milk was procured from the Experimental Dairy of SRS of ICAR-NDRI, Bengaluru, filtered and standardized to 3.0% fat and 8.5% Solid-Not-Fat for *dahi* making by adding required quantity of skim milk and cream computed using the Pearson square method (De, 1980).

3.9.2 Preparation of Curd

The standardized milk was heated to 85 ^{0}C for 10 min and cooled to 30-37 ^{0}C before inoculation with the *dahi* culture @ 2%. The mix was mixed well to uniformly distribute the culture in the milk. It was then incubated at $37^0 \pm 1^0$C for 12 h and the set *dahi* was transferred to a refrigerator for cooling.

3.9.3 Preparation of *Lassi* in the Universal Disperser

The required quantity of curd was measured into the processing vessel of Universal Disperser. The amount of water to be added was calculated at 25 per cent and sugar was calculated at 12.5 per cent on curd basis and the ingredients were added to the curd in the vessel. The mixture was then stirred at the preset speed for the period of 5 min. Based on preliminary trials, three impeller speeds chosen for *lassi* preparation were 300, 400 and 500 rpm.

3.9.4 Selection of Impeller

Three different impeller designs *viz.*, Pitched blade, Saw tooth high shear and Multivane churn impeller were tested and evaluated for *lassi* making. The pattern of the mixing using each of the selected impeller was mapped by studying the distribution pattern of introduced colour in the mix. A fixed amount of food grade colored dye was introduced at edge of surface of curd in the vessel admixed with required quantity of water and sugar. Then impeller was allowed to rotate at the preset speed. The distribution of the colour within the mix during the trials were recorded using a video camera and video grabs at regular intervals were analysed to understand the mixing patterns generated by each impeller and the impeller with the better mixing pattern was identified and selected for further trials.

3.9.5. Optimization of Process Parameters for Preparation of *Lassi* Using Universal Disperser

Response Surface Methodology (RSM) using Design Expert V. 10.0 was applied to optimize the process parameters for preparation of *Lassi* using Universal Disperser. Two input variables (independent) *viz.*, impeller speed and off-bottom clearance (OBC) (Table 3.2) were identified as parameters to optimize the parameters for *lassi.* The Randomized Face Centered Central Composite Design was used to finalize the experimental run, a total of 13 runs were obtained in the experimental design. Four dependent variables (responses), namely, mixing index, mixing time, power consumption and sensory score were considered for the optimization process.

Table 3.2: Experimental variables for preparation of *Lassi* by Universal Disperser

Factor	Unit	Lower Range	Higher Range
Impeller speed	rpm	300	500
Off-Bottom Clearance	cm	3	9

3.10 Method of Preparation of Processed Cheese Spread

Processed cheese spread was prepared using the Universal Disperser as per the methodology proposed by Giri and Kanawjia (2018) with slight modifications. A blend of cheddar cheese (40 per cent 6 months old Cheddar cheese and 60 per cent 1 ½ month old young cheddar cheese) sourced from the Experimental Dairy Plant of SRS, ICAR-NDRI, Bengaluru was taken as the base material preparation of processed cheese spread. The amount of other ingredients such as water, salt and tri-sodium citrate as emulsifier to be added were calculated on the basis of final product (processed cheese spread). The young and old cheddar cheeses were cleaned, quartered and grated. The grated cheese was added into the processing vessel of universal disperser set to the desired temperature using water in the jacketed space. The calculated amounts of salt and emulsifier were added after mixing into predetermined amount of water. On complete melting of the cheese, the impeller design identified for the operation *viz.,* saw tooth high shear impeller was allowed to start, in order to homogenize the contents in the vessel for a period of 10 min. The prepared product was hot packed in PE cups and stored at refrigeration temperature.

A control sample was prepared by same method except that components were heated to 85 ^{o}C and mixed using a hand blender (Make: Maharaja Whiteline Turbomix 350W) for 10 min.

3.10.1. Optimization of Process Parameters for Preparation of Processed Cheese Spread Using Universal Disperser

Optimization of process parameters for preparation of cheese spread using the Universal Disperser was carried by Response Surface Methodology using the software Design Expert V.10.0. Three levels each of two independent parameters, viz., impeller speed and process temperature were identified as listed in Table 3.3.

Table 3.3: Experimental variables for preparation of processed cheese spread

Factor	Unit	Lower Range	Higher Range
Temperature	^{o}C	50	80
Impeller speed	rpm	10000	20000

The trials were carried out on a central composite rotatable design constituting 8 model points with 5 replicate points and the experimental design required a total of 13 runs of trials. For each trial, the response was recorded in terms of 5 dependent variables, namely mixing index, mixing time, power consumption, sensory score and work of shear.

3.11 Method of Preparation of Recombined Milk

The recombined milk was prepared by mixing the butteroil, skim milk powder (SMP) and water in the process vessel at selected temperature and impeller speed. The SMP (Brand Nandini) used for the study was purchased from the local Nandini Milk Parlour (Karnataka Milk Federation, Bengaluru). Butter oil was prepared using butter freshly prepared from the cream which was procured from Experimental Dairy Plant, SRS, ICAR-NDRI, Bengaluru. The cream was standardized to 40 per cent fat and kept for ageing for 10-12 h. The aged cream was churned in the Universal Disperser using multivane churn impeller by maintaining the jacket temperature at 5 ^{o}C. The butter thus obtained was stored at refrigerated temperature till further use. Each batch of butteroil was prepared by melting the butter at 80-90^{o}C, followed by straining of the supernatant anhydrous milk fat. Potable water, sourced from R. O. system located in the Dairy Engineering Section, SRS, NDRI, Bengaluru, was boiled and allowed to cool before use in the preparation of recombined milk. The method for the recombination process is outlined in Fig. 3.5.

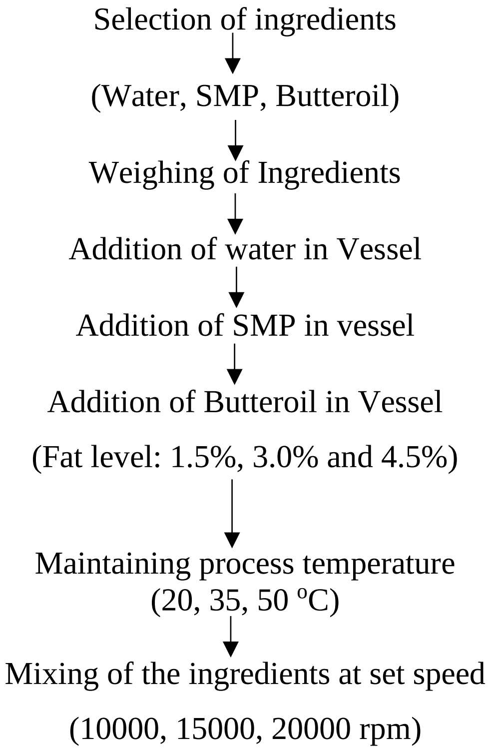


Fig 3.5: Flow diagram for preparation of recombined milk

3.11.1. Optimization of Process Parameters for Recombination of Milk Using Universal Disperser

Trials were conducted as per an experimental design obtained for a Randomized Face Centered Central Composite Design constituting 13 runs for 8 model points with 5 replicate points.

Table 3.4: Experimental variables for preparation recombined milk

Factor	Unit	Lower Range	Higher Range
Temperature	^{o}C	20	50
Impeller speed	rpm	10000	20000

Two independent parameters at 3 levels were identified as listed in Table 3.4 and the responses obtained for each experimental run in terms of the mixing index, mixing time, power consumption, sensory score and creaming index of the recombined milk were analysed by Response Surface Methodology using the software Design Expert V.10.0. The most optimal combination of parameters to achieve the set goals for the responses were located for recombined milk at three levels of fat (1.5, 3.0 and 4.5 %). The selected fat corresponded to the standards for double toned, toned and standardized milk, respectively.

3.12 Methodology for Analysis of Samples

3.12.1 Determination of Mixing Index

The quality of mixing of real mixtures would fall between that of totally unmixed (segregated) state and that of a perfectly mixed (random) mixtures (Berk, 2018). The goodness of mixing is quantified in terms of mixing index or index of mixedness as follows (Lacey, 1954):

$$M = \frac{s_0^2 - s^2}{s_0^2 - s_R^2} \qquad \ldots(3.7)$$

Where,

S^2 is the variance in the real mixture.

S_0^2 , the variance in totally unmixed system,

S_R^2 variance in completely randomized system,

S_R^2 is determined using Eqn. (3.8) as:

$$s_0^2 = q(1-q) = \mathrm{q}\,p$$

$$S_R^2 = \frac{q-p}{N} \qquad \ldots(3.8)$$

p and q are mass fraction of two components, N is the total number of the readings from a sample. Berk (2018) stated that for large samples sizes, the variance S_R^2 approaches zero and equation (3.7) is simplifies as:

$$M = 1 - \frac{s^2}{s_0^2} \qquad \ldots(3.9)$$

Where S^2 is known as variance.

The mixing index *M* lies between 0 (totally segregated) and 1(totally randomized). It would be logical to assume that complete mixedness, *M* =1, is approached asymptotically as mixing is continued and to seek a quantitative relationship between mixing time and mixing quality (Kuakpetoon *et al*., 2001).

For evaluating the mixing index in the present study, the mix was assumed to be a binary phase of total solids and the liquid phase (moisture). Representative samples from different locations in the tank were drawn while the impeller was in motion, at different instances of time within the mixing period and analyzed for its total solids content by the standard gravimetric method. The data was analyzed to evaluate the variance in the mix, during the mixing process and substituted in Equation 3.9 to compute the mixing index.

3.12.2 Determination of Mixing Time

The mixing time is defined as the time taken for the uniformity 'U' to reach the equilibrium concentration (Oshinowo, 2000). The mixing effectiveness was determined using the following equation with some modifications:

$$U_{(t)} = 1 - \frac{C_\infty - C_{(t)}}{C_\infty} \qquad \dots (3.10)$$

In this expression, C_∞ is the equilibrium or the final concentration and $C_{(t)}$ is the concentration at a point at some instant in time. The mixing time was read from the plot of Mixing effectiveness vs Time, as the time corresponding to the point when the mixing effectiveness reached a steady state.

3.12.3 Determination of Power Consumption

The power consumption was determined using a digital wattmeter (Model: PM03, Make HTC). The input of motor was connected to the socket of digital wattmeter which was connected to main power supply. The power consumed during the processing of the products in the Universal Disperser was monitored inline by recording the data from the wattmeter.

3.12.4 Determination of Creaming Index

The creaming index was determined as per the method given by Ertugay *et al*. (2004). In this method, the recombined milk was placed into a graduated cylinder of 250 ml and kept undisturbed in a refrigerator for 48 h. Samples were then drawn from the top layer (i..e top 10% of the volume) and the bottom layer (bottom 90 % of the volume) and the fat content of the individual layers were estimated using the standard Gerber method. The following equation was used to calculate the creaming index of the samples:

$$Creaming\ Index = \frac{a-b}{a} \times 100 \qquad \ldots(3.11)$$

Where, a and b were the fat content of the top and bottom layers of the recombined milk, respectively.

3.12.5 Determination of Moisture

The moisture content of Cheddar cheese as well as processed cheese spread was determined by standard gravimetric method as described in IS: SP: 18 (Part-XI), 1981.

3.12.6 Determination of Total Solids

About 5g of sample was weighed accurately in previously dried and cooled Aluminum dish. It was kept on water bath for evaporation. It was transferred to oven at 105 ± 1^0C and heated for 4 hours and then cooled in desiccator for 30 minutes and weighed. The same procedure of heating and cooling, then weighing was repeated till successive weight difference did not exceed 1.0 mg (IS: SP: 18, part XI, 1981). Lowest observed weight was noted and TS calculated as follows:

$$\text{TS (\% by weight)} = \frac{100 \text{ x weight of sample after drying}}{\text{Weight of sample taken}}$$

3.12.7 Estimation of Fat

Fat in milk and cream was determined by Gerber method and the fat content of *Lassi* samples were determined using Mojonnier fat-extraction apparatus according to the method detailed in (IS: SP: 18, part XI,1981). Well mixed sample of about 2 g was weighed into a small beaker followed by addition of 1 ml of conc. ammonia and swirled gently for dispersion.

With 10 ml of alcohol, the above contents were transferred to the Mojonnier fat extraction apparatus. Diethyl ether (25 ml) was added and shaken vigorously for one minute followed by addition of 25 ml of petroleum ether (40-60 ^oC) with repeated vigorous shaking. The Mojonnier tube contents were allowed to settle for 15 min. The ethereal layer was decanted into a pre-weighed Al dish along with a few pumice stones. The extraction of aqueous layer was repeated twice using 30 ml ether mixture (1:1). The solvent in the dish was evaporated on steam bath and residual fat was further dried in the oven at 100+10 ^oC for 1 h followed by cooling in desiccator and then weighed. Fat percentage was calculated as follows:

$$\text{Fat (\%, by mass)} = \frac{W2 \times 100}{W1}$$

Where, W1 = weight of sample (g); W2 = weight of fat residue after drying (g).

The fat content in Cheddar cheese and processed cheese spread was determined by the Gerber method described in AOAC (2005).

3.12.8 Estimation of Titrable Acidity

The titrable acidity (TA) of the samples was determined according to the procedure given in IS (IS:SP: 18, part 1) (1981). In each analysis, 10 g of the sample was diluted with 10 ml of distilled water and titrated against 0.1N NaOH using 3-4 drops of phenolphthalein as indicator. The acidity was expressed as percent lactic acid.

Calculation:

$$\text{Acidity (\%)} = (V/W) \times 0.9$$

Where, V = volume of NaOH used (ml); W = weight of yoghurt sample taken (g)

3.12.9 Estimation of pH

The pH of the samples was measured by taking 50-60 ml sample in 100 ml beaker. Sample was taken out from refrigerator and tempered to about 20 ^oC. The electrode of a digital pH meter was directly dipped into the samples and the reading on the display panel was recorded after it became stable.

3.13 Sensory Evaluation of Samples

3.13.1 *Lassi* and Recombined Milk

The 9-point Hedonic scale was used to adjudge the sensory quality of *Lassi* and recombined milk prepared at various speeds and off-bottom clearances. The samples were evaluated for its sensory attributes in terms of colour and appearance, body and texture, flavor and overall acceptability by a sensory panel (min. 6 members) comprising of members of the faculty and students of the Institute. The serving temperature of *Lassi* was kept between 7-8 ^{o}C. The score card for the evaluation of *lassi* and recombined milk is included in Appendix I and II, respectively.

3.13.2 Processed Cheese Spread

The processed cheese spread samples were also subjected for sensorial evaluation by 9-point hedonic scale. The samples were served at room temperature in a plastic cup along with breads. A plastic spreading spoon was provided to spread the cheese spread sample on bread. Sensory evaluation of the samples was carried out and the panelists were asked to score the parameters as per score card appended in Appendix III.

3.14 Analysis of Rheological Properties

3.14.1 Apparent Viscosity of *Lassi*

The apparent viscosities of *Lassi* sample were determined using a rotational viscometer i.e. Brookfield Viscometer (Model: RV DV2T, TC500) at spindle (RV-02) speed of 200 rpm. The viscosity measurements were carried out at about 15 ^{o}C. The spindle was lowered into the sample at a depth indicated by the notch on the spindle. The spindle depth was kept constant throughout the measurements. The samples for viscosity measurement were taken in 500 ml beakers and the viscosity value was recorded every thirty seconds for a period of 5 min.

3.14.2 Texture Analysis of Processed Cheese Spread

The sample of processed cheese spread was filled up to 3.5 cm height of sample container (50 ml capacity, 5.5 cm height, 4 cm internal diameter) made of high density poly-ethylene and evaluated for its textural attributes, using Texture Analyzer TAXT21 (Stable Micro Systems, Godalming, Surrey, UK) at 20 °C. The product was subjected to application of force to a depth of 22 mm by a P-25 cylindrical aluminum probe attached to the texture analyser fitted with a 5 kg load cell. Three measurements were made for each type of sample. Parameters measured consisted of firmness, work of shear, stickiness and work of adhesion.

The test conditions maintained were as under:

Mode : Measure force in compression
Option : Return to start
Pre-test speed : 2.0 mm/s
Test speed : 1.0 mm/s
Post-test speed : 2.0 mm/s
Trigger type : Auto
Force : 0.10 N
Data acquisition rate : 200.00 PPS

The textural parameters were worked out from the force-time curve thus obtained for each sample with force experienced by the probe on Y-axis and time on X-axis. The textural quality of the spread was expressed in terms of its firmness (maximum positive peak force), work of shear (the amount of energy required to perform the shearing process, computed as the area under the penetration cycle (down stroke) in the force distance curve) and stickiness (the maximum negative peak force). The area of negative peak force i.e. energy required to remove the probe represents the work of adhesion for the sample. A representative curve with the respective parameters is presented in Fig 3.6.

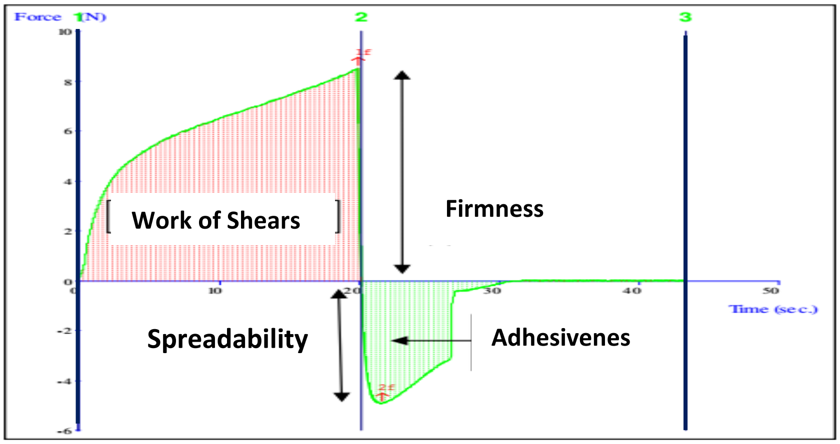


Fig 3.6: Force time-curve of compression test of processed cheese spread

3.14.3 Kinematic Viscosity of Recombined Milk

The kinematic viscosity of the recombined milk was determined by Ostwald's Viscometer (Make: Vensil Glassware, Chennai). Thirteen millilitre of distilled water was tempered to a temperature of 25 ^{0}C and filled into the receiving arm of the viscometer. The time for flowing of distilled water through capillary of opposite arm was recorded. Similarly, time for flow of equal volume of recombined milk was calculated at the same temperature and the viscosity was calculated by the following formula. The viscosity thus obtained was represented in centistoke**:**

$$\eta = k \times t \qquad \ldots(3.12)$$

$$(k = \frac{\eta}{t} \text{ of water})$$

Where,

η = viscosity, centistoke
k = conversion factor
t = time, s

3.15 Statistical Analysis

The experimental data obtained during the present research work were subjected to statistical analysis. All the experimental data for analysis of *lassi*, processed cheese spread and recombined milk were expressed as mean ± standard error of mean calculated from three independent replication experiments. Analysis of variance (ANOVA) was applied and Duncan multiple range test was performed to measure the test of significance by post hoc test using the software SPSS v16.0 (SPSS Italia, Bologna, Italy).

Results and Discussion

4. RESULTS AND DISCUSSION

This chapter deals with the design of the Universal Disperser and the results obtained during performance evaluation of the developed unit for the processing of the selected dairy products viz., *Lassi*, *Processed Cheese Spread* and *Recombined Milk.* The performance evaluation study was conducted in two phases. The first phase of the study was related with performance evaluation of impellers which was carried out with a simulant fluid i.e., Carboxymethylcellulose (CMC) solution. The second phase of the performance evaluation was related to the study of preparing the products using the Universal Disperser including optimization of the process parameters. The results obtained in the study have been presented and discussed in this chapter.

4.1 Design of Universal Disperser

The first objective of the present study involved the development of Universal Disperser for processing different dairy products. Accordingly, various design equations, models and techniques were studied and applied for development of the Universal Disperser. The Universal Disperser was designed in terms of the following components:

1. Process Vessel
2. Low Speed Motor (for operations within speed ≤ 2000 rpm)
3. High Speed Motor (for operations with a speed ≥ 2000 and ≤ 20000 rpm)
4. Impellers
5. Support framework and accessories

4.1.1 Design of Process Vessel

The process vessel module was designed to facilitate the mixing / agitating / shearing operations with simultaneous heating/cooling of the experimental product. The process vessel unit comprised of three concentric cylinders i.e. inner cylindrical vessel, jacket vessel, outer cylinder along with necessary heating elements and controllers. A plate heater of computed rating and specifications was placed in the jacket to heat the water in the jacket space to desired process temperature. The heater was integrated to thermostatic controls to regulate the temperature of the water in the jacket to set a temperature within range of ± 1℃. For cooling applications, externally chilled water was added in the jacket space. The various components of process vessel were designed and selected as described below:

4.1.1.1 Design of Inner Cylinder

The dimensions of processing vessel were computed considering a capacity of 3 L of the product. The standard design for the agitated vessel were taken into consideration while dimensioning the vessel. It was assumed that a free board of 40% would be provided to avoid the spillage during high speed processing and 60 % would be the product volume. Considering vessel height: diameter ratio 1:1, the dimensions of the vessel were obtained as D = 0.185 m and H = 0.185 m. However, for ease of machining and other practical consideration, a vessel of dimensions D = 0.18 m and H = 0.20 m was finalized.

The bottom of the inner cylinder vessel was machined as a shallow dished head to eliminate localized stresses and for effective mixing of the product. An outlet at the center of the vessel was provided to facilitate complete draining of the vessel contents.

4.1.1.2 Design of Jacket Vessel

The jacket space was designed with two considerations in mind; firstly, the jacket volume should accommodate sufficient water for heating the process fluid. Secondly, enough clearance needs to be provided for ease of machining and other practical considerations during fabrications as well to house the heater coil, outlet valve and their fittings. Hence, a jacket clearance of 5 cm was assumed. Additional clearance was provided to the height of outer vessel to accommodate the accessories. Thus, the computed dimensions of the diameter and height of the jacket cylinder was obtained as 0.23 and 0.26 m respectively.

The volume of the jacket space was computed as the difference in the cylindrical volume of the jacket and inner cylinders.

Volume of the outer cylinder= $\pi r^2 h = 3.14\times(0.115)^2\times0.26$

$$=0.0108\ m^3 = 10.8\ L$$

Volume of Jacket Space= (Vol. of outer cylinder) − (Vol. of inner cylinder)

$$= 10.8 - 5$$

Volume of Jacket Space = 5.8 L

Thus, the volume of heating medium that could be accommodated in the jacket space was considered to be 5 L (5kg).

4.1.2 Rating of Heater Coil

The capacity of heater coil was determined by considering total heat load that would be incurred in heating of the product. It was assumed that the initial temperature of water would be 20 ^{o}C and the upper limit to which the water may be heated in the jacket space was considered as 95 ^{o}C. The required heat load was computed as follows:

$$Q = mCp\Delta T$$

Where,

Q = Heat Load, kJ

m = mass of water, kg

Cp = Specific heat of water, 4.18 kJ/kg℃

ΔT = Temperature difference between initial and set temperature of water

$$Q = 5 \times 4.18 \times (95-20)$$

$$Q = 1567.5 \text{ kJ}$$

The wattage rating of heater coil was then calculated as,

$$Power = \frac{Heatload}{Time}$$

Assuming that the heating time is restricted to 15 min.

$$\text{Power} = 1567.5/900$$

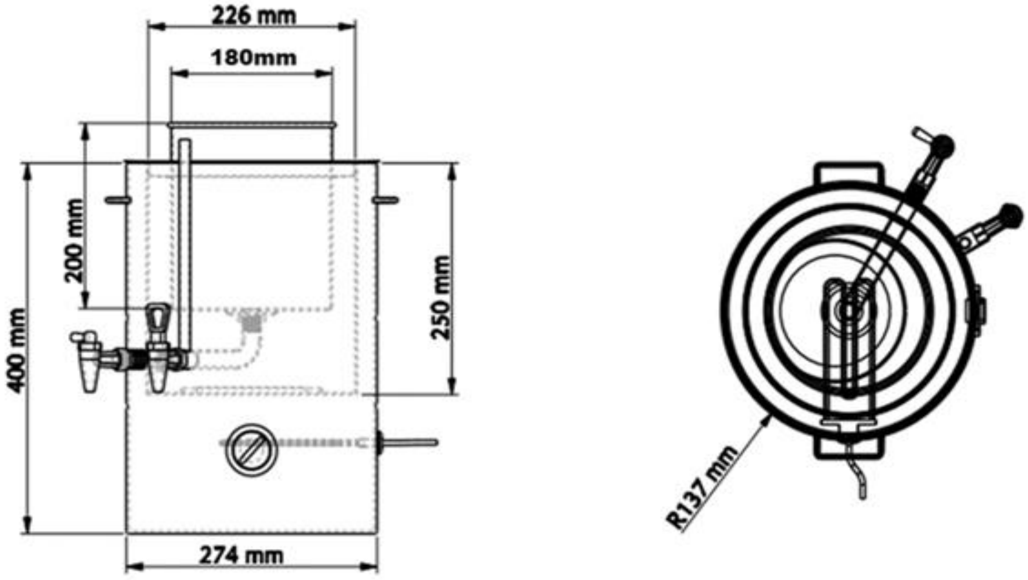
$$Q = 1.74 \text{ kW}$$

Hence, 2 kW electrical heater was selected to be installed in the heat exchanger.

4.1.3. Design of the Outer Cylinder

Critical thickness of insulation was determined as per the standard methodology for cylindrical geometries (Eqn 3.4). Hence, a layer of 0.02 m of PUF was provided as the external insulation for the Universal Disperser. Further, additional clearance at the base of the outer cylinder needs to be provided for housing the necessary controls for temperature regulation. Based on the above considerations, the final dimensions arrived for the outer cylinder of the developed unit was diameter of 0.27 m and an overall height of 0.40 m.

Drawing of the process vessel module of the proposed Universal Disperser is presented in Fig. 4.1.



Front view **Top view**

Fig. 4.1: Line diagram of process vessel of Universal Disperser

4.1.4 Design of Cylindrical Shell Thickness

Based on the principles of sanitary design SS 316- was selected as the appropriate material of construction for the proposed Universal Disperser. The thickness of the sheet was calculated based on guidelines outlined in section UG-27 of ASME Section VIII, Division 1, 2011 edition code book.

$$t = \frac{P*R}{2\,SE - 0.6\,P}$$

where,

t = Sheet thickness in corroded condition, m

P = Design pressure, MPa (atmospheric pressure)

R = Inside diameter of the vessel, m

S = Maximum Allowable Stress at design temperature, MPa (97.85 MPa)

E= Joint Efficiency (fraction), (0.80)

Based on the above calculation, a sheet thickness of 2mm was selected for the fabrication of the Universal Disperser.

4.1.5 Design of Impellers

According to standard design equation, the ratio of impeller diameter to vessel diameter was kept between 1/4 to 2/3. Three different impellers were selected to facilitate the different unit operations in the preparation of the selected product. Each impeller was characterized by its ability for top-to-bottom mixing, power delivery and high speed shearing. Based on literature survey and type of product selection, the impellers shape and size were finalized. The dimensions in Table 4.1 and design drawings of the selected impellers is presented and Fig. 4.2, Fig. 4.3, Fig. 4.4 are presented. The three-dimensional representation of the impellers is depicted in Fig. 4.5.

Table 4.1 Dimensions of the impeller designs

Impeller design	Description	Diameter of impeller	Width of impeller
Pitched blade	SS314 Four bladed, mounted at 45^o angle	0.06 m	0.015 m
Saw tooth impeller	Disc impeller with saw tooth edges	0.06 m	0.015 m
Multivane churn impeller	anchor shape projections originating from the shaft of the impeller	0.08 m	0.04 m

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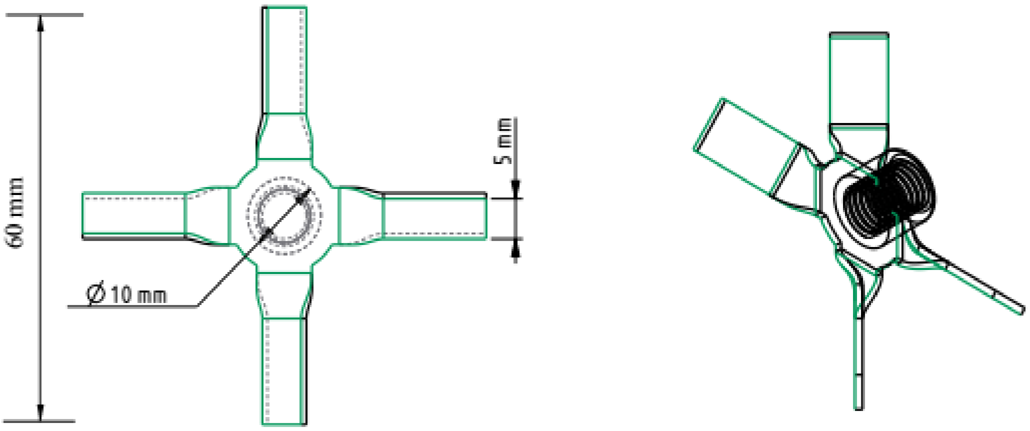
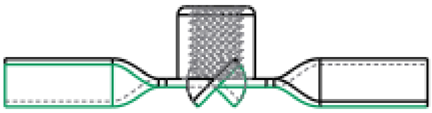


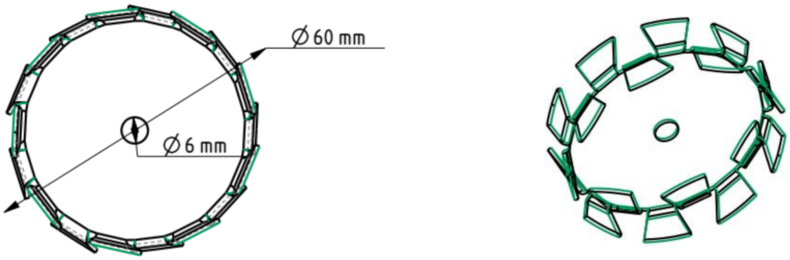
Top view

Isometric view



Front view

Fig. 4.2: **Drawing of pitched blade impeller**

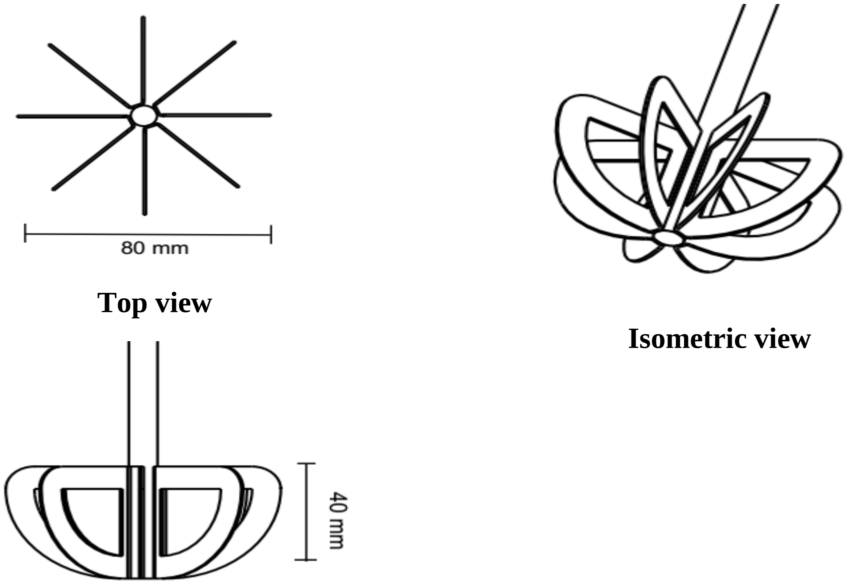


Top view

Isometric view

Side view

Fig. 4.3: **Drawing of saw tooth impeller**

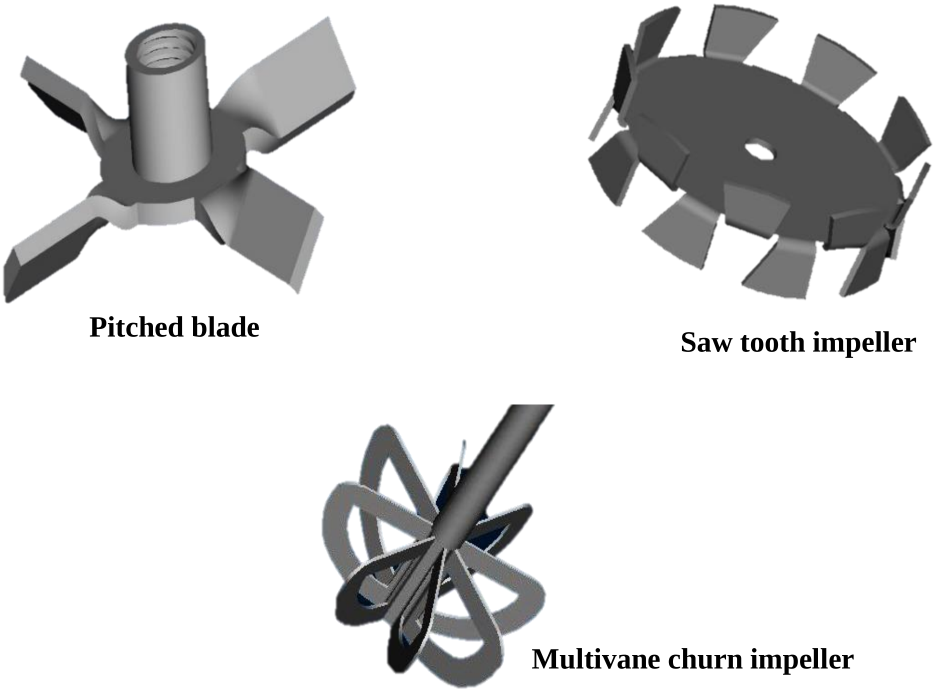


Top view

Isometric view

Front view

Fig. 4.4: Drawing of multivane churn impeller



Pitched blade

Saw tooth impeller

Multivane churn impeller

Fig. 4.5: Solid modelling of the impellers

4.1.6 Motor Selection

Based on the need of application, it was decided to provide two different motors of varying capacity, a low speed motor for gentle agitation and high speed motor to mount high shear impeller. The power rating of the two motors were computed based on the power number; an average power number of 2.0 was considered for the low speed operations (range varying from 0.5 to 3.0, while the power number for the high speed applications was considered in the range 3.0-7.0 and averaged at 5.0. Accordingly, the power rating for the low speed and high speed motors were determined as 120 and 400 W, respectively. The technical specification of the motors selected for the two speeds is listed in Table 4.2. The impeller shaft was coupled to the motor drive using drill chuck.

Table 4.2 Technical Specifications of motors selected for Universal Disperser

Parameter	**Low speed Motor**	**High Speed Motor**
Power Rating	120 W	400 W
Power supply	220V, 50Hz	220V, 50Hz
Speed range	0 – 2000 rpm	< 25000 rpm
Speed display	Four figure LCD display	-
Maximum shaft torque	150 Ncm	178 Ncm
Medium-contact material	SS316	SS 316

Further, to regulate the speed of the motor, the mechanical drive was integrated with an Electronic Voltage Regulator with an adjustable range of voltage ranging from 0-220 V.

4.1.7 Support Framework

Adequate support was given to mount the motor on the support stand. The clamp like structure was provided to fix the motor on the stand; the height of motor was adjusted by sliding the clamp assembly up and down the stand as required.

4.2 Fabrication and Assembly of the Process Vessel

Once the design computations were completed and the specifications for the items to bought-out was finalized, the fabrications drawings for the proposed unit was prepared (Fig. 4.6). A 3-D solid modelling of the final assembled unit was also created in AutoCAD. The fabrication of the various components of the designed Universal Disperser was carried out with assistance from M/s Milk Tech Engineers, Bengaluru and the final unit was assembled. The final assembled unit is shown in Fig. 4.7.

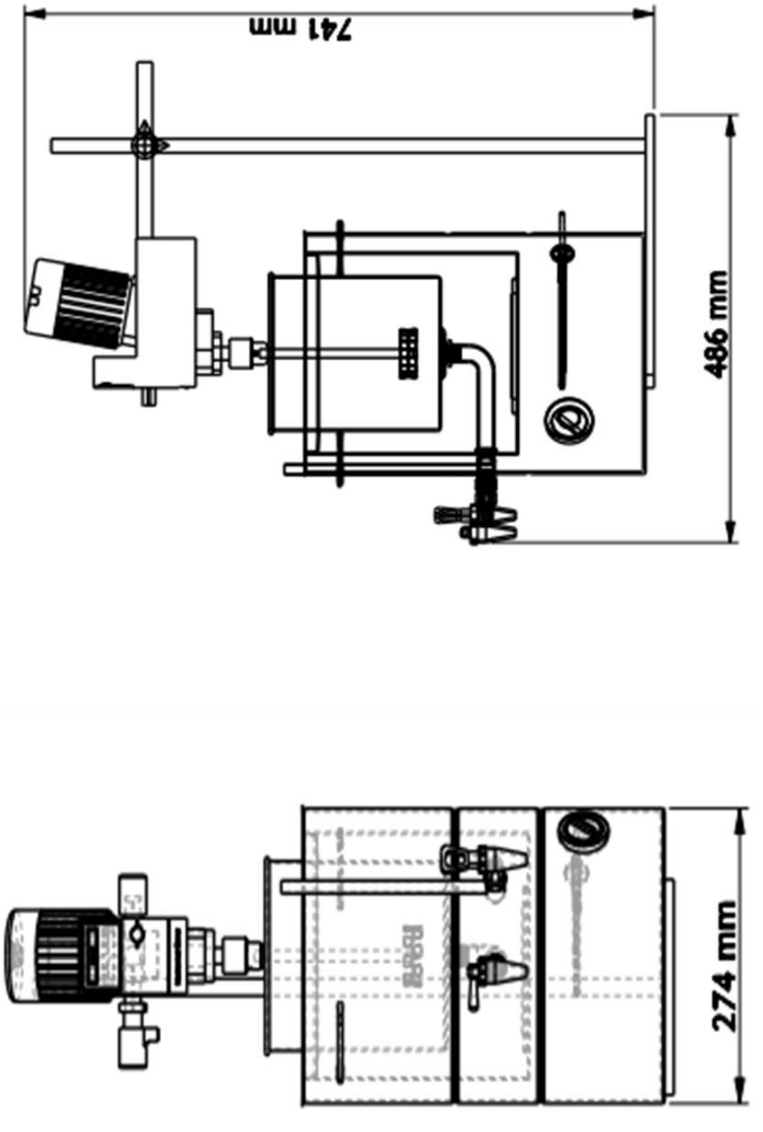
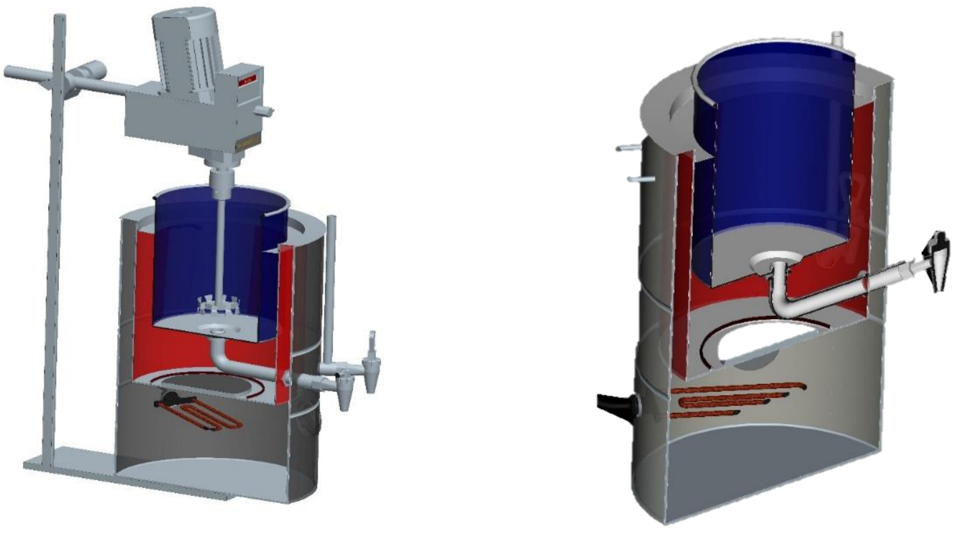


Fig. 4.6b

Fig. 4.6a

Fig. 4.6: Line diagram of Universal Disperser a) Front view b) Side view

Complete 3-D view



Cut sectional view **Cut sectional view**

Fig. 4.7: Solid model view of the complete Universal Disperser

Fig. 4.8: View of Universal Disperser

4.3. Performance Evaluation of Impellers with CMC Solution

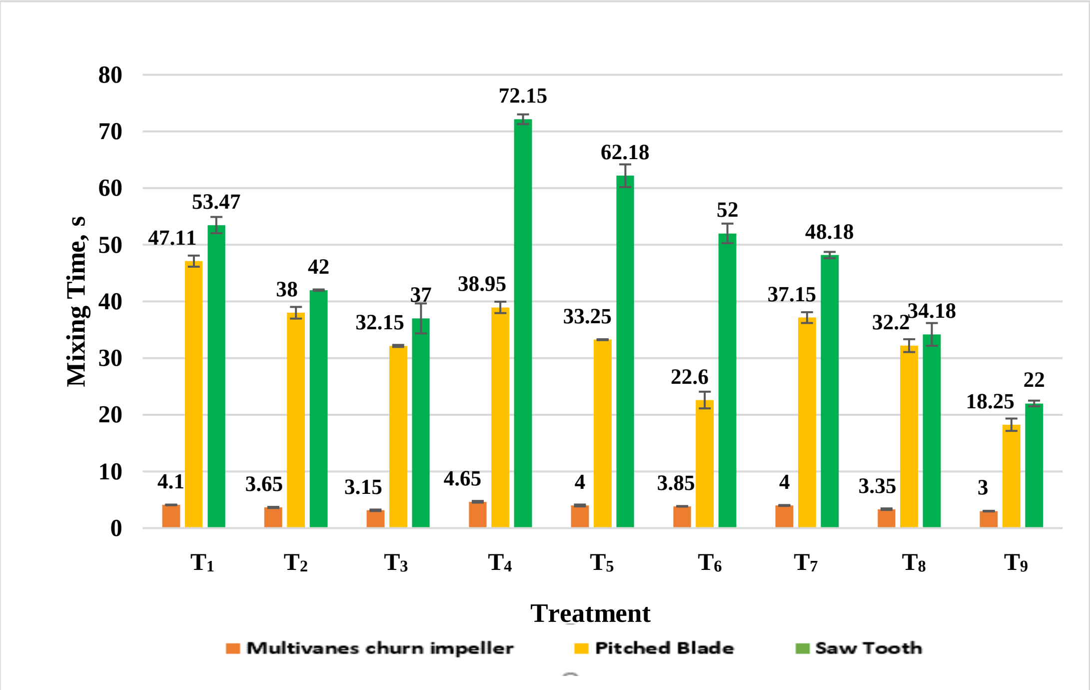
Preliminary evaluation of the performance of the developed unit was conducted using a simulant fluid prepared using CMC solution. The flow characteristics and mixing efficiency of the select impellers was evaluated using the acid-base neutralization method and mapping the electrical conductivity of the simulant fluid added with an electrolyte.

4.3.1 Acid-Base Neutralization Method

In this method, the three impellers were tested to determine the mixing efficiency of the impellers in a given set of conditions. The mixing efficiency studies were done by varying the different independent factors as discussed in Section 3.1. The mixing time and power consumption were monitored for determining the performance of individual impeller. The liquid depth was kept constant at D:H=1 i.e. 18 cm and temperature of CMC solution was kept at 37 ^{o}C.

4.3.1.1 Effect of Off-Bottom Clearance (OBC) and Impeller Speed on Mixing Time

Impellers were positioned at three different level i.e. 3 cm, 6 cm and 9 cm from the bottom of the vessel and the performance was recorded at three different impeller speed of 300, 400 and 500 rpm. The mixing time recorded is presented in Fig 4.9.



[**T_1** (300 rpm, 3cm OBC), **T_2** (400 rpm, 3cm OBC), **T_3** (500 rpm, 3cm OBC), **T_4** (300 rpm, 6cm OBC), **T_5** (400 rpm, 6cm OBC), **T_6** (500 rpm, 6cm OBC), **T_7** (300 rpm, 9cm OBC), **T_8** (400 rpm, 9cm OBC), **T_9** (500 rpm, 9cm OBC)]

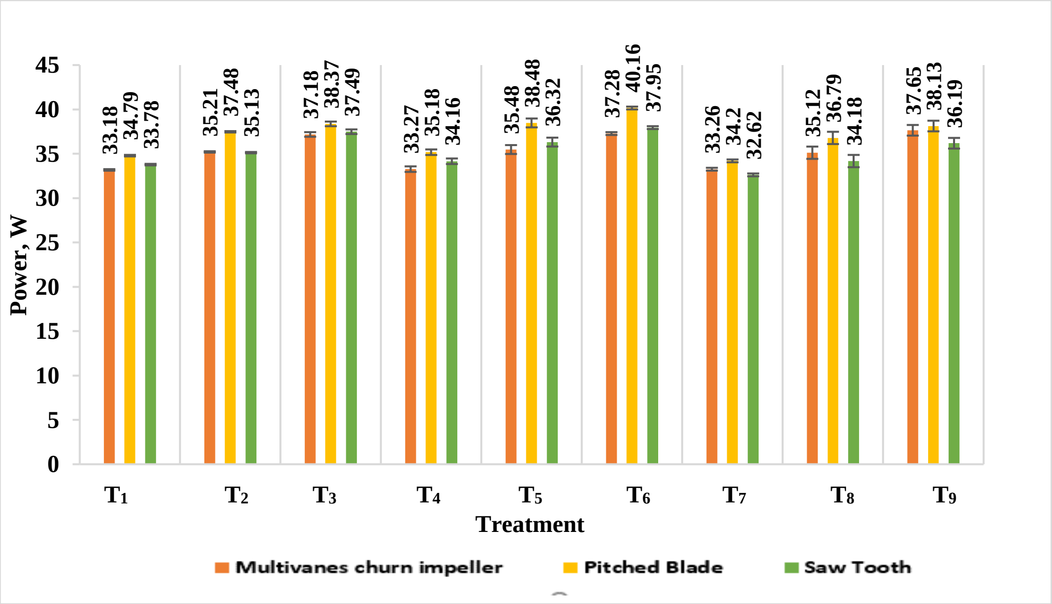
Fig. 4.9: Effect of off-bottom clearance on mixing time

A close perusal of Fig. 4.9 clearly indicated that the mixing time was significantly lower when the fluid was mixed using the multivane churn impeller. Moreover, for the multivane churn impeller, the off-bottom clearance and speed of rotation did not significantly influence the mixing process. For the pitched blade and saw tooth impeller, both off bottom clearance and speed of rotation were significant in its influence on the mixing time, both in isolation and in interaction.

Armenante and Nagamine (1998) discussed the significance of off bottom clearance on the flow patterns and mixing effectiveness in a stirred tank and stated that the clearance influenced the recirculation loops set up in the tank and resulted in transient interaction of the fluid with the tank vessel bottom. Among the three levels of OBC evaluated in this study, the value of 9 cm corresponding to a level of half of the tank diameter was found to be most suitable in terms of minimizing the mixing time for three impeller designs; the higher impeller speed resulted in lower mixing times. This was in contrast to the recommendation by Luan *et al*. (2017) who proposed a clearance of 1/3rd of the tank diameter for most efficient mixing using a perturbed six-bent-bladed turbine.

4.3.1.2 Effect of Off-Bottom Clearance and Impeller Speed on Power Consumption

The power consumed for complete mixing of the simulant fluid was recorded using an inline wattmeter and the results are plotted in Fig 4.10.



[**T**$_1$ (300 rpm, 3cm OBC), **T**$_2$ (400 rpm, 3cm OBC), **T**$_3$ (500 rpm, 3cm OBC), **T**$_4$ (300 rpm, 6cm OBC), **T**$_5$ (400 rpm, 6cm OBC), **T**$_6$ (500 rpm, 6cm OBC), **T**$_7$ (300 rpm, 9cm OBC), **T**$_8$ (400 rpm, 9cm OBC), **T**$_9$ (500 rpm, 9cm OBC)]

Fig. 4.10: Effect of off-bottom clearance and impeller speed on power consumption on mixing efficiency

The results indicated that the power consumption during the mixing process was most influenced by the impeller speed; higher power consumption was recorded for 500 rpm for all the three impeller designs evaluated at all three levels of OBC. Among the impeller designs evaluated, the least power was consumed by the multivane churn impeller while maximum power consumption was registered by the pitched blade impeller. A similar finding was reported by Hiraoka *et al.* (2001) who reported that in identical mixing systems, maximum power was consumed by pitched blade impellers while minimum power consumption was observed by a paddle impeller design.

4.3.2 Electrical Conductivity Method

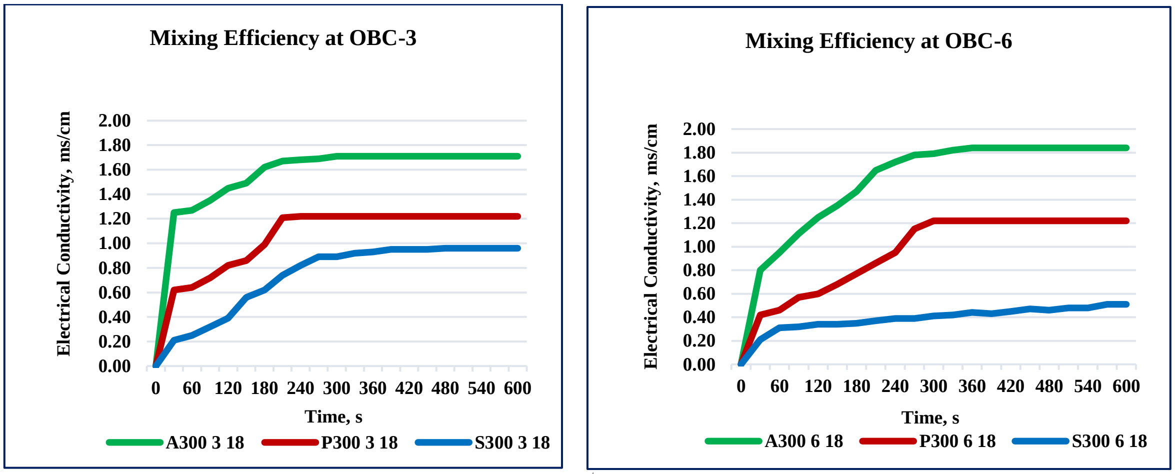
In this method, the mixing efficiency of individual impeller was adjudged by measuring the change in electrical conductivity as a function of time. Sodium chloride salt was added in the CMC solution as an electrolyte and the electrical conductivity was mapped for a period of 10 min at interval of 30 sec.

4.3.2.1 Effect of Off-Bottom Clearance and Impeller Speed on Mixing Efficiency

The experimental design for the evaluation comprised of 3 impeller design x 3 levels of off-bottom clearance (OBC) (viz., 3 cm, 6 cm and 9 cm) x three impeller speeds (i.e., 300,400 and 500 rpm) x three replications. The results obtained in the study are plotted in Fig. 4.11.

A close perusal of the plots reveals that irrespective of the OBC and impeller speed, the saw tooth high shear impeller resulted in significantly lower values of final electrical conductivity than the values obtained when the mix was processed using the multivane churn / pitched blade impellers. This could be attributed to poor top – bottom mixing of this design, which is primarily suited for applications requiring higher power delivery such as emulsification (Zhang *et al*, 2012). Since, the conductivity detector was placed near the upper surface of the CMC solution, higher conductivity values could be correlated with better top to bottom mixing of the salt in the solution.

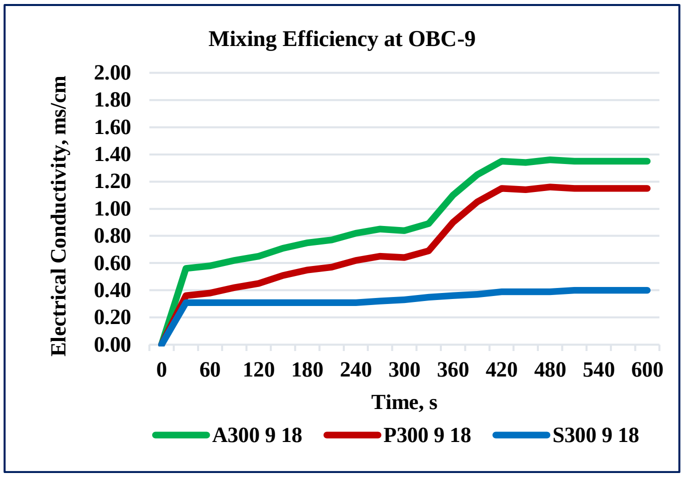
Further, it was observed that for all the OBC level and impeller speeds evaluated, the multivane impeller depicted better mixing effectiveness in terms of minimum mixing time. At the OBC level of 3 cm, after 10 min of mixing, the multivane churn impeller recorded the steady electrical conductivity (EC) values (1.71 mS/cm) in the solution indicating that the NaCl was mixed well in the CMC solution. On the other hand, pitched blade achieved the EC value of 1.22 mS/cm and saw tooth recorded the least value of EC i.e. 0.96 mS/cm. Multivane churn impeller took 180 s to arrive at constant EC value, while the pitched blade and saw tooth disc achieved steady values of EC in 240 and 270 s, respectively.



A300 3 18 (Multivane churn impellerr, 300 rpm, 3cm OBC, 18cm liquid height), **P300 3 18** (Pitched blade, 300 rpm, 3cm OBC, 18cm liquid height) , **S300 3 18** (Saw tooth, 300 rpm, 3cm OBC, 18 cm liquid height)

A300 6 18 (Multivane churn impller, 300 rpm, 6cm OBC, 18cm liquid height), **P300 6 18** (Pitched blade, 300 rpm, 6cm OBC, 18cm liquid height), **S300 6 18** (Saw tooth, 300 rpm, 6cm OBC, 18 cm liquid height)

d



A300 9 18 (Multivane churn impeller, 300 rpm, 9cm OBC, 18cm liquid height), **P300 9 18** (Pitched blade, 300 rpm, 9cm OBC, 18cm liquid height), **S300 9 18** (Saw tooth, 300 rpm, 9cm OBC, 18 cm liquid height)

Fig. 4.11: Effect of different types of impeller, their speed and off-bottom clearance (OBC) on mixing efficiency (represented in terms of electrical conductivity)

A similar trend with respect to mixing effectiveness of the three impellers was recorded for OBC values of 6 cm and 9 cm evaluated. Significant improvement in the mixing effectiveness measured in terms of electrical conductivity detection of an added electrolyte was observed when the off-bottom clearance was increased to 6 and 9 cm.

From the analysis of the impellers using the acid-base neutralization (decolourization) method and the electrical conductivity test, it was deduced that the off-bottom clearance in the range 3-9 cm (impeller positioned at a level of 1/2 to 1/3 of tank diameter from the bottom of the tank) were the limits for the entity. Further, multivane churn impeller and pitched blade impellers were better suited for applications requiring good top to bottom mixing, the saw tooth disc impeller was better for applications requiring good power delivery to the process fluid.

4.4 Preparation and Optimization of *Lassi* Using Universal Disperser

Being a popular fermented product in India, *lassi* was identified as one of the products for testing the Universal Disperser. *Lassi* was made from mixture of curd, water and sugar as detailed in section 3. 9. This product mix of curd, water and sugar was processed at different impeller speeds (300-500 rpm) and off-bottom clearance (3-9 cm). Before finalising the selection of the impeller for processing of *lassi*, the three impellers were evaluated by videographing the dispersion of a food grade dye in the product when the mix was processed at 500 rpm and the impellers positioned at an OBC of 9 cm. The temporal static view of the experiment are depicted in Fig. 4.12.

From the temporal profiles plotted in Fig 4. 12, it can be deduced that the saw tooth disc impeller performed poorly for the mixing of the product as anticipated; the streak of the colour dye remained unmixed and was clearly visible even after 5 min of processing at 500 rpm. Complete mixing was observed for both the multivane churn and pitched blade impellers after 5 min of processing. However, a close perusal of the videographs clearly showed unmixed zones around the edges of the product at 3 min, while the mixing appeared more uniform for the multivane impeller after the lapse of the same time. Thus, this further reaffirmed that multivane churn impeller performed better for mixing effectiveness for the processing of medium viscous products such as *lassi*.

The effect of processing conditions, such as OBC and impeller speed on the preparation of lassi was evaluated in terms of mixing performance and product quality parameters. Each

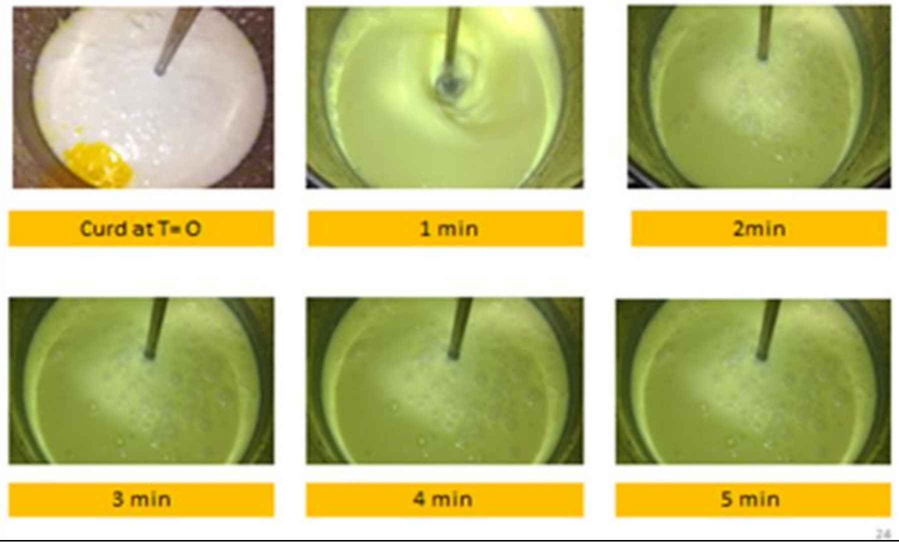
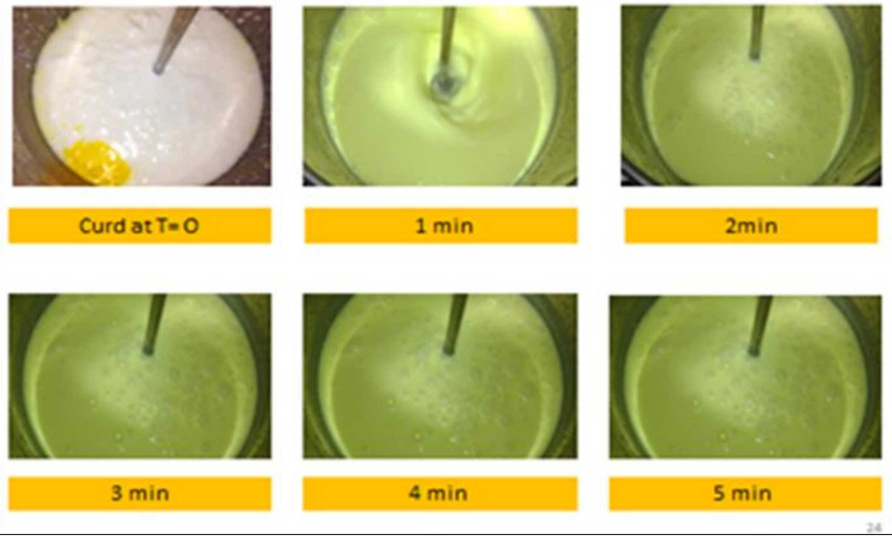
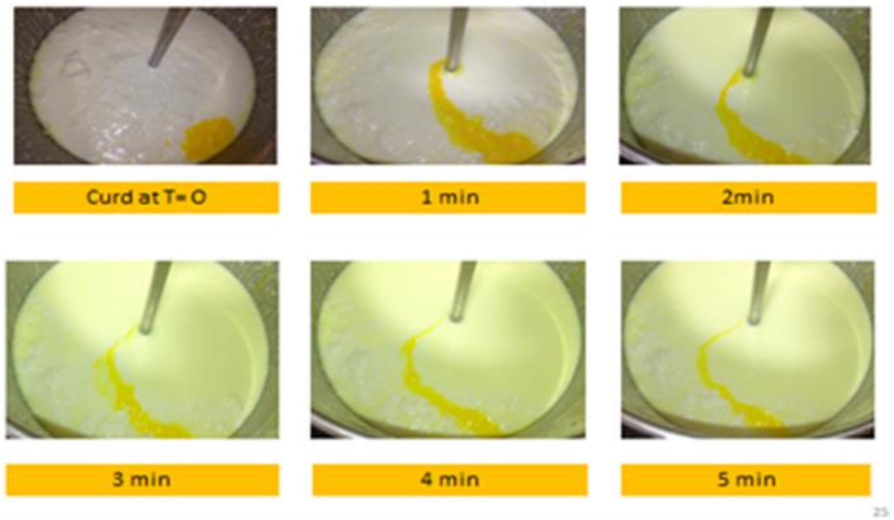
Multivane churn impeller	
Pitched blade	
Saw tooth high shear impeller	

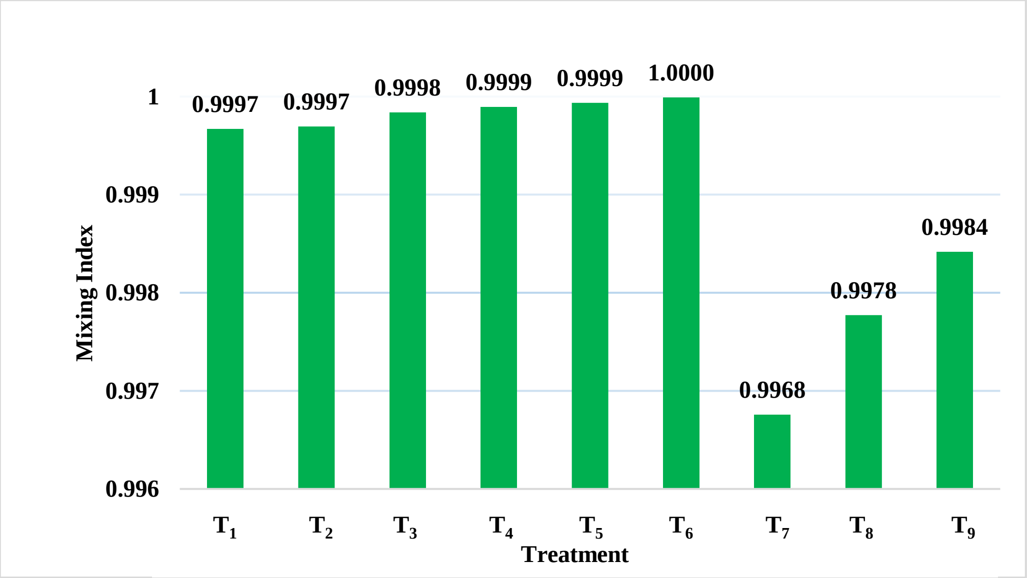
Fig. 4.12: Static view of mixing profile of curd using different impellers

batch of experiment involved the preparation of lassi (3kg), which corresponded to a product height of 12 cm in the process vessel. The mixing performance was recorded in terms of the mixing index, mixing time and power consumption per batch, while the product characteristics were quantified in terms of its objective textural quality and subjective sensory score.

4.4.1 Effect of Off-Bottom Clearance and Speed of Impeller on Mixing Index of *Lassi*

The mixing index provides the idea of mixedness of a product processed with a given set of parameters. It is broadly described as the ratio of actual mixedness obtained to the mixedness that was expected (Berk, 2018). The value zero (0) indicates the totally segregated condition while value of one (1) is representative of total randomness of mixture or an ideally mixed state. Representative samples were drawn at regular intervals during the processing of *lassi* in the Universal Disperser fitted with the multivane churn impeller and its total solids was determined. This data was then applied to compute the mixing index according to Eqn. 3.7. The results obtained is summarised in Fig. 4.13.

From the data presented in Fig. 4.13, it can be concluded that the mixing index was not significantly affected by the impeller speed and off-bottom clearance. The mixing index was recorded as near to unity



[**T_1** (300 rpm, 3cm OBC), **T_2** (400 rpm, 3cm OBC), **T_3** (500 rpm, 3cm OBC), **T_4** (300 rpm, 6cm OBC), **T_5** (400 rpm, 6cm OBC), **T_6** (500 rpm, 6cm OBC), **T_7** (300 rpm, 9cm OBC), **T_8** (400 rpm, 9cm OBC), **T_9** (500 rpm, 9cm OBC)]

Fig. 4.13: Effect of off-bottom clearance and speed of impeller on mixing index of *lassi*

4.4.2 Effect of Off-Bottom Clearance and Speed of Impeller on Mixing Time of *Lassi*

Mixing time was determined as the time at which certain degree of uniformity was achieved in the vessel. Mixing time is an important operational parameter and lower time is associated with better mixing performance (Zhang *et al.*, 2012). The mixing time recorded during the processing of *lassi* in the Universal Disperser at different values of OBC and rpm of impeller is presented in Fig 4.14

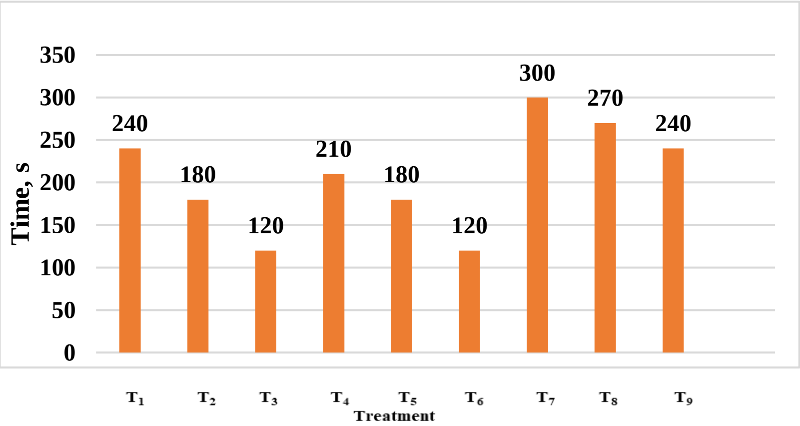
From the investigation, it was found that both the factors, i.e. off-bottom clearance and impeller speed significantly influence the mixing time; the effect of impeller speed was more pronounced than the effect of OBC. At 3 and 6 cm, the effect of OBC was observed only at the lower rpm; at 400 and 500 rpm, the impeller speed negated the influence of OBC and the process recorded near identical mixing times of 180 and 120 s, respectively. Higher mixing times were recorded when the impeller was placed at an OBC of 9 cm for all impeller speed. The effect of speed of impeller was inversely proportional to the mixing time; as the impeller speed increased, the mixing time was found to decrease.

4.4.3 Effect of Off-Bottom Clearance and Speed of Impeller on Power Consumption of *Lassi*

Power consumption, along with the mixing time, is an important criterion to evaluate the performance of a mixing equipment. In food mixing applications, it is always endeavoured to minimize power consumption for the given product application. The power consumed during the processing of *lassi* in the Universal Disperser is presented in Fig. 4.15. It was observed that both OBC and impeller speed significantly influence the power consumption; impeller speed was the dominant factor and power consumption (33 -36 W) varied directly with increasing rpm of the impeller.

4.4.4 Effect of Off-Bottom Clearance and Speed of Impeller on Sensory Quality of *Lassi*

The sensory quality of *lassi* was adjudged by 9-point hedonic scale as per the score card in Appendix-I. The parameters like colour and appearance, body and texture, flavour and overall acceptability were evaluated by sensory panellists. The effect of processing conditions on sensory parameters such as body and texture and overall acceptability was discussed here in details.

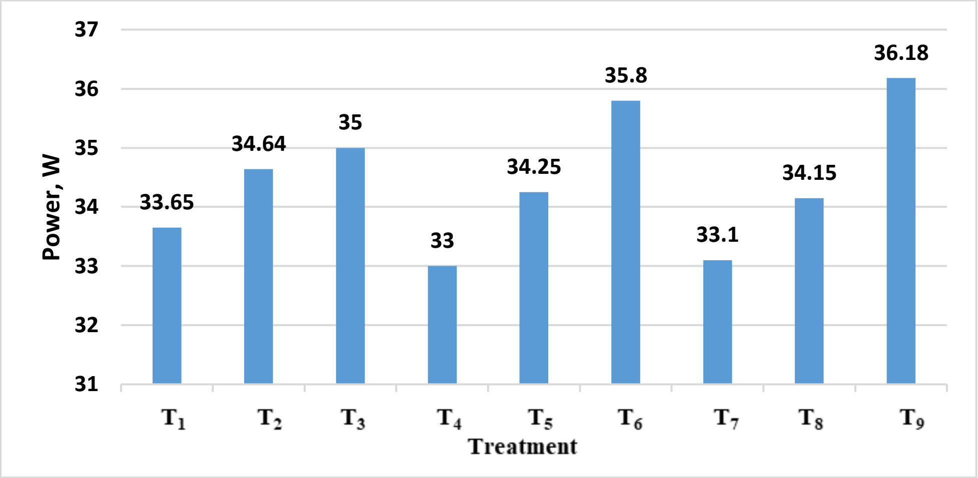


[**T_1** (300 rpm, 3cm OBC), **T_2** (400 rpm, 3cm OBC), **T_3** (500 rpm, 3cm OBC), **T_4** (300 rpm, 6cm OBC), **T_5** (400 rpm, 6cm OBC), **T_6** (500 rpm, 6cm OBC), **T_7** (300 rpm, 9cm OBC), **T_8** (400 rpm, 9cm OBC), **T_9** (500 rpm, 9cm OBC)]

Fig. 4.14: Effect of off-bottom clearance and impeller speed on mixing time of *lassi*

4.4.4.1 Effect of Off-Bottom Clearance and Impeller Speed on Body and Texture

Good quality *lassi* should have no curd particles or any flakes and should have a good mouthfeel and good viscosity. From the sensory data obtained in this study, it was observed that the lassi prepared in the Universal Disperser fitted with the impeller placed at an OBC of 6 cm scored better (8.19) than the other samples (OBC 3cm and OBC 9 cm). Moreover, it was observed that the body and texture of *lassi* prepared with the OBC of 9 cm was distorted (i.e. with unusual whey separation) when the processed samples stored at refrigerated condition for 3 days and no such effect was observed for the samples processed at OBC of 3 and 6 cm.



[**T_1** (300 rpm, 3cm OBC), **T_2** (400 rpm, 3cm OBC), **T_3** (500 rpm, 3cm OBC), **T_4** (300 rpm, 6cm OBC), **T_5** (400 rpm, 6cm OBC), **T_6** (500 rpm, 6cm OBC), **T_7** (300 rpm, 9cm OBC), **T_8** (400 rpm, 9cm OBC), **T_9** (500 rpm, 9cm OBC)]

Fig. 4.15: Effect of off-botom clearance and impeller speed on power consumption during preparation of *lassi*

The stirring speed had significant effect on body and texture of the *lassi* prepared at different levels of off-bottom clearance. Among 3 levels of stirring speed, *lassi* prepared at 400 rpm scored high followed by 300 rpm and 500 rpm, irrespective of the off-bottom clearance. The maximum score of 8.19 was found when processed with an impeller positioned at an OBC of 6 cm and impeller speed of 400 rpm. When the *lassi* was stirred at 300 rpm, a thicker consistency was perceived while stirring at 500 rpm, the product reported a thin consistency which are not liked by many judges. *Lassi* prepared at 400 rpm was neither too thick nor thin and in general, was preferred by the judges.

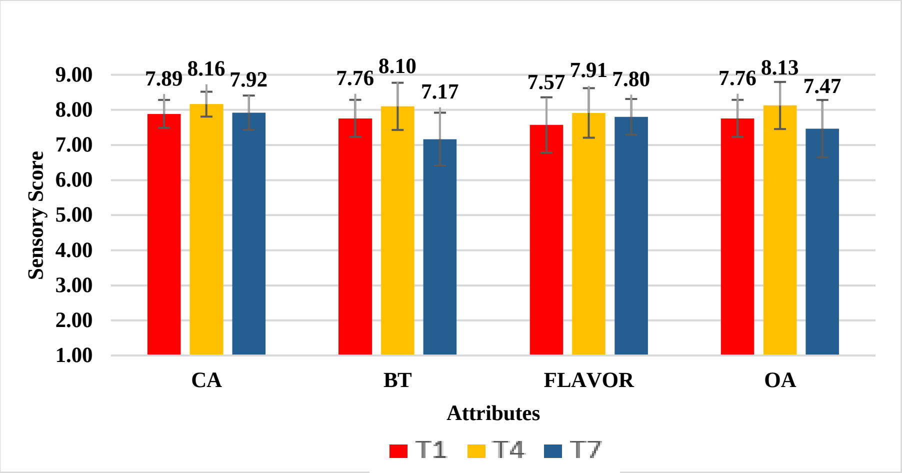
4.4.4.2 Effect of Off-Bottom Clearance and Impeller Speed on Overall Acceptability of *Lassi*

The overall acceptability scores recorded for the *lassi* samples processed at different off bottom clearance and impeller speed is presented in Fig 4.16. Both parameters were observed to have significant effect on overall acceptability of *lassi.* The overall acceptability corresponded with the trend reported for the body and texture scores, samples prepared at 400 rpm and OBC of 6 cm was more acceptable than the other samples of *lassi.*

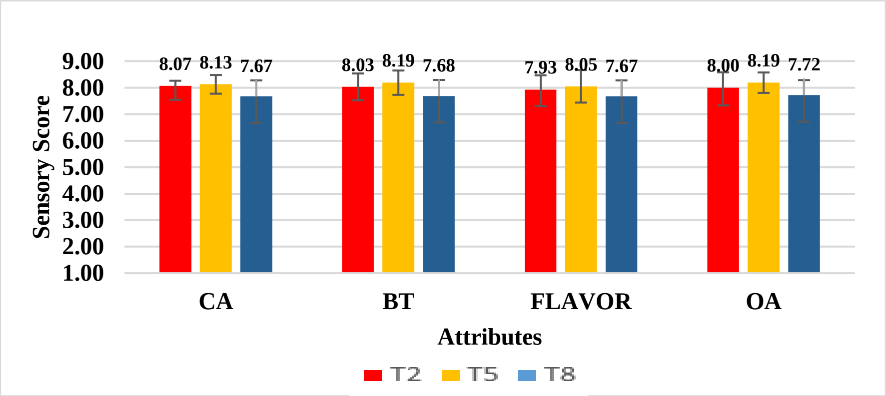
4.4.5 Effect of Off-Bottom Clearance and Impeller Speed on Viscosity of *Lassi*

The viscosity of *lassi* was measured using Brookfield viscometer at a spindle rpm of 200 and temperature of 15 ^{o}C. The various values of viscosity of *lassi* can be seen from the Fig. 4.17. Both off-bottom clearance and impeller speed were exerted significant influence on the viscosity of the product. The midpoint combination of 6 cm of OBC and 400 rpm was found to result in *lassi* samples of lowest viscosity, while the combination of the extreme points of the parameters resulted in more viscous product. This was in contrast to the subjective perception recorded for the product, where the judges remarked that higher rpm resulted in thinner *lassi.*

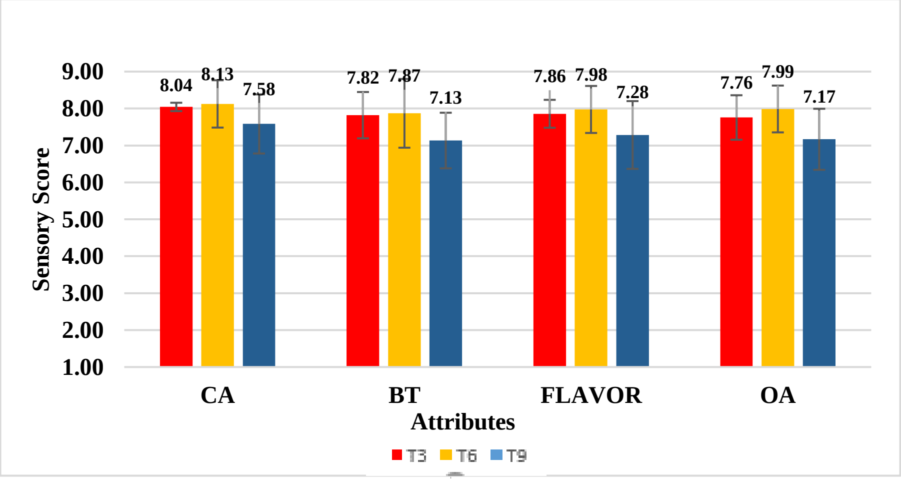
Impeller speed or stirring speed also had a significant effect on viscosity of *lassi*. For a given off-bottom clearance, it was observed that as the impeller speed increased, the product viscosity decreased. This may be attributed to the greater shearing action on curd leading to decrease in the viscosity, Lee and Lucey (2010) highlighted the effect of shearing on gel breakdown in fermented products such as yoghurt and its effect on the product rheology.



T₁ **(**300 rpm, 3cm OBC), **T**₄ (300 rpm, 6cm OBC), **T**₇ (300 rpm, 9cm OBC)
CA-Color and appearance**, BT**-Body and texture**, OA**-Overall acceptability



T₂ **(4**00 rpm, 3cm OBC), **T**₅ (400 rpm, 6cm OBC), **T**₈ (400 rpm, 9cm OBC)
CA-Color and appearance**, BT**-Body and texture**, OA**-Overall acceptability



T₃ **(**500 rpm, 3cm OBC), **T**₆ (500 rpm, 6cm OBC), **T**₉ (500 rpm, 9cm OBC)
CA-Color and appearance**, BT**-Body and texture**, OA**-Overall acceptability

Fig. 4.16: Changes in sensorial attributes of *lassi* processed at different impeller speeds and off-bottom clearances (OBC)

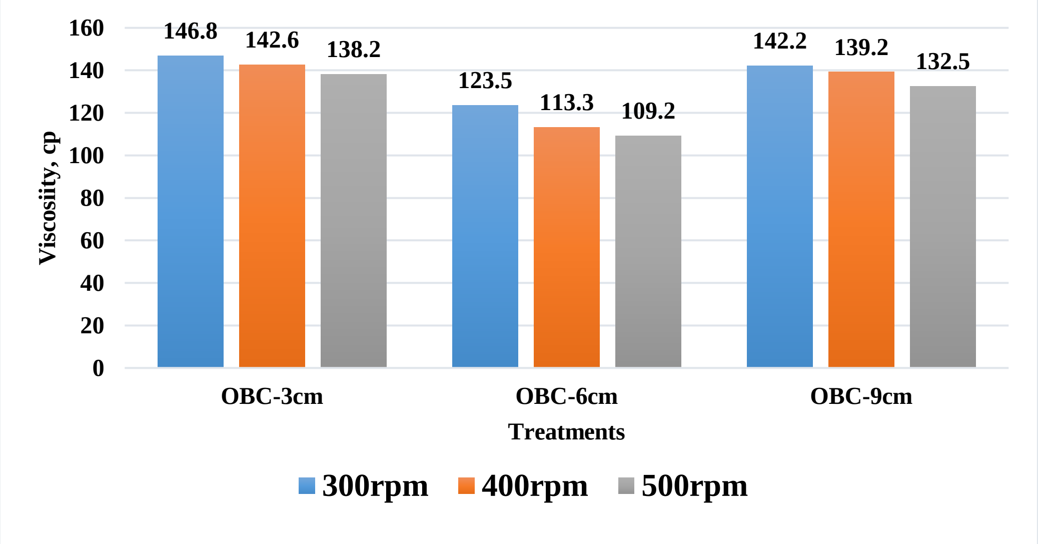


Fig. 4.17: Changes in viscosity of *lassi* processed at different Off-bottom clearance (OBC) and impeller speed

4.4.6 Effect of Processing Parameters on Various Responses during Preparation of *Lassi*

The effect of processing conditions namely, off bottom clearance and impeller speed was assessed in terms of mixing performance and product characteristics as per an experimental design of 13 runs presented in Table 4.3.

4.4.6.1 Mixing Time

The regression analysis of data on mixing time presented in Table-4.4 revealed that the coefficient of determination (R^2) for the quadratic model was 0.97 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of *lassi* made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 25.16, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F-value (62.31) being significant ($p \leq 0.01$). The interaction among variables and their effect on mixing time is shown in 3-D graph (Fig. 4.18)

The coefficients of estimates for mixing time model (Table-4.4) indicated that impeller speed had negative while OBC had significant ($p \leq 0.01$) positive effect on mixing time at linear terms. It indicates that decreasing impeller speed and increasing OBC at linear levels increased mixing time of lassi. Among possible interactions, there was a positive significant ($p \leq 0.01$) effect found between OBC and impeller speed.

The mixing time of *lassi* could be predicted by the equation (for actual values of the variables) given below:

$$\text{Mixing time} = 172.75 + 45\text{OBC} - 45\text{RPM} + 15(\text{OBC})(\text{RPM}) + 55.34(\text{OBC})^2 - 4.65(\text{RPM})^2$$

4.4.6.2 Mixing Index

The regression analysis of data on mixing index presented in Table-4.4 revealed that the coefficient of determination (R^2) for the quadratic model was 0.13 and the “lack of fit” test which inversely measures the fitness of the model was significant. This indicated that the model was sufficiently accurate for predicting mixing index of *lassi* made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 1.480 which is very lower than the minimum desirable 4

Table 4.3: Effect of processing parameters on various responses during preparation of *lassi*

Std Order	Factor 1 A: OBC	Factor 2 B: RPM	Mixing Time	Mixing Index	Power consumption	Overall Acceptability
1	3	300	240	0.999669	33.65	7.74
2	9	300	300	0.996757	33.10	7.58
3	3	500	120	0.999839	35.00	7.87
4	9	500	240	0.998417	36.18	7.29
5	3	400	180	0.999695	34.64	8.00
6	9	400	270	0.997773	34.15	7.68
7	6	300	210	0.999894	33.00	8.07
8	6	500	120	0.999991	35.80	7.98
9	6	400	180	0.999934	34.56	8.13
10	6	400	180	0.991234	34.25	8.21
11	6	400	180	0.999923	37.15	8.11
12	6	400	180	0.999895	34.25	8.06
13	6	400	150	0.999937	34.12	8.16

(for high prediction ability). The F-value (0.22) was not significant and not considered for optimization. This indicated that the processing parameters had no significant influence on mixing index of the *lassi*. The interaction among variables and their effect on mixing index is shown in 3-D graph (Fig. 4.18).

4.4.6.3 Power Consumption

The regression analysis of data on power consumption presented in Table-4.4 revealed that the coefficient of determination (R^2) for the quadratic model was 0.57 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting power consumption while preparation of *lassi* made with any combination of the factors within the range evaluated. The 'adequate precision' was found to be 4.76, which is higher than the minimum desirable 4 (for high prediction ability). The statistical analysis indicated that the model F-value (1.92) was non-significant. The interaction among variables and their effect on power consumption is shown in 3-D graph (Fig. 4.19).

Table 4.4: Regression coefficients and ANOVA of quadratic model of Mixing time, Mixing index, Power consumption and Overall acceptability for different levels of off-bottom clearance (A) and impeller speed (RPM) (B)

Factor	Mixing Time	Mixing Index	Power Consumption	Overall Acceptability
Intercept	172.75	0.99	34.60	8.14
A	45*	-0.0010^{NS}	0.023^{NS}	-0.176*
B	-45*	0.0003^{NS}	1.205**	-0.041^{NS}
AB	15**	0.00037^{NS}	0.4325^{NS}	-0.105*
A^2	55.34*	-0.000329^{NS}	-0.2037^{NS}	-0.347*
B^2	-4.65^{NS}	0.00087^{NS}	-0.1987^{NS}	-0.162*
R^2	0.97	0.13	0.57	0.97
Adj R^2	0.96	-0.48	0.27	0.95
Adq. Pre.	25.16	1.480	4.76	21.94
Model F-value	62.31*	0.22^{NS}	1.92^{NS}	54.80*
Lack of Fit	NS	NS	NS	NS

*Significant at p <.01, **Significant at p <. 05, NS=Nonsignificant

The coefficients of estimate for power consumption indicated that OBC had no significant effect while impeller speed had significant ($p \leq 0.05$) effect. The interaction showed non-significant effect on power consumption.

The power consumption for preparation of *lassi* could be predicted by the equation (for actual values of the variables) given below:

$$\text{Power consumption} = 34.78 + 1.20\ (\text{RPM})$$

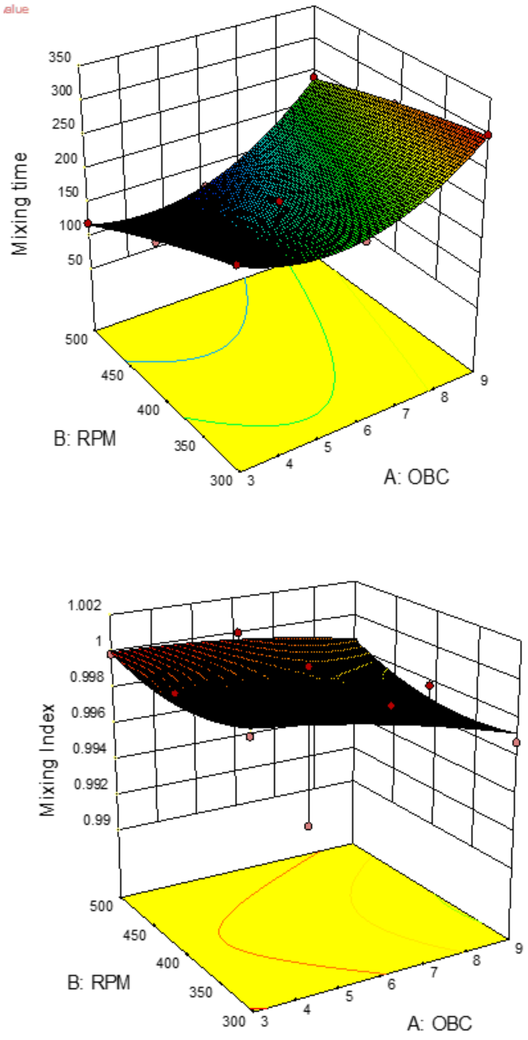


Fig. 4.18: Response surface graph relating mixing time and mixing index value as influenced by off-bottom clearance (OBC) and impeller speed (RPM)

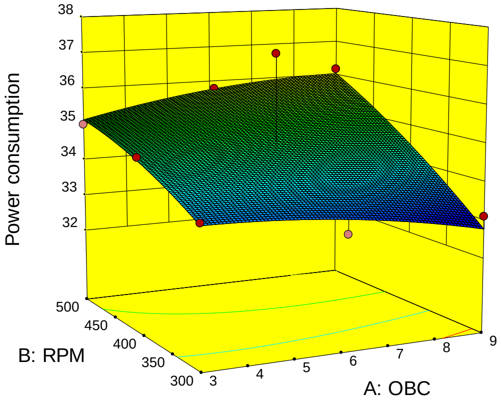


Fig. 4.19: Response surface graph relating power consumption value as influenced by off-bottom clearance (OBC) and impeller speed (RPM)

4.4.6.4 Overall Acceptability

The regression analysis of data on overall acceptability presented in Table-4.4 revealed that the coefficient of determination (R^2) for the quadratic model was 0.97 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting overall acceptability score of *lassi* made with any combination of the factors within the range evaluated. The 'adequate precision' was found to be 21.94, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F-value (54.80) was significant ($p \leq 0.01$). The interaction among variables and their effect on overall acceptability is shown in 3-D graph (Fig. 4.20).

The coefficients of estimate for overall acceptability (Table-4.4) indicated that OBC had negative significant ($p \leq 0.01$) effect while impeller speed had no significant effect. It indicates that, decreasing OBC showed increasing overall acceptability score, while impeller speed was found to have no significant effect.

The overall acceptability of *lassi* could be predicted by the equation (for actual values of the variables) given below:

$$\text{Overall Acceptability} = 8.14 - 0.17\,(\text{OBC}) - 0.10\,(\text{OBC})(\text{RPM}) - 0.34(\text{OBC})^2 - 0.16\,(\text{RPM})^2$$

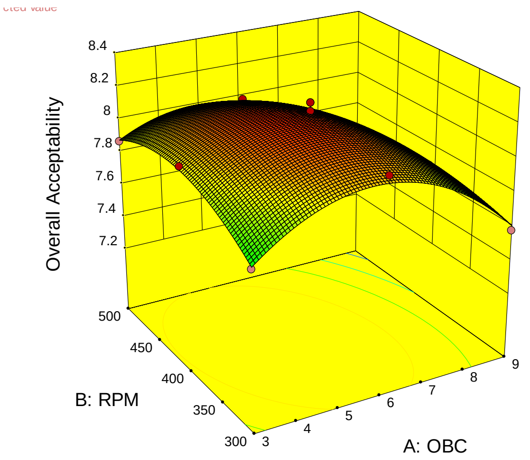


Fig. 4.20: Response surface graph relating overall acceptability value as influenced by off-bottom clearance (OBC) and impeller speed (RPM)

4.4.7 Optimization of Process Parameters for *Lassi*

The inbuilt numerical optimization menu of Design Expert V. 10.0 was applied to obtain the optimal conditions of the process parameters namely, off-bottom clearance and speed of impeller for *lassi* preparation. The constraints for optimization were set as presented in Table-4.5. The criteria for optimization was set to maximize the sensory score and mixing index while minimizing the mixing time and power consumption.

Parallelly, constraints were set for the remaining parameters to remain within the range recorded for the experimental values. The upper and lower limits of the goal set for the constraints for optimization of processing parameters for *lassi* preparation is listed in Table-4.5. From amongst the suggestions given by the software after analysis for the optimal combination of off-bottom clearance and speed of impeller meeting the constraints listed in Table-4.5, the solution with the most desirability factor (0.80) was chosen as the optimal point. Processing conditions of off-bottom clearance of 4.84 cm in combination with an impeller speed of 389 rpm was identified as the most optimal process conditions to prepare the *lassi* with multivane impeller using Universal Disperser.

4.4.8 Validation of the Optimized Formulation

The process conditions optimized in the study was validated against experimental values obtained by preparing the *lassi* under the recommended process conditions (OBC-4.84

cm, 389 rpm) and recording the real time values of all the responses i.e., mixing time, mixing index, power consumption and sensory scores for overall acceptability.

The obtained values were compared with the predicted value (generated by the software) and statistical difference between the experimental and predicted values were tested using the Students' t-test (α = 0.05). The results of validation are presented in Table-4.6, no significant difference was observed between the experimental and predicted values, confirming the adequacy of the developed model.

Table 4.5: Goal set for constraints for optimization of process parameter for *lassi*

Particulars	Name	Goal	Lower limit	Upper limit
Factors	Off-bottom clearance	Is in range	3	9
	Speed	Is in range	300	500
	Mixing time	Minimize	120	300
	Power consumption	Minimize	33	37.15
	Overall acceptability	Maximize	7.29	8.21

Table 4.6: Comparison of predicted and observed values of responses to validate the optimized results

Attributes	Predicted value	Observed value	Calculated t (α=0.05) value
Mixing Time, s	168	160±17.32	0.999^{NS}
Mixing Index	0.999		
Power Consumption, W	34.47	34.21±0.701	0.3716^{NS}
Overall Acceptability	8.16	8.16±0.153	0.2931^{NS}

NS: Non-Significant, (Mean±SD, n=3)

4.5 Preparation and Optimization of Process Parameters for Processed Cheese Spread

Process cheese spread (PCS) is popular dairy product which is consumed widely due to its sensorial and nutritional qualities (Giri and Kanawjia, 2018). It is a good source of protein and fat and is mostly eaten as a table spread on bread for breakfast. Generally, processed cheese spread prepared from old cheddar cheese and fresh cheddar cheese and contains other ingredients like emulsifier, butteroil, SMP and water. The mixture is cooked and blended at high temperature up to a consistency which can be easily spreadable. A special equipment has been developed for the cooking of PCS.

In present study, the developed Universal Disperser was tested to prepare the processed cheese spread of satisfactory quality. The blending of product was done using the high shear saw tooth impeller at different impeller speed and process temperature. PCS is high viscous product and therefore requires high speed and more power.

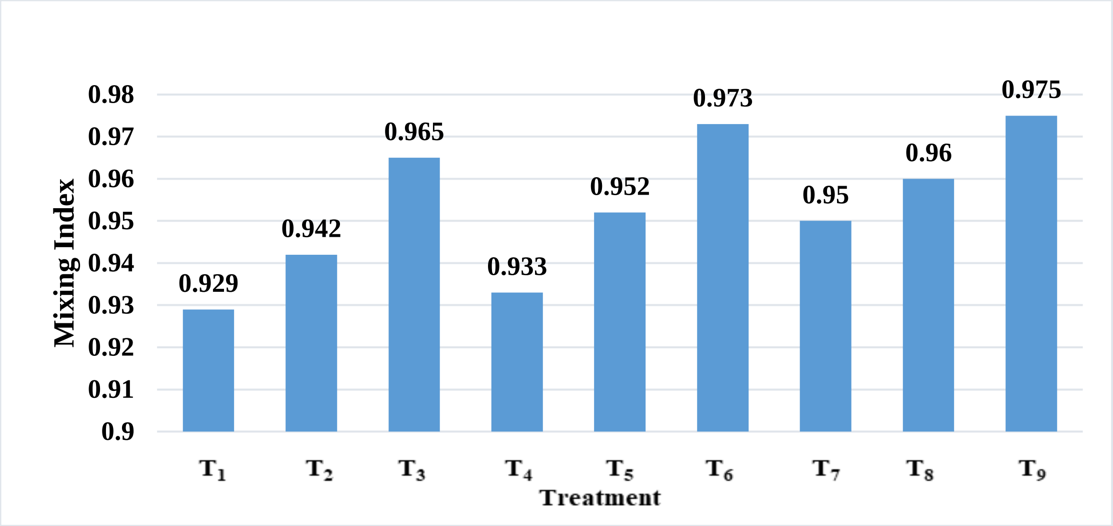
The experiment was conducted at three different level of melting temperature viz., 50 ^{o}C, 65 ^{o}C and 80 ^{o}C. The impeller speed to blend the content was set at three different levels namely 10000, 15000 and 20000 rpm. The speed and temperature were selected on the results obtained in the preliminary trials. The control sample was prepared at melting temperature of 80 ^{o}C with the use of hand blender having speed up to 20000 rpm with two blade geometry (4 mm dia).

The PCS was formulated using 60 percent 1 ½ month old cheddar cheese, 40 per cent 6 month old cheddar cheese, 3 per cent trisodium citrate as emulsifier, 1 per cent sodium chloride (Table salt) and water to makeup moisture of processed cheese spread to 60 per cent (15 per cent water was extra added to compensate the evaporation during processing). The blending was done for a period of 10 min and samples were drawn every 1 min to analyse mixing index and mixing time. The power consumption was also noted down at a defined impeller speed and temperature.

4.5.1 Effect of Impeller Speed on Mixing Index

The mixing index, a quantitative entity representative of the randomness (degree of uniformity) of the mixing ingredient in a product at a given set of processing conditions, was computed based in the total solids in the product mix as the mixing progressed over a period of 10 min. Three levels of blending speed namely 10000 rpm, 15000 rpm and 20000 rpm were selected to study the effect of different impeller speed on mixing index. It can be seen from the Fig. 4.21 that as the speed of blending increases from 10000 to 20000, mixing index found to increase when processed at same melting temperature. The highest mixing index value of 0.975

was observed at 20000 rpm when processed at 80 °C while the lowest value was observed at 10000 rpm at 50 °C.



T₁ (50°C, 10000 rpm), **T₂**(50°C, 15000 rpm), **T₃** (50°C, 20000 rpm)
T₄ (65°C, 10000 rpm), **T₅** (65°C, 15000 rpm), **T₆** (65°C, 20000 rpm)
T₇ (80°C, 10000 rpm), **T₈** (80°C, 15000 rpm), **T₉** (80°C, 20000 rpm)

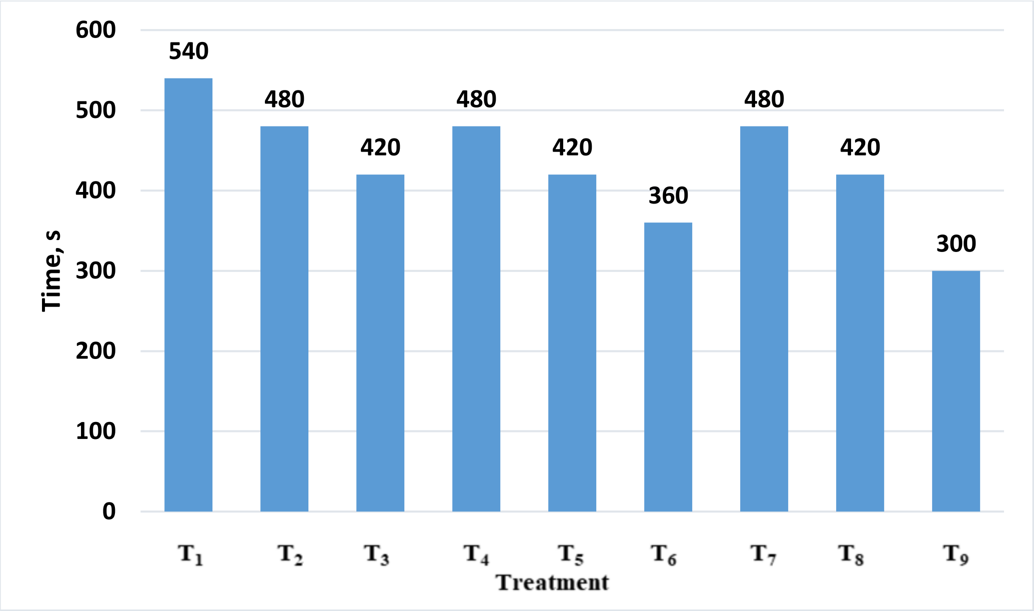
Fig. 4.21: Effect of impeller speed and melting temperature on mixing index of PCS

4.5.2 Effect of Melting Temperature on Mixing Index

Three temperature levels viz., 50 °C, 65 °C and 80 °C were identified for the preparation of processed cheese spread in the Universal Disperser. The melting temperature had a significant effect on mixing index of the PCS. As the temperature increased, mixing index also improved. Kapoor and Metzger (2008) listed process temperature as a primary factor influencing manufacture of process cheese; in the present study higher temperature might have aided the easy blending which in turn would have resulted in higher mixing index. The highest mixing index of 0.975 was observed at 80 °C while lowest mixing index (0.929) scored at 50 °C.

4.5.3 Effect of Impeller Speed on Mixing Time

Mixing time is an important parameter to judge the performance of the mixing equipment and impeller efficiency. Lower mixing time is desirable to reduce the time for preparing a batch (Pordal and Matice, 2003). In the present study, the effect of impeller speed on mixing time was evaluated and the result is presented in Fig. 4.22.



T_1 (50^{o}C, 10000 rpm), **T_2**(50^{o}C, 15000 rpm), **T_3** (50^{o}C, 20000 rpm)
T_4 (65^{o}C, 10000 rpm), **T_5** (65^{o}C, 15000 rpm), **T_6** (65^{o}C, 20000 rpm)
T_7 (80^{o}C, 10000 rpm), **T_8** (80^{o}C, 15000 rpm), **T_9** (80^{o}C, 20000 rpm)

Fig. 4.22: Effect of impeller speed and melting temperature on mixing time of PCS

From the results, it can be observed that the impeller speed had a significant effect on mixing time. As impeller speed increased from 10000 to 20000 rpm, the mixing time was found to decrease when processed at same temperature. The maximum mixing time of 540 s was observed at 10000 rpm when processed at 50 ^{o}C while the lowest time was recorded at 20000 rpm at 80 ^{o}C. The mixing time was observed to vary inversely with the impeller speed. Guinee (2007) highlighted that proper blending of the ingredients is a primary step in the preparation of good quality processed cheese spread, before its texturization to desired levels and discussed the interactive effect of process temperature and process time in the product preparation.

4.5.4 Effect of Melting Temperature on Mixing Time

PCS, being a product with complex food structure, the melting temperature is considerable significant parameter which influenced the mixing properties of PCS components. The analysis showed that as the temperature of processing increased from 50 to 80 ^{o}C, the mixing time progressively decreased, indicating a negative correlation between process temperature and mixing time.

4.5.5 Effect of Impeller Speed on Work of Shear

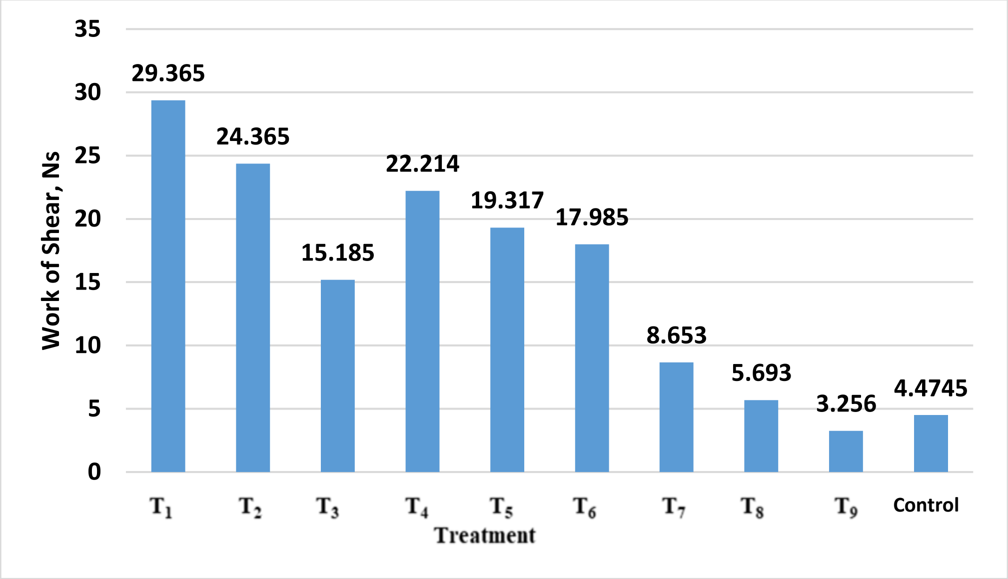
Work of shear is inversely proportional to spreadibility; hence for a product like processed cheese spread, it is desirable to have minimum work of shear. Work of shear (N.s) was determined using a texture analyser, as the area under the penetration cycle (down stroke) in the force distance curves. The result is plotted in Fig. 4.23.

Impeller speed had a pronounced effect on work of shear or spreadibility of the PCS. The highest value of work of shear was observed at 10000 rpm when processed at 50 ^{o}C while the lowest value was observed at 20000 rpm when processed at 80 ^{o}C. As the impeller speed increased from 10000 to 20000, the spreadibility was found to increase for a given melting temperature. The process temperature was also found to have a synergistic effect on impeller speed while influencing spreadibility of the product.

4.5.6 Effect of Melting Temperature on Work of Shear

Melting temperature had a significant effect on shear work of PCS. If the product is rigid, it requires more force to spread while if it is soft, it requires less force to spread out. In the present study, processing the PCS ingredients at higher temperature was found to improve the spreadibility of the PCS. In an experiment, Lee *et al.,* (1981) manufactured processed Emmental cheese at 4 different cook temperatures (80, 100, 120 and 140 ^{o}C) and subsequently analysed the firmness (using penetrometry) and the microstructure of the product. They found that the increase in cooking temperature during cheese manufacture increased the firmness of the process cheese and strength of the process cheese emulsion also increased.

This means that above certain value of cooking temperature; the firmness of process cheese increased. The PCS contained higher moisture than processed cheese; the added water was known to decrease the hardness or firmness of processed cheese (Zuber *et al*., 1987; Pereira *et al*., 2001) and to improve the product meltability (Gupta and Reuter,1993).



T_1 (50°C, 10000 rpm), **T_2**(50°C, 15000 rpm), **T_3** (50°C, 20000 rpm)
T_4 (65°C, 10000 rpm), **T_5** (65°C, 15000 rpm), **T_6** (65°C, 20000 rpm)
T_7 (80°C, 10000 rpm), **T_8** (80°C, 15000 rpm), **T_9** (80°C, 20000 rpm)

Fig. 4.23: Effect of impeller speed and melting temperature on work of shear of PCS

4.5.7 Effect of Impeller Speed and Temperature on Power Consumption

Impeller speed had significant effect on power consumption of the motor (Fig 4.24). As the speed increased from 10000 to 20000; the power consumption was also found to increase. The highest power consumption (365.58 W) was noted at 20000 rpm when product was treated at 50 °C while the lowest value (168.56 W) was recorded at 10000 rpm and 80 °C. The power consumption values provided the evidence to the fact that as the cooking temperature increased from 50 to 80 °C, the spreadibility of PCS increased. Power consumption at 80 °C was found to be lower than at 65 °C followed by 50 °C. This was due to the fact that at higher temperature, product offered less resistance during mixing to the impeller.

4.5.8 Effect of Impeller Speed and Temperature on Sensory Quality of PCS

The sensory evaluation of processed cheese spread was done using the 9-point hedonic scale. The sensory attributes like colour and appearance, flavour, consistency, spreadibility and overall acceptability were judged on the scale of 1 to 9. The scorecard is presented in Appendix-II.

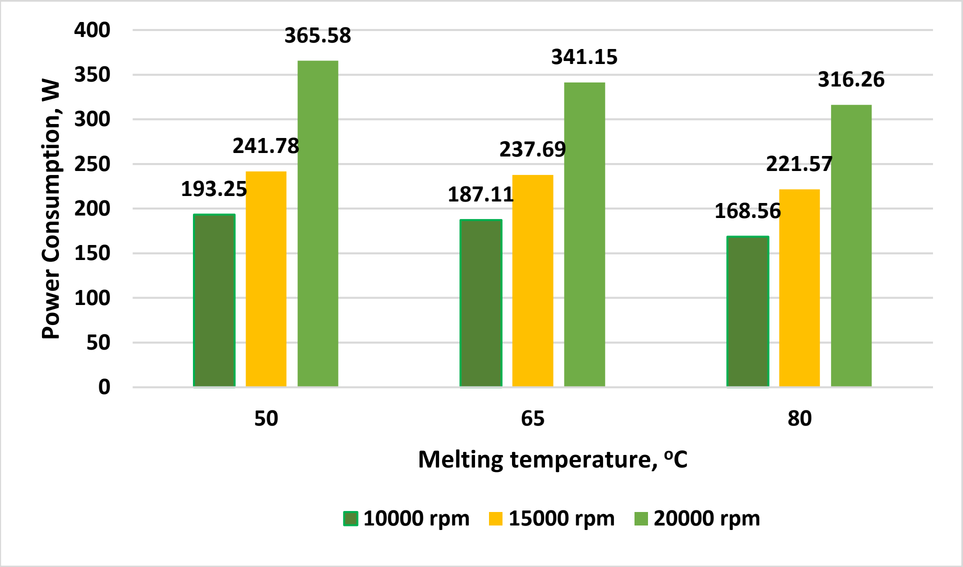


Fig. 4.24: Effect of impeller speed and melting temperature on power consumption in preparation of PCS

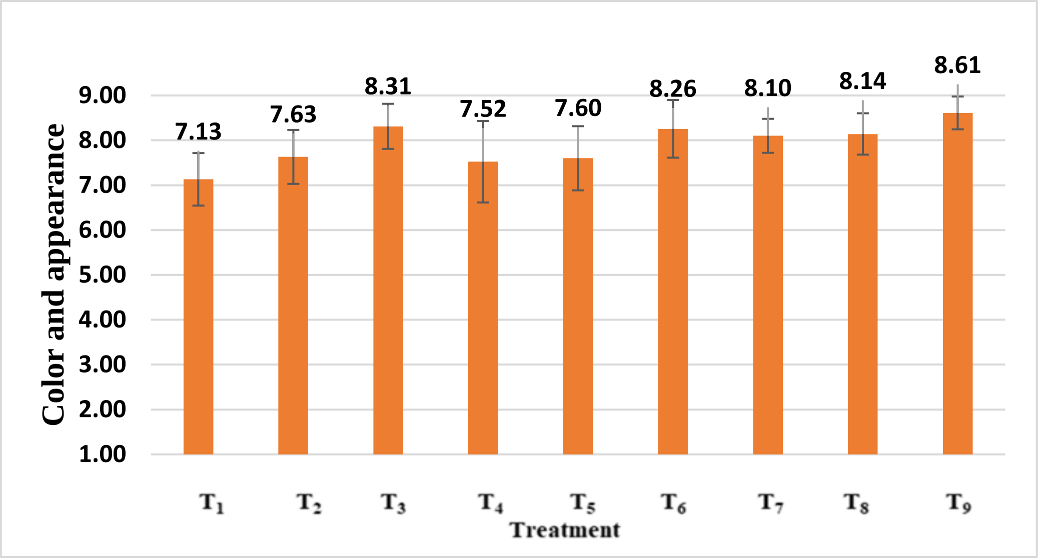
4.5.8.1 Effect on Colour and Appearance

In the present study, the colour and appearance (CA) score (Fig. 4.25) of the control and experimental samples ranged from 7.13 to 8.16. The CA score was found to increase with increase in the impeller speed and temperature. The highest CA score (8.16) was observed at 80 ^{o}C and 20000 rpm while lowest score (7.13) was noted at 10000 rpm at 50 ^{o}C. The control sample prepared using a conventional hand blender scored 8.18 on 9-point hedonic scale.

4.5.8.2 Effect on Flavour

Flavour and texture have been identified as important sensory attributes influencing the acceptability of processed cheese spreads (Diam and Ibtisam, 2007). In the current investigation, the flavour score (Fig. 4.26) recorded during the sensory evaluation ranged from 7.59 to 8.42, while the flavour score obtained for control sample was 7.88. Even though the product formulation was identical, processing conditions, mainly the process temperature influenced the flavour development in the product. The highest flavour score was recorded for the samples processed at 80 ^{o}C, followed by 65 ^{o}C and 50 ^{o}C. The interactive effect of temperature and impeller speed was also found to improve the flavour score marginally. The maximum sensory score was recorded for samples processed at 80 ^{o}C and 20000 rpm.

4.5.8.3 Effect on Consistency and Spreadibility



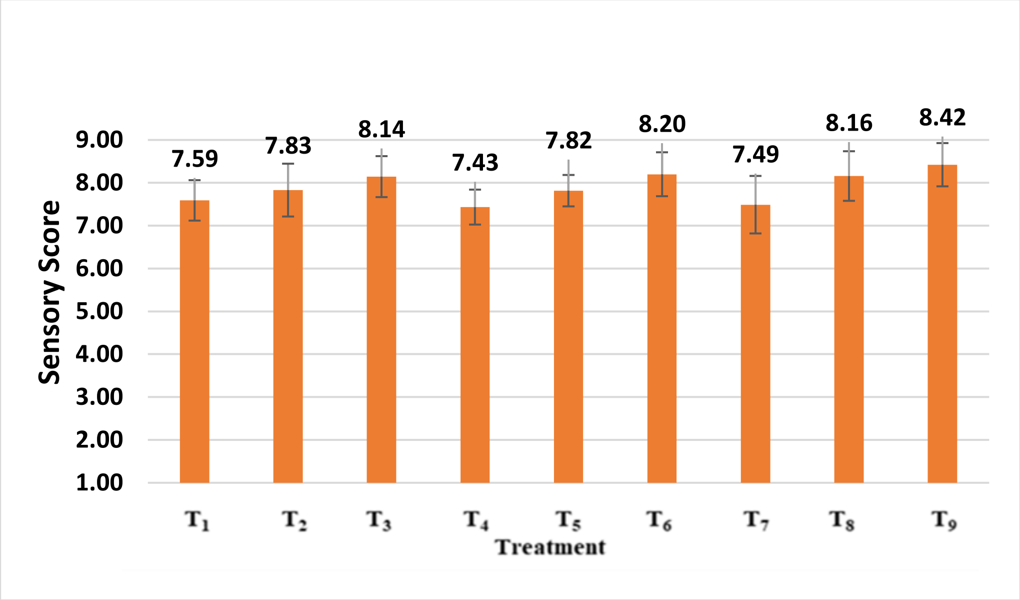
T_1 (50°C, 10000 rpm), **T_2**(50°C, 15000 rpm), **T_3** (50°C, 20000 rpm)
T_4 (65°C, 10000 rpm), **T_5** (65°C, 15000 rpm), **T_6** (65°C, 20000 rpm)
T_7 (80°C, 10000 rpm), **T_8** (80°C, 15000 rpm), **T_9** (80°C, 20000 rpm)

Fig. 4.25: Effect of impeller speed and melting temperature on colour and appearance of PCS

Spreadability is a very important functional characteristic of any spread and the spreadibility of processed cheese spreads is ascribed to the interactive effects of the added emulsifiers and processing parameters like melting temperature and extent of shear (Guinee, 2007). A smooth consistency is also listed as a desirable quality attribute of cheese spreads (Guinee, 2016).

In the current investigation, the sensory profiling of the textural attributes of the prepared spread was recorded in terms of subjective consistency and spreadibility (C & S) scores and the findings are plotted in Fig. 4.27. It was observed that the C & S score recorded for the product ranged between 7.20-8.39. Both impeller speed and process temperature were found to exert significant influence on the texture development in the product; the ingredients appeared well mixed and spreadibility was improved as impeller speed increased from 10000-20000 rpm. High temperature was also found to aid the mixing process and improved overall spreadibility of the cheese spread. Maximum C & S score (8.39) was recorded for the sample prepared at 80 ^{o}C when processed at 20000 rpm while lowest score (7.20) was observed at 50

^{o}C at 10000 rpm. In comparison, the control sample scored 7.98 for consistency and spreadibility.

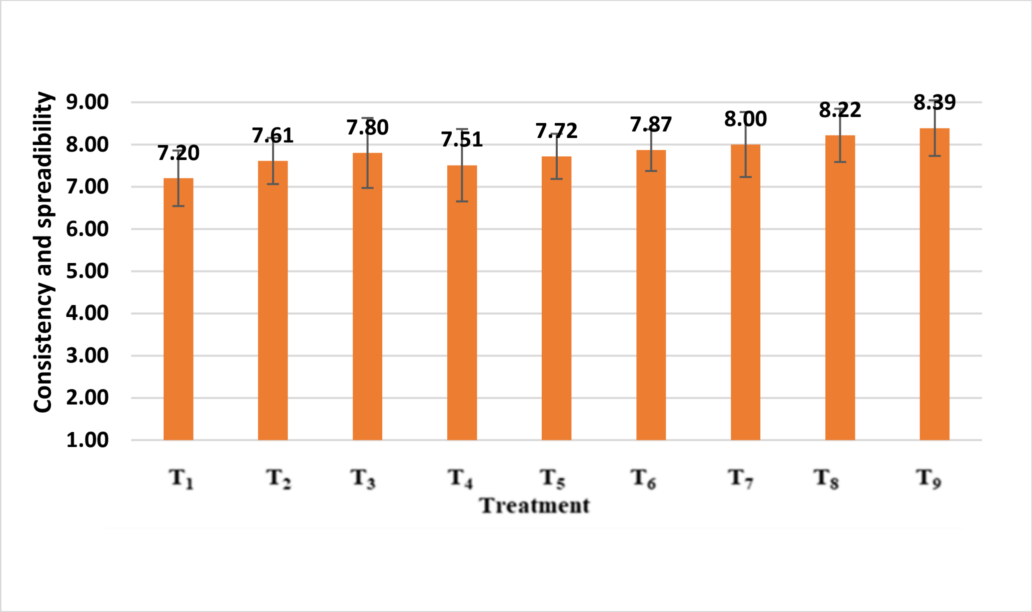


T_1 (50^{o}C, 10000 rpm), **T_2**(50^{o}C, 15000 rpm), **T_3** (50^{o}C, 20000 rpm)
T_4 (65^{o}C, 10000 rpm), **T_5** (65^{o}C, 15000 rpm), **T_6** (65^{o}C, 20000 rpm)
T_7 (80^{o}C, 10000 rpm), **T_8** (80^{o}C, 15000 rpm), **T_9** (80^{o}C, 20000 rpm)

Fig. 4.26: Effect of impeller speed and melting temperature on flavour of PCS

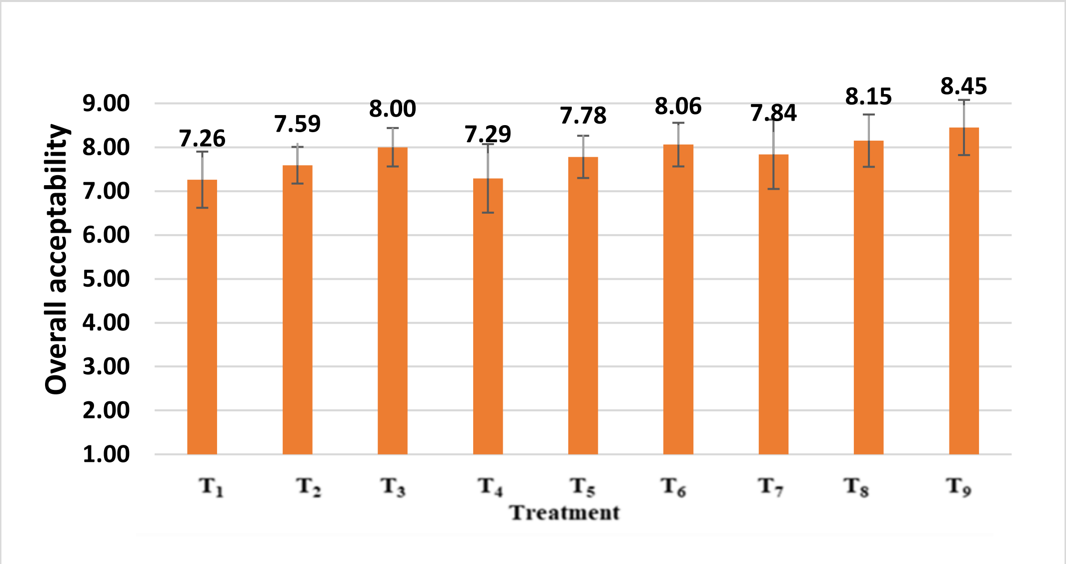
4.5.8.4 Effect on Overall Acceptability

The overall acceptability (OA) score (Fig. 4.28) of PCS at different impeller speeds and temperatures ranged between 7.26-8.45. As the temperature of cooking and impeller speed increased, the overall acceptability score was found to improve significantly. Both temperature and impeller speed had significant effect on PCS sensory quality and their interactive effect yielded better spreadibility. The OA score of 8.45 was found highest at 80 ^{o}C when processed at 20000 rpm while lowest (7.26) was noted at 10000 rpm at 50 ^{o}C. In comparison, the control sample scored 7.94 on 9-point hedonic scale.



T_1 (50°C, 10000 rpm), **T_2**(50°C, 15000 rpm), **T_3** (50°C, 20000 rpm)
T_4 (65°C, 10000 rpm), **T_5** (65°C, 15000 rpm), **T_6** (65°C, 20000 rpm)
T_7 (80°C, 10000 rpm), **T_8** (80°C, 15000 rpm), **T_9** (80°C, 20000 rpm)

Fig. 4.27: Effect of impeller speed and melting temperature on consistency and spreadibility of PCS



T_1 (50°C, 10000 rpm), **T_2**(50°C, 15000 rpm), **T_3** (50°C, 20000 rpm)
T_4 (65°C, 10000 rpm), **T_5** (65°C, 15000 rpm), **T_6** (65°C, 20000 rpm)
T_7 (80°C, 10000 rpm), **T_8** (80°C, 15000 rpm), **T_9** (80°C, 20000 rpm)

Fig. 4.28: Effect of impeller speed and melting temperature on overall acceptability of PCS

4.5.9 Effect of Process Parameters on Various Responses during Preparation of Processed Cheese Spread

The effect of process parameters on the mixing performance and product quality of processed cheese spread (PCS) was evaluated across 13 runs of experimental combinations and the results are tabulated in Table 4.7.

4.5.9.1 Mixing Time

The regression analysis of data on mixing time presented in Table-4.8 for mixing time revealed that the coefficient of determination (R^2) for the quadratic model was 0.85 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of PCS made with any combination of the factors within the range experiments. The 'adequate precision' was found to be 13.57, which is appreciably higher than the minimum desirable value of 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F-value (14.95) being significant ($p \leq 0.01$). The interaction among variables and their effect on mixing time is shown in 3-D graph (Fig.4.29).

The coefficient of estimates for mixing time model (Table-4.8) indicated that temperature and impeller speed had significant ($p < 0.01$) negative effect on mixing time. Decreasing impeller speed and melting temperature increased the mixing time. Interaction among them had no significant effect.

The mixing time of PCS could be predicted by the equation (for actual values of the variables) given below:

$$\text{Mixing time} = 428.28 - 39.54\,T - 65.00\,RPM + 12.87(T)^2$$

4.5.9.2 Mixing Index

The regression analysis of data on mixing index presented in Table-4.8 for mixing index revealed that the coefficient of determination (R^2) for the quadratic model was 0.95 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of PCS made with any combination of the factors within the range evaluated. The 'adequate precision' was found to be 25.00, which is appreciably higher than the minimum desirable 4 (for high prediction ability).

Table 4.7: Effect of processing parameters on various responses during preparation of processed cheese spread

Std order	Factor 1 A: Temperature	Factor 2 B:RPM	Mixing Time	Mixing Index	Power Consumption	Overall Acceptability	Work of shear
1	50	10000	540	0.9295	193.25	7.26	29.36
2	80	10000	480	0.9502	168.56	8.00	08.65
3	50	20000	420	0.9653	365.58	7.84	15.18
4	80	20000	300	0.9752	316.26	8.45	03.25
5	50	15000	480	0.9429	241.78	7.22	24.36
6	80	15000	420	0.9608	221.57	8.06	05.69
7	65	10000	480	0.9334	187.11	7.78	22.21
8	65	20000	360	0.9737	341.15	8.15	17.98
9	65	15000	420	0.9533	235.65	7.80	17.62
10	65	15000	420	0.9538	235.15	7.63	20.31
11	65	15000	420	0.9523	245.33	7.62	17.34
12	65	15000	360	0.9478	238.74	7.60	17.58
13	65	15000	420	0.9530	236.62	7.50	17.25

Further, the statistical analysis indicated that the model fitted the observed data well, the model F-value (49.79) being significant ($p \leq 0.01$). The interaction among variables and their effect on mixing index is shown in 3-D graph (Fig. 4.29).

The coefficient of estimates for mixing index model (Table-4.8) indicated that both temperature and impellers speed had significant ($p < 0.01$) positive effect on mixing index. Increase in melting temperature and impeller speed increased the mixing index. Interaction among the factors found to have no significant effect.

The mixing index of PCS could be predicted by the equation (for actual values of the variables) given below:

$$\text{Mixing index} = 0.95 + 5.137\text{E-}003T + 0.018RPM$$

Table 4.8: Regression coefficients and ANOVA of quadratic model of Mixing time, Mixing index, Power consumption, Work of shear and Overall acceptability for different levels of Temperature (A) and Impeller speed (B)

Factor	Mixing Time	Mixing Index	Power Consumption	Work of Shear	Overall Acceptability
Intercept	428.27	0.94	242.51	20.79	7.51
A	-39.54*	0.0051*	-8.25*	-3.72*	0.257*
B	-65*	0.0177*	81.06*	-4.69*	0.244*
AB	-10^{NS}	-0.0018^{NS}	-4.105***	1.46^{NS}	-0.021^{NS}
A^2	12.87**	0.00026^{NS}	-2.21^{NS}	-1.97^{NS}	-0.014^{NS}
B^2	-1.03^{NS}	0.0023^{NS}	27.47*	0.63*	0.29*
R^2	0.91	0.97	0.99	0.96	0.95
Adj R^2	0.85	0.95	0.99	0.93	0.91
Adq. Pre.	13.57	25.00	54.48	19.51	18.25
Model F-value	14.95*	49.79*	315.21*	34.24*	28.49*
Lack of Fit	NS	NS	NS	NS	NS

*Significant at p <0.01, **Significant at 0.05<= p <0.10, ***Significant at 0.01<= p <0.05, NS-Nonsignificant

4.5.9.3 Power Consumption

The regression analysis of data on power consumption presented in Table-4.8 for power consumption revealed that the coefficient of determination (R^2) for the quadratic model was 0.99 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of PCS made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 54.48, which is appreciably higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F-value (315.21) was significant ($p \leq 0.01$). The interaction among variables and their effect on power consumption is shown in 3-D graph (Fig. 4.29)

The coefficient of estimates for power consumption model (Table-4.8) indicated that temperature had negative while impeller speed had positive significant ($p < 0.01$) effect on power consumption. It indicated that the decrease in temperature and increase in impeller speed increased the power consumption. Among possible interaction, it can be seen negative significant ($0.01 <= p < 0.05$) effect. The power consumption for preparation of PCS could be predicted by the equation (for actual values of the variables) given below:

$$\text{Power consumption} = 242.51 - 8.26\ T + 81.06\ RPM - 4.11(T)(RPM) + 27.48(RPM)^2$$

4.5.9.4 Work of Shear

The regression analysis of data on work of shear presented in Table-4.8 revealed that the coefficient of determination (R^2) for the quadratic model was 0.96 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of PCS made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 19.51, which is appreciably higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F-value (34.24) being significant ($p \leq 0.01$). The interaction among variables and their effect on work of shear is shown in 3-D graph (Fig.4.29).

The coefficient of estimates for work of shear model (Table-4.6) indicated that, temperature and impeller sped had negative significant (<0.01) effect on work of shear. It indicated that, decrease in temperature and impeller speed increases the work of shear. Interaction among temperature and impeller found to have no significant effect on work of shear.

The work of shear for PCS could be predicted by the equation (for actual values of the variables) given below:

$$\text{Work of shear} = 20.80 - 3.73T - 4.70RPM + 0.63(RPM)^2$$

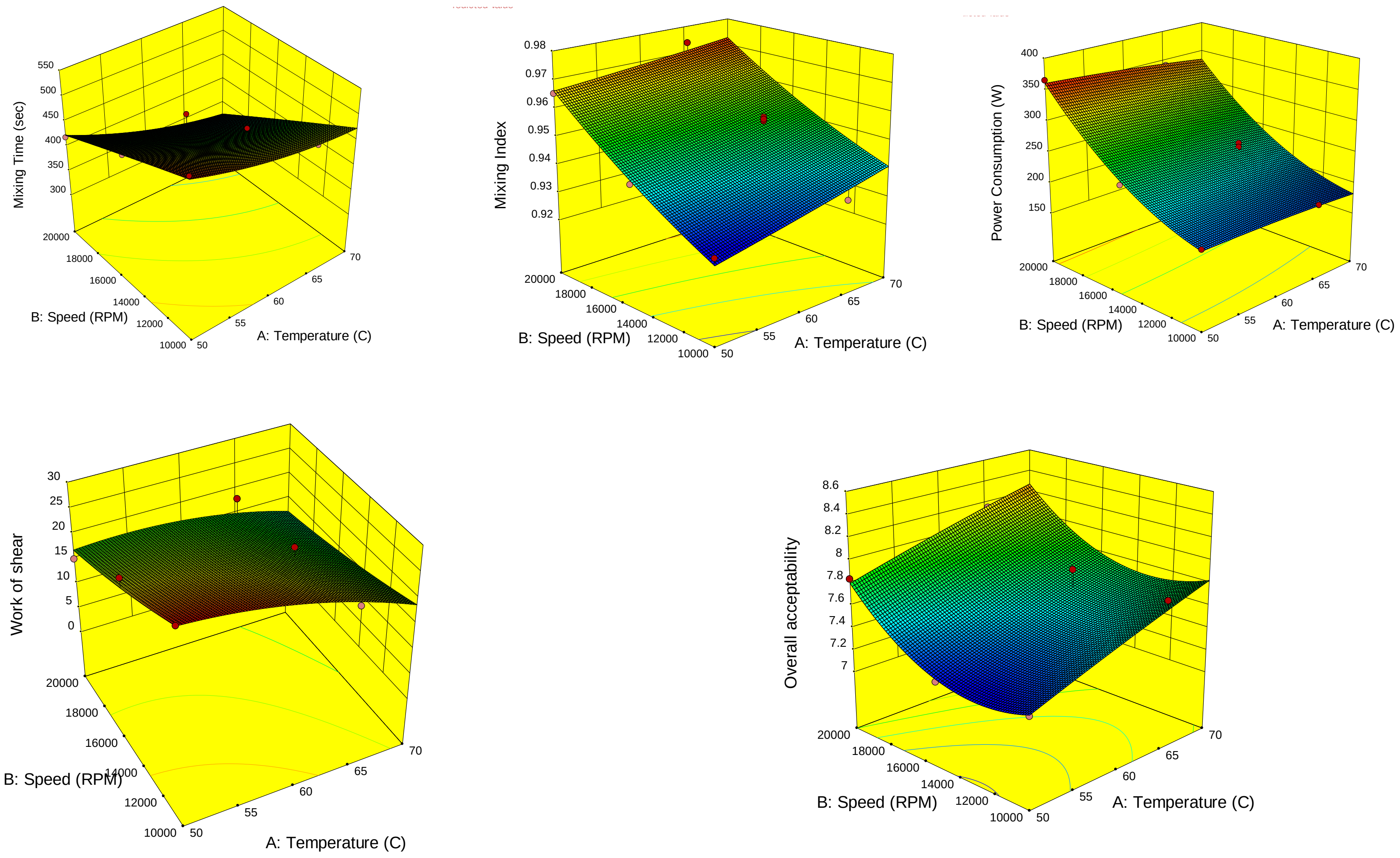


Fig. 4.29: Response surface graphs relating mixing time, mixing index, power consumption, work of shear and overall acceptability value as influenced by temperature and impeller speed

4.5.9.5 Overall Acceptability

The regression analysis of data on overall acceptability presented in Table-4.8 for acceptability revealed that the coefficient of determination (R^2) for the quadratic model was 0.91 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of PCS made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 18.25, which is appreciably higher than the minimum desirable 4(for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F-value (28.49) was significant ($p \leq 0.01$). The interaction among variables and their effect on overall acceptability is shown in 3-D graph (Fig.4.29).

The coefficient of estimates for overall acceptability model (Table-4.8) indicated that the temperature and impeller sped had positive significant (<0.01) effect on work of shear. It indicated that the increase in temperature and impeller speed increased the overall acceptability. Interaction among temperature and impeller found to have no significant effect on work of shear.

The mixing time of PCS could be predicted by the equation (for actual values of the variables) given below:

$$\text{Overall acceptability} = 7.52 + 0.26T + 0.24RPM + 0.29(RPM)^2$$

4.5.10 Optimization of Process Parameters for Process Cheese Spread Using Universal Disperser

The inbuilt numerical optimization menu of Design Expert V. 10.0 was applied to obtain the optimal conditions of the process parameters. The constraints for optimization were set as presented in Table-4.9. The criteria for optimization was set to maximize the sensory score and mixing index while minimize the mixing time, work of shear and power consumption.

Parallelly, constraints were set for the remaining parameters to remain within the range recorded for the experimental values. The upper and lower limits of the goal set for the constraints for optimization of processing parameters for process cheese spread preparation is listed in Table-4.9. From amongst the suggestions given by the software after analysis for the optimal combination of temperature and speed of impeller meeting the constraints listed in Table-4.9, the solution with the most desirability factor (0.80) was chosen as the optimal point. Processing conditions of temperature 80 °C and speed of impeller 19124 rpm was identified as the most optimal process conditions to prepare the PCS with saw tooth impeller using Universal Disperser.

4.5.11 Validation of the Optimized Formulation

The process conditions optimized in the study was validated against experimental values obtained by preparing the PCS under the recommended process conditions (temperature-80 °C and 19124 rpm) and recording the real time values of all the responses, i.e. mixing time, mixing index, work of shear, power consumption and sensory scores for overall acceptability.

The obtained values were compared with the predicted value (generated by the software) and statistical difference between the experimental and predicted values were tested using the Students' t-test ($\alpha = 0.05$). The results of validation are presented in Table-4.10. No significant difference was observed between the experimental and predicted values, confirming the adequacy of the developed model.

Table 4.9: Goal set for constraints for optimization of process parameter for PCS

Particulars	Name	Goal	Lower limit	Upper limit
Factors	Temperature	Is in range	50	80
	Impeller speed	Is in range	10000	20000
Responses	Mixing index	Maximize	0.929	0.973
	Mixing time	Minimize	300	540
	Work of shear	Minimize	3.256	29.36
	Power consumption	Minimize	168.56	36.55
	Overall acceptability	Maximize	7.22	8.45

Table 4.10: Comparison of predicted and observed values of responses to validate the optimized results

Attributes	Predicted value	Observed value	Calculated t (α=0.05) value
Mixing time, s	326	340±28.28	0.5225^{NS}
Mixing index	0.975	0.9746±0.003	0.3636^{NS}
Work of shear	4.14	4.13±0.20	0.9656^{NS}
Power consumption, W	295.93	292.88±2.28	0.1330^{NS}
Overall acceptability	8.3	8.3±0.08	0.999^{NS}

NS: Non-Significant, (Mean±SD, n=3)

4.6 Preparation and Optimization of Recombined Milk Using Universal Disperser

Recombination of milk has been growing as a concept, which facilitates the reconversion of excess milk converted to milk powder to fluid milk to meet the demand in the lean season or in milk deficient areas (Kneifel, 2003). Today milk is also recombined in the food industry while formulating custom designed products and filled dairy products.

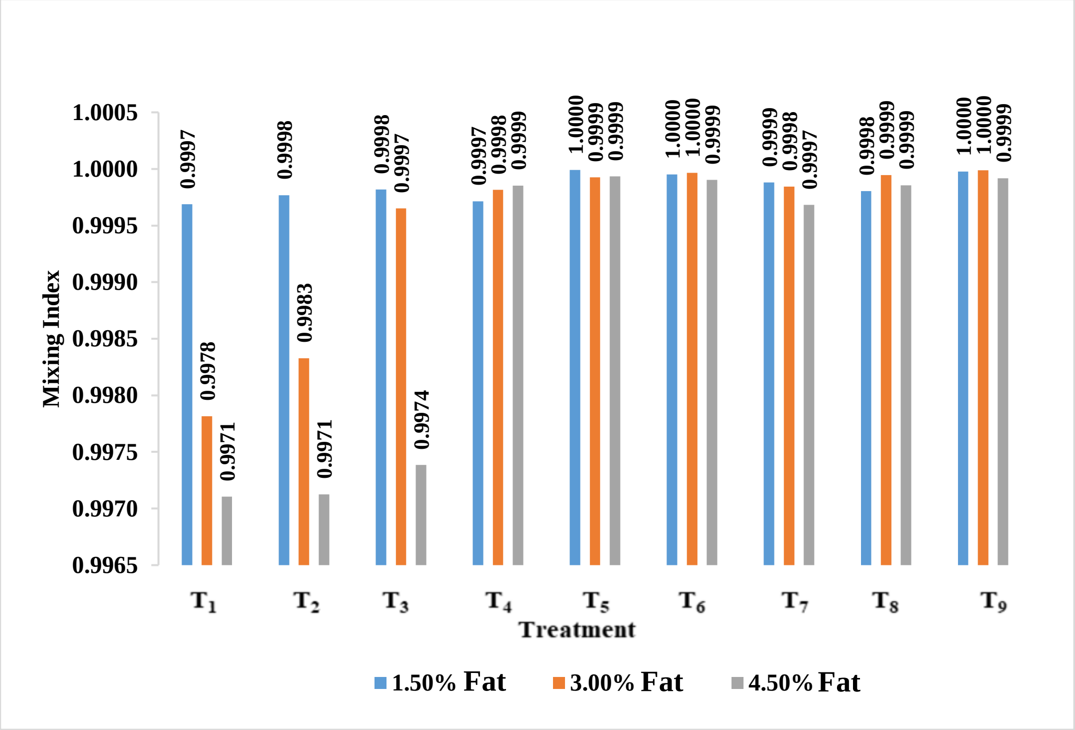
Therefore, the universal disperser was evaluated for its efficacy to prepare the recombined milk. The basic ingredients such as skim milk powder, butteroil and water were mixed and processed using saw tooth high shear impeller; this impeller was selected since the process requires adequate dispersion of the ingredients in the fluid phase in to a stable emulsion. The operation was carried out at different levels of fat percentage, temperature and impeller speed.

Recombined milk was prepared at three levels of fat percentage corresponding to three accepted standards of commercial milk (i.e. 1.5%, 3% and 4.5%). It was processed at three levels of temperature i.e. 20, 35 and 50 ^{o}C. As butteroil needs to be emulsified well within the matrix of water and SMP and in order to bring down the cream formation, the operation needed to be carried out at high shear rate. Therefore, a speed of 10000, 15000 and 20000 rpm were selected to impart the sufficient shear action to the process liquid for the manufacture of recombined milk. The mixture of raw materials was high sheared for a period of 5 minutes.

The overall process conditions were fed to Design Expert V. 10.0 and experimental runs were determined. Total 13 runs for each level of fat percentage at different level of process conditions were finalized and proceeded accordingly. The responses such as mixing index, mixing time, creaming index, power consumption and overall acceptability were recorded and subsequently optimized with the help of Design Expert software. The effect of various processing conditions on the response factors are discussed in the following section.

4.6.1 Mixing Index of the Recombined Milk

Mixing index of the recombined milk samples were determined at various levels of fat content in recombined milk to evaluate the mixing efficiency (Fig 4.30). Both temperature and impeller speed significantly influenced the mixing index of the low fat recombined milk. At the higher temperature (35 and 50 ^{o}C), this effect was not obvious. This was due to the fact that at lower temperature of 20^{o}C, the melting of milk fat was not initiated and the soft fat was difficult to homogenize and emulsify in the SMP-Water matrix. A near unity mixing index obtained at higher temperatures for all the impeller speed and fat levels evaluated are indicative of completely randomized (well mixed) milk (Berk, 2018).



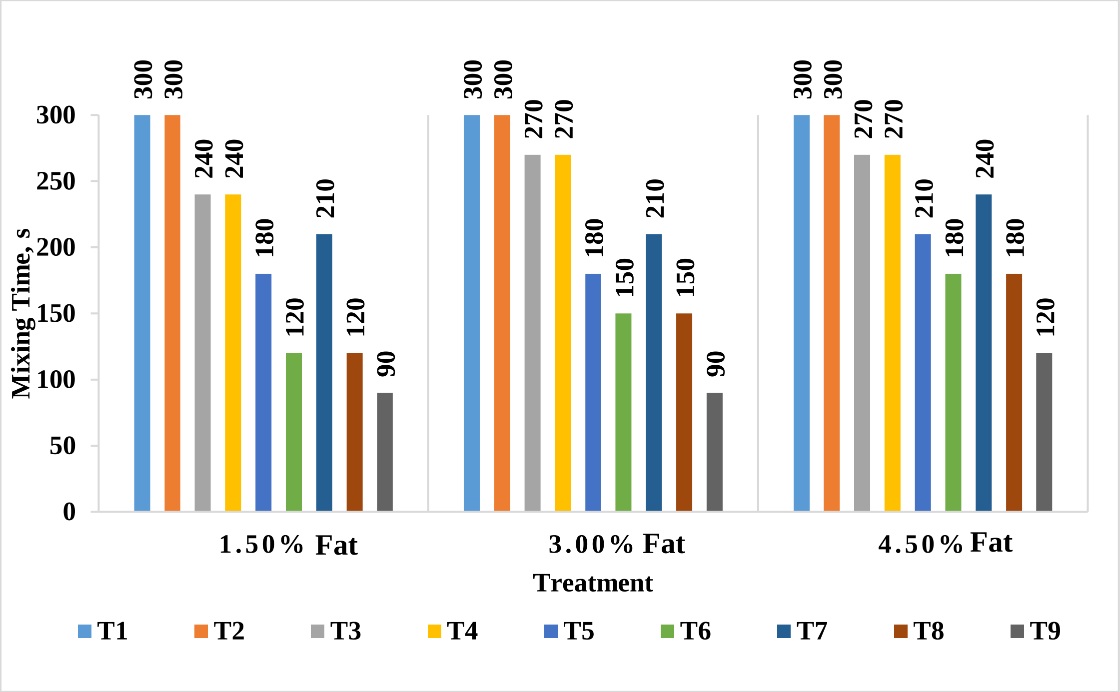
T$_1$ (20°C, 10000 rpm), **T**$_2$ (20°C, 15000 rpm), **T**$_3$ (20°C, 20000 rpm)
T$_4$ (35°C, 10000 rpm), **T**$_5$ (35°C, 15000 rpm), **T**$_6$ (35°C, 20000 rpm)
T$_7$ (50°C, 10000 rpm), **T**$_8$ (50°C, 15000 rpm), **T**$_9$ (50°C, 20000 rpm)

Fig. 4.30: Effect of temperature and impeller speed on mixing index of recombined milk

4.6.2 Mixing Time of the Recombined Milk

Mixing time was noted as the minimum time required for the non-dimensional concentration ratio (Eqn 3.10) to asymptotically approach a steady value. The effect of fat level and processing parameters on the mixing time for recombination of milk using the developed universal disperser is presented in Fig 4.31.

A close perusal of the data indicated that the processing conditions during the recombination had a more telling effect on the mixing time than the fat level itself. When processed at 20 °C, the mixing time was recorded as 300 s at 10000 and 15000 rpm, while when processed at 20000 rpm, the mixing time marginally reduced to 240-270 s. The higher mixing time could be attributed to low melting of the fat as well as poor solubility and wettability of milk powder at the temperature (Jeantet *et al.*, 2010). For higher process temperature, the mixing time varied linearly with the impeller speed and inversely with the fat content. A mixing time of 90 s was noted in 1.5 and 3.0 per cent fat recombined milk while in case of 4.5 per cent fat, it was 120 s when processed at 20000 rpm at 50 °C.



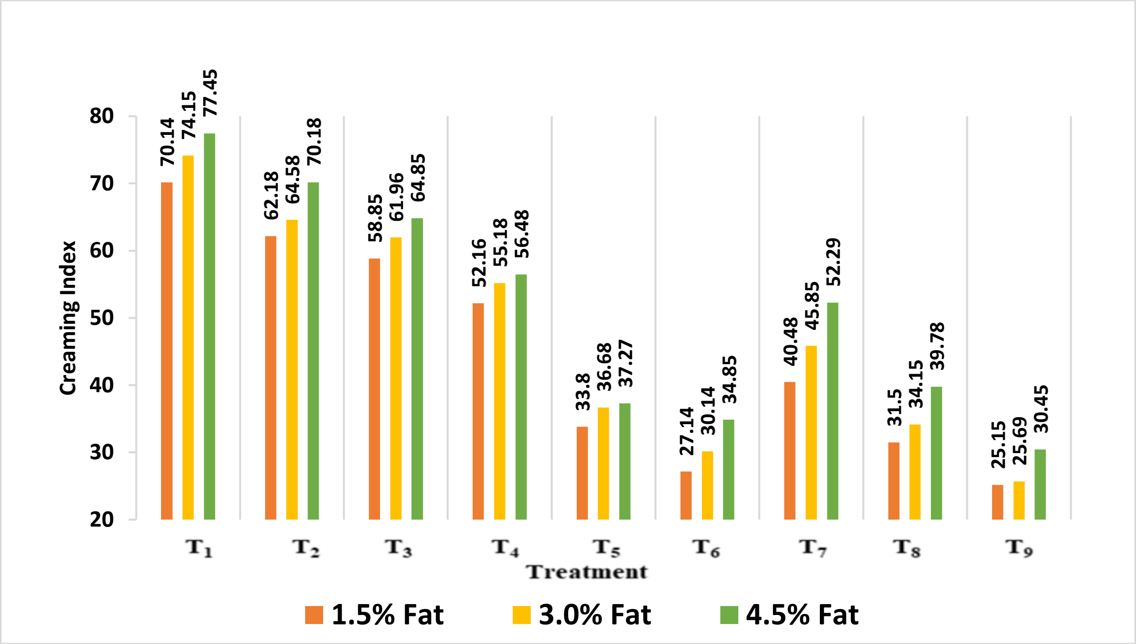
T$_1$ (20°C, 10000 rpm), **T**$_2$ (20°C, 15000 rpm), **T**$_3$ (20°C, 20000 rpm)
T$_4$ (35°C, 10000 rpm), **T**$_5$ (35°C, 15000 rpm), **T**$_6$ (35°C, 20000 rpm)
T$_7$ (50°C, 10000 rpm), **T**$_8$ (50°C, 15000 rpm), **T**$_9$ (50°C, 20000 rpm)

Fig. 4.31: Effect of temperature, impeller speed on mixing time of recombined milk

4.6.3 Creaming Index of the Recombined Milk

The creaming index gives an idea about the stability of fat in the water-SMP metrix. It is desirable to have less creaming index to keep the fat globules in suspended state and uniformly distributed in the milk. The creaming index of 10 is denoted as excellent while 11-20 is very good, 21-30 is good and >30 is poor (Ertugay *et al*., 2004). The effect of fat level on the creaming index observed for the recombined milk in the study is discussed below.

For obvious reasons, the fat level in the recombination had significant effect on creaming index of the recombined milk. If we compare the different fat levels at same processing conditions (Fig. 4.32), it can be seen that creaming index increased as the fat level increased. When recombined milk (1.5, 3, 4.5 % fat) was processed at 20 °C at 10000, 15000 and 20000 rpm, the creaming index increased at higher fat levels. Similar trends were also observed when processed at 35 and 50 °C. The lowest creaming index of 25.15 was noted when recombined milk of 1.5 per cent fat level was processed at 50 °C at a speed of 20000 rpm, while the highest creaming index (77.45) was observed at 10000 rpm (20 ^{o}C).



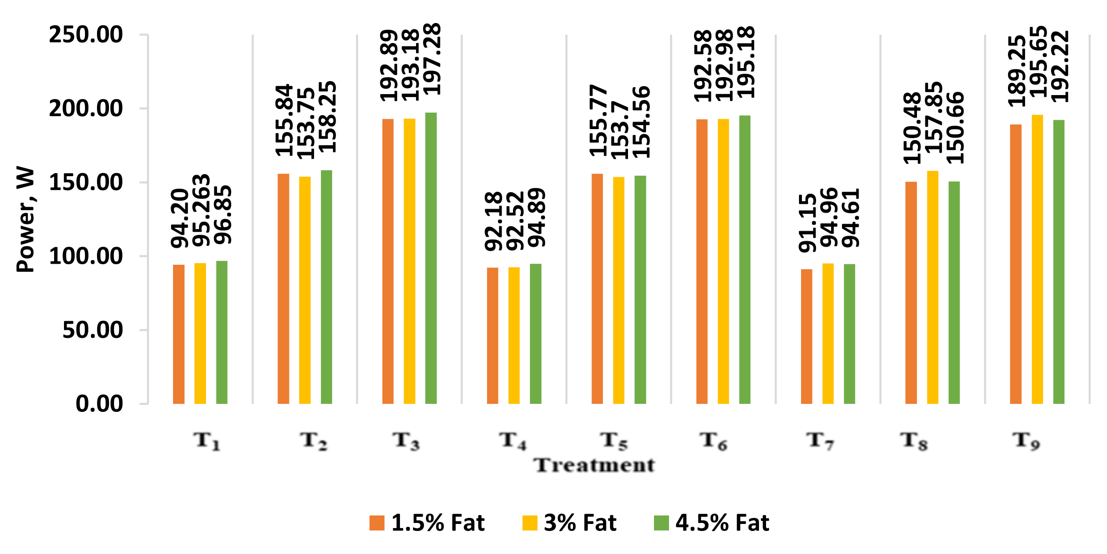
T_1 (20^{o}C, 10000 rpm), **T_2** (20^{o}C, 15000 rpm), **T_3** (20^{o}C, 20000 rpm)
T_4 (35^{o}C, 10000 rpm), **T_5** (35^{o}C, 15000 rpm), **T_6** (35^{o}C, 20000 rpm)
T_7 (50^{o}C, 10000 rpm), **T_8** (50^{o}C, 15000 rpm), **T_9** (50^{o}C, 20000 rpm)

Fig. 4.32: Effect of processing parameters on creaming index of various fat content milk

Both the process parameters, namely the impeller speed and the process temperature showed a synergistic effect on the creaming index observed**.** The degree of shear that imparted to milk determines the reduction in fat globule size. Therefore, higher the shearing action, more is the size reduction (Rybak, 2016) resulting in lower creaming index. Similarly, the processing temperature plays crucial role in preparation of recombined milk. The raw materials such as butteroil and SMP have a tendency to mix well when processed at higher temperature. This is attributed to the softer fat at higher temperature due to its meltability (Aken and Visser, 2000), and the enhanced solubility and dispersability of milk powder at elevated temperatures (Jeantet *et al.*, 2010) leading to more stable emulsions. The creaming index at 35 ^{o}C was in the range of (27.14-56.8) while at 50 ^{o}C, it was in the range of 25.15-52.29.

4.6.4 Effect of Temperature and Impeller Speed on Power Consumption

The power consumed during processing of recombined milk was noted against each level of fat, temperature and impeller speed (Fig. 4.33). Upon evaluation, it was found that the power consumption varied linearly with the impeller speed. At 10000 rpm, the power consumption ranged from 91.95 to 96.85 W, at 15000 rpm, it was from 150.48 to 158.25 W, while at 20000 rpm, the power consumed was recorded from 189.25 to 197.28 W. Only marginal difference in power consumptions was observed for different fat levels in the recombined milk when processed at same temperature and impeller speed. Further, temperature had a negative correlation with power consumption. This could be ascribed to multiple influence of temperature on the recombination process and the resultant power draw namely, ease of fat globule fragmentation, improved powder dispersability as well as viscosity changes in recombined milk fluid itself.

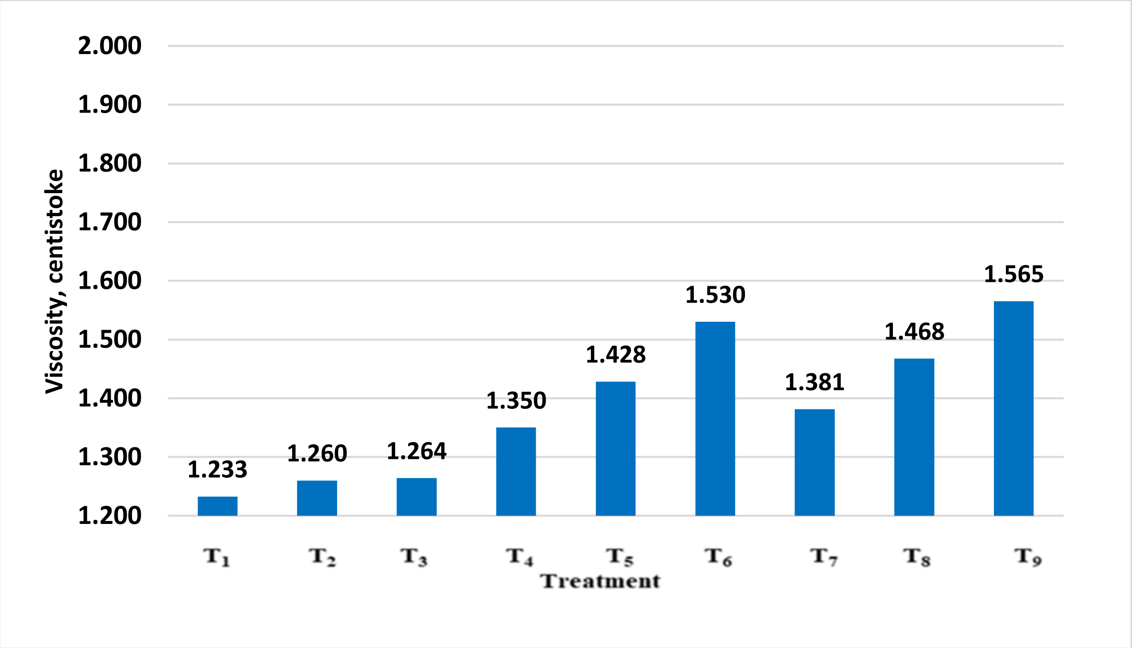


T_1 (20°C, 10000 rpm), **T_2** (20°C, 15000 rpm), **T_3** (20°C, 20000 rpm)
T_4 (35°C, 10000 rpm), **T_5** (35°C, 15000 rpm), **T_6** (35°C, 20000 rpm)
T_7 (50°C, 10000 rpm), **T_8** (50°C, 15000 rpm), **T_9** (50°C, 20000 rpm)

Fig. 4.33: Effect of temperature and impeller speed on power consumption in preparation of recombined milk

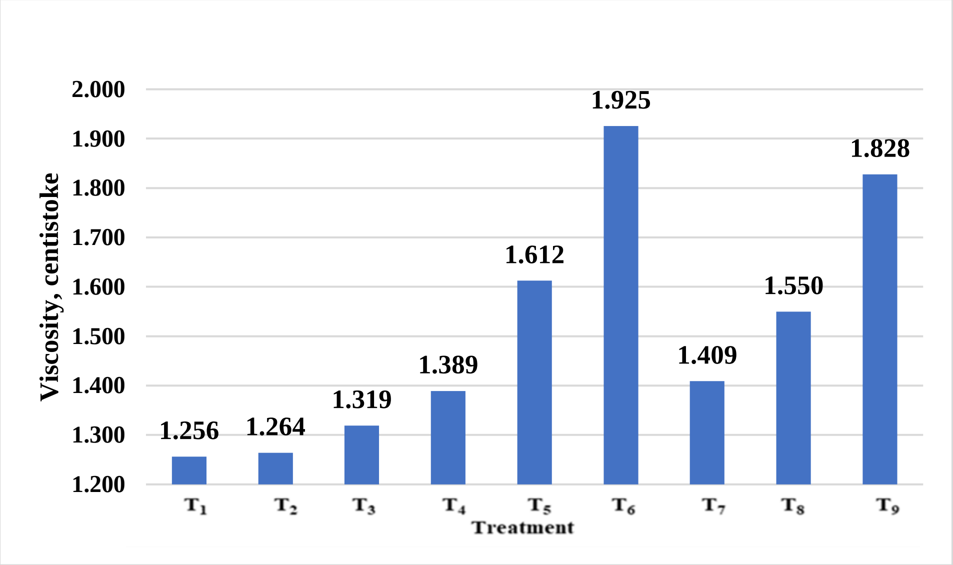
4.6.5 Kinematic Viscosity of Recombined Milk

The kinematic viscosity of recombined milk was determined by using Ostwald's viscometer at 26 °C. An interactive effect of all the process parameters was observed on the viscosity of the recombined milk. At same processing temperature, the kinematic viscosity found to vary linearly as the impeller speed increased from 10000 to 20000 rpm, for all the three fat levels evaluated. This could be attributed to the effect of high shearing causing the fat and SMP to disperse well in the liquid phase to a more stable emulsion, positively influencing the viscosity of the recombined milk. For 1.5 % fat sample, the highest kinematic viscosity value of 1.565 centistokes was recorded at 20000 rpm at 50 °C while lowest was noted as 1.233 centistokes at 10000 rpm at 20 °C. In case of 3.0 per cent fat level, highest viscosity value of 1.925 centistokes was recorded at 20000 rpm at 35 °C while the lowest value of 1.256 centistokes was found to at 10000 rpm when processed at 20 °C. Similarly, for 4.5 per cent fat recombined milk, the highest viscosity value of 1.894 centistoke was observed at 20000 rpm at 50 °C while lowest value 1.299 centistoke was found at 20 °C at 10000 rpm. Li *et al.*, (2018) found that the fat content significantly increased milk viscosity. A potential reason for the increase in viscosity for different fat levels was that the presence of higher number of large size fat globules in higher fat content milk which offered resistance to flow.



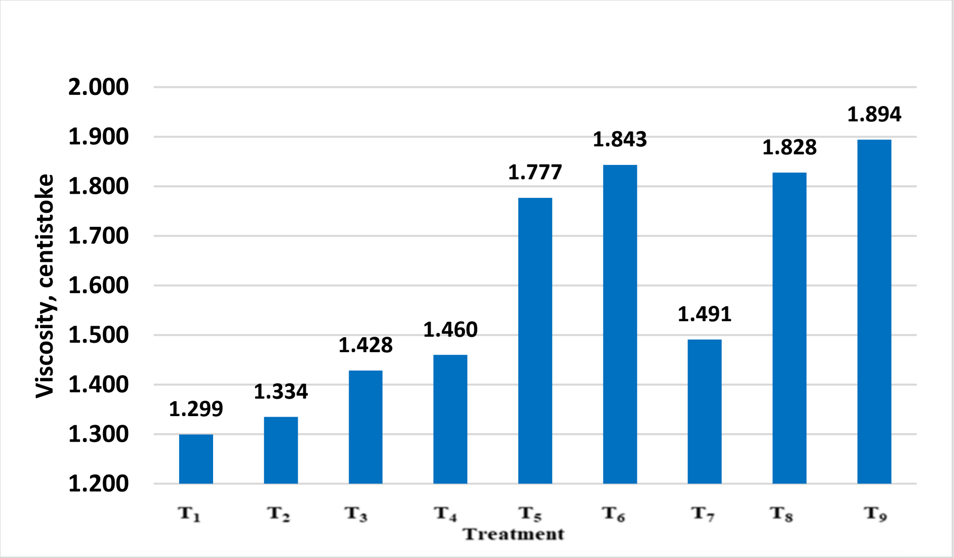
T$_1$ (20°C, 10000 rpm), **T**$_2$ (20°C, 15000 rpm), **T**$_3$ (20°C, 20000 rpm)
T$_4$ (35°C, 10000 rpm), **T**$_5$ (35°C, 15000 rpm), **T**$_6$ (35°C, 20000 rpm)
T$_7$ (50°C, 10000 rpm), **T**$_8$ (50°C, 15000 rpm), **T**$_9$ (50°C, 20000 rpm)

Fig. 4.34: Effect of impeller speed and temperature on kinematic viscosity of recombined milk (1.5 %Fat)



T$_1$ (20°C, 10000 rpm), **T**$_2$ (20°C, 15000 rpm), **T**$_3$ (20°C, 20000 rpm)
T$_4$ (35°C, 10000 rpm), **T**$_5$ (35°C, 15000 rpm), **T**$_6$ (35°C, 20000 rpm)
T$_7$ (50°C, 10000 rpm), **T**$_8$ (50°C, 15000 rpm), **T**$_9$ (50°C, 20000 rpm)

Fig. 4.35: Effect of impeller speed and temperature on kinematic viscosity of recombined milk (3.0 %Fat)

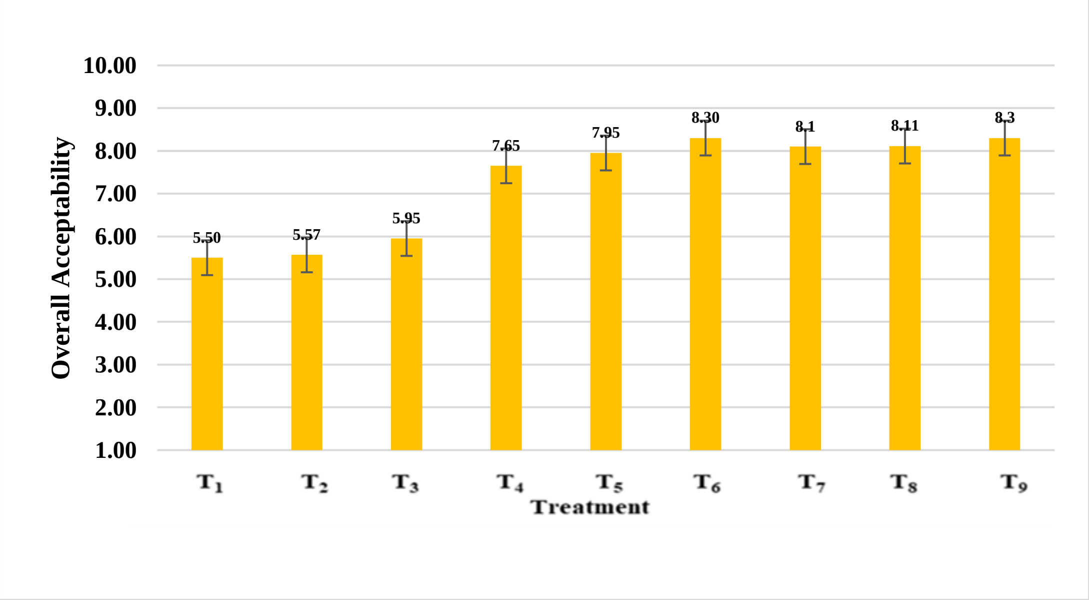


T$_1$ (20°C, 10000 rpm), **T**$_2$ (20°C, 15000 rpm), **T**$_3$ (20°C, 20000 rpm)
T$_4$ (35°C, 10000 rpm), **T**$_5$ (35°C, 15000 rpm), **T**$_6$ (35°C, 20000 rpm)
T$_7$ (50°C, 10000 rpm), **T**$_8$ (50°C, 15000 rpm), **T**$_9$ (50°C, 20000 rpm)

Fig. 4.36: Effect of impeller speed and temperature on kinematic viscosity of recombined milk (4.5 %Fat)

4.6.6 Effect of Temperature and Impeller Speed on Overall Acceptability of Recombined Milk of 1.5 % Fat

The recombined milk prepared using the universal disperser was served to a panel of judges to evaluate its quality in terms of sensory attributes on a 9-point hedonic scale as per the score card in Appendix-III. The obtained data is presented in Fig. 4.37. It can be seen that both temperature and impeller speed had synergistic effect on sensory quality of the recombined milk. The low fat recombined milk (1.5 % Fat) prepared at higher temperature and impeller speed (20000 rpm at 50 °C) obtained a sensory score 8.3 which implied a linguistic description of “like very much”. Samples prepared at the lower temperature scored significantly poorly, due to the unsatisfactory dispersion of both fat and SMP at this temperature. Among the three fat levels evaluated, the sensory panel preferred that samples prepared using 3.0 % fat. This was in contrast to the general expectation, that higher fat content improves the sensory quality of milk. However, Mccarthy *et al.* (2017) has disproved this assumption and highlighted the different sensory appeal of milk based on its fat content based on the consumer profile and their familiarity with fat level in the milk they use for daily consumption.



T$_1$ (20°C, 10000 rpm), **T$_2$** (20°C, 15000 rpm), **T$_3$** (20°C, 20000 rpm)
T$_4$ (35°C, 10000 rpm), **T$_5$** (35°C, 15000 rpm), **T$_6$** (35°C, 20000 rpm)
T$_7$ (50°C, 10000 rpm), **T$_8$** (50°C, 15000 rpm), **T$_9$** (50°C, 20000 rpm)

Fig. 4.37: Effect of temperature and impeller speed on overall acceptability of recombined milk (1.5 %Fat)

4.6.7 Effect of Processing Parameters on Various Responses during Preparation of Recombined Low Fat Milk (1.5 % Fat)

The effect of the processing parameters during the preparation of recombined milk using Universal Disperser having 1.5 % fat was studied in terms of its mixing performance and product quality and the results are discussed in this section.

4.6.7.1 Mixing Index

The regression analysis of data presented in Table-4.11 for mixing index revealed that the coefficient of determination (R^2) for the quadratic model was 0.69 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing index of recombined milk made with any combination of the factors within the experimental range. The ‘adequate precision’ was found to be 6.19, which is higher than the minimum desirable 4 (for high prediction ability). Statistical analysis indicated that the model F value (3.20) was not significant. The interaction among variables and their effect on mixing index is shown in 3-D graph (Fig.4.38). The coefficients estimate for mixing index model (Table-4.11) indicated that impeller speed and temperature had positive significant effect at $p<0.01$. However, statistically, the process was not influenced by the interactive effects.

Table 4.11: Effect of processing parameters on various responses during preparation of Recombined Milk *(1.5% Fat)*

Run	Factor 1 A: RPM	Factor 2 B: Temp	Mixing Index	Mixing Time, s	Creaming Index	Power Cons., W	OA
1	15000	35	0.9998	150	27.18	155.29	7.93
2	20000	35	0.9999	120	30.15	192.58	8.03
3	10000	50	0.9998	270	52.22	91.15	7.97
4	20000	20	0.9998	240	58.85	192.89	5.95
5	15000	35	0.9998	150	34.88	154.85	7.7
6	15000	35	0.9999	180	33.25	157.85	7.5
7	20000	50	0.9999	90	25.15	189.25	8.2
8	15000	20	0.9997	300	65.18	155.84	5.52
9	10000	20	0.9996	300	70.14	94.2	5.42
10	15000	50	0.9998	120	39.78	150.48	8.09
11	10000	35	0.9997	210	65.25	92.18	7.63
12	15000	35	0.9999	180	40.5	154.56	7.9
13	15000	35	0.9998	180	33.18	156.28	7.8

The mixing index of RM (1.5% Fat) could be predicted by the equation (for actual values of the variables) given below:

Mixing Index = 0.99 +7.73E-005RPM + 6.43E-005T

Table 4.12: Regression coefficients and ANOVA of quadratic model of Mixing time, Mixing index, Creaming index, Power consumption and Overall acceptability for different levels of Impeller speed (RPM) (A) and Temperature (B)

Factor	Mixing Index	Mixing Time	Creaming Index	Power Consumption	Overall Acceptability
Intercept	0.99	165.51	35.83	155.47	7.76
A	7.73E-005**	-55*	-12.24*	49.53*	0.19**
B	6.43839E-005***	-60*	-12.83*	-2.00*	1.22*
AB	-8.66118E-006^{NS}	-30**	-3.94^{NS}	-0.14^{NS}	-0.075^{NS}
A^2	-1.18244E-005^{NS}	5.68**	6.76^{NS}	-12.37*	0.071^{NS}
B^2	-5.98244E-005^{NS}	50.68**	11.54**	-1.59***	-0.952*
R^2	0.69	0.92	0.89	0.99	0.98
Adj R^2	0.47	0.87	0.81	0.99	0.98
Adq. Pre.	6.19	13.65	10.81	111.95	30.58
Model F-value	3.20^{NS}	17.07*	11.68*	1665.47*	129.08*
Lack of Fit	NS	NS	NS	NS	NS

*Significant at p <0.01, **Significant at 0.01<= p <.05, ***Significant at 0.05<= p <0.10, NS-Nonsignificant.

4.6.7.2 Mixing Time

The regression analysis of data presented in Table-4.12 for mixing time revealed that the coefficient of determination (R^2) for the quadratic model was 0.92 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of recombined milk made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 13.65, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (17.07) was significant ($p \le 0.01$ and $p \le 0.05$). The interaction among variables and their effect on mixing time is shown in 3-D graph (Fig.4.39) The coefficient of estimate for mixing time model (Table-4.11) indicated that temperature and impeller speed had negative significant ($p<0.01$) effect on mixing time of recombined milk. It indicated that decrease in impeller speed and temperature decreased the mixing time. The interaction among variables had significant ($p<0.05$) negative effect.

The mixing time of recombined milk (1.5% Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Mixing Time} = 165.51 - 55\text{RPM} - 60\text{T} - 30(\text{RPM})(\text{T}) + 5.68(\text{RPM})^2 + 50.68(\text{T})^2$$

4.6.7.3 Creaming Index

The regression analysis of data presented in Table-4.12 for creaming index revealed that the coefficient of determination (R^2) for the quadratic model was 0.89 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting creaming index of recombined milk made with any combination of the factors within the range evaluated. The 'adequate precision' was found to be 13.65, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (17.07) was significant ($p \leq 0.01$). The interaction among variables and their effect on creaming index is shown in 3-D graph (Fig.4.40).

The coefficients of estimates for creaming index model (Table-4.11) indicated that impeller speed and temperature had significant ($p \leq 0.01$) negative effect on creaming index of the recombined milk (1.5% fat). The interactions found to have no significant effect.

The creaming index of recombined milk (1.5% Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Creaming Index} = 35.83 - 12.24\text{RPM} - 12.83\text{T} + 11.54(\text{T})^2$$

4.6.7.4 Power Consumption

The regression analysis of data on power consumption presented in Table-4.12 revealed that the coefficient of determination (R^2) for the quadratic model was 0.99 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting power consumption of recombined milk made with any combination of the factors within the range evaluated.

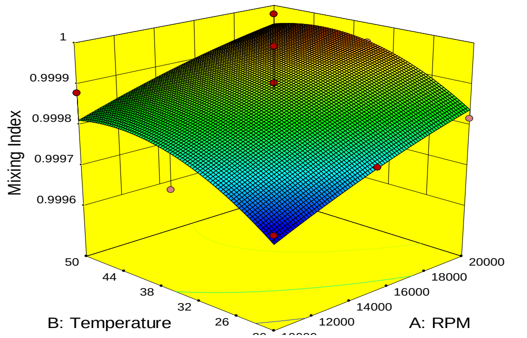


Fig. 4.38: Mixing index of recombined milk influenced by temperature and impeller speed

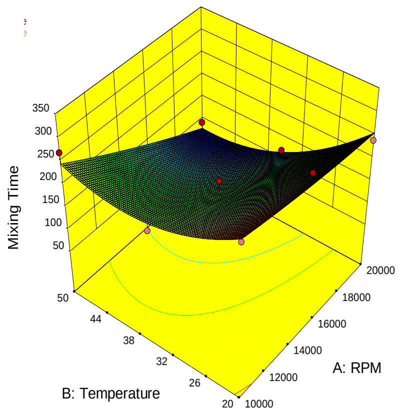


Fig. 4.39: Mixing time of recombined milk influenced by temperature and impeller speed

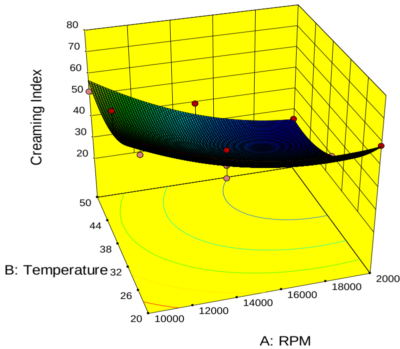


Fig. 4.40: Creaming index of recombined milk influenced by temperature and impeller speed

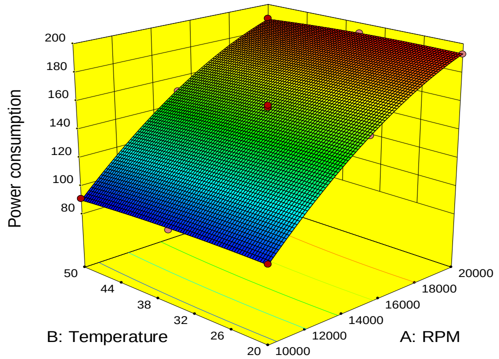


Fig. 4.41: Power consumption in preparation of recombined milk influenced by temperature and impeller speed

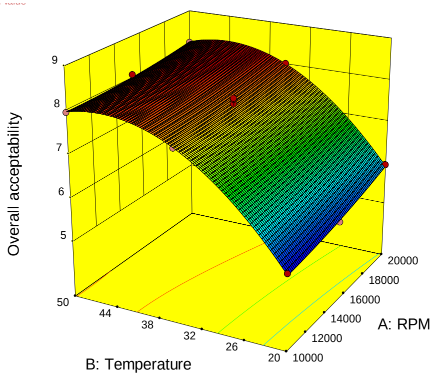


Fig. 4.42: Overall acceptability of recombined milk influenced by temperature and impeller speed

The 'adequate precision' was found to be 111.95, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (1665.47) being significant ($p \leq 0.01$). The interaction among variables and their effect on power consumption is shown in 3-D graph (Fig.4.41).

The coefficient of estimates for power consumption model (Table-4.11) indicated that impeller speed had positive significant ($p \leq 0.01$) effect while temperature had negative significant ($p \leq 0.01$) effect on power consumption. It indicated that increase in impeller speed and decrease in temperature increased power consumption. Interaction of both factors found to have no significant effect.

The power consumption of RM (1.5% Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Power Consumption} = +155.476 + 49.53RPM - 2T - 12.37(T)^2 - 1.59(T)^2$$

4.6.7.5 Overall Acceptability

The regression analysis of data on overall acceptability presented in Table-4.12 revealed that the coefficient of determination (R^2) for the quadratic model was 0.98 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of recombined milk made with any combination of the factors within the range evaluated. The 'adequate precision' was found to be 30.58 which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well and the model F value (129.08) was significant ($p \leq 0.01$). The interaction among variables and their effect on overall acceptability is shown in 3-D graph (Fig. 4.42).

The coefficients of estimates for overall acceptability model (Table-4.11) indicated that temperature and impeller speed had significant effect on overall acceptability score of recombined milk (1.5% fat). It indicated that the increase in impeller speed and temperature increased overall acceptability. The combined effect was found to have no significant effect on overall acceptability.

The overall acceptability of recombined milk (1.5% Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Overall Acceptability} = 7.76 + 0.19RPM + 1.22T - 0.95(T)^2$$

4.6.8 Optimization of Processing Parameters for Recombined Milk (1.5 % Fat)

The inbuilt numerical optimization menu of Design Expert V. 10.0 was applied to obtain the optimal conditions of the process parameters namely, temperature and speed of impeller for recombined milk preparation. The constraints for optimization were set as presented in Table-4.13. The criteria for optimization was set to maximize the sensory score and mixing index while minimize the creaming index, mixing time and power consumption.

Parallelly, constraints were set for the remaining parameters to remain within the range recorded of experimental values. The upper and lower limits of the goal set for the constraints for optimization of processing parameters for recombined milk preparation are listed in Table-4.13. Amongst the various suggestions given by the software after analysis for the optimal combination, the solution with the most desirability factor (0.78) was chosen as the optimal point. Processing at temperature 48 ^{o}C and 17820 rpm speed were identified as the most optimal process conditions to prepare the recombined milk (1.5 % fat) with saw tooth high shear impeller using universal disperser.

4.6.9 Validation of the Optimized Formulation

The process conditions optimized in the study was validated experimentally by preparing the recombined milk under the recommended process conditions (temperature – 48 ^{o}C, speed – 17820 rpm) and recording the real time values of all the responses, i.e. mixing time, mixing index, creaming index, power consumption and sensory scores for overall acceptability.

The obtained values were compared with the predicted value (generated by the software) and statistical difference between the experimental and predicted values were tested using the Students' t-test ($\alpha = 0.05$). The results of validation are presented in Table-4.14. No significant difference was observed between the experimental and predicted values, confirming the adequacy of the developed model.

4.6.10 Effect of Process Parameters on Various Responses of Recombined Milk with 3.0% Fat

The effect of the processing parameters during the recombination of milk in the universal disperser prepared with 3.0 % fat was evaluated in terms of its mixing performance and product quality and the results are discussed in this section.

Table 4.13: Goal set for constraints for optimization process parameter for recombined milk (1.5 % Fat)

Parameter	Goal	Limits (Lower-Upper)	Importance
Temperature	In range	20 – 50	3
Speed of impeller, rpm	In range	10000 – 20000	3
Mixing Index	Maximize	0.9996 – 0.9999	3
Mixing Time, s	Minimize	90 – 300	3
Creaming Index	Minimize	25.15 – 70.14	3
Power Consumption, W	Minimize	91.15 – 192.89	2
Sensory Evaluation	Maximize	5.42 – 8.2	3

Table 4.14: Comparison of predicted and observed values of responses to validate the optimized results (1.5 % Fat)

Particulars	Parameter	Predicted	Observed	Calculated *t value* (α=0.05)
Responses	Mixing index	1	0.99±0.0005	0.3739^{NS}
	Mixing time, s	109	110±17.32	0.9252^{NS}
	Creaming index	30.67	29.24±0.89	0.3273^{NS}
	Overall acceptability	8.19	8.21±0.07	0.5994^{NS}
	Power consumption, W	177	176.39±1.21	0.4342^{NS}

NS: Non-Significant, (Mean±SD, n=3)

4.6.10.1 Mixing Index

The regression analysis of data presented in Table-4.15 for mixing index revealed that the coefficient of determination (R^2) for the quadratic model was 0.87 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing index of recombined milk made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 10.79, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (9.60) being significant ($p \leq 0.01$). The interaction among variables and their effect on mixing index is shown in 3-D graph (Fig.4.43).

The coefficient of estimates for mixing index model (Table-4.15) indicated that impeller speed had positive significant ($p < 0.05$) effect while temperature had positive significant ($p < 0.01$) effect on mixing index. It indicates that increase in impeller speed and temperature increases the mixing index. Interactions among both factors had negative significant ($p < 0.05$) effect. The mixing index of the product (3.0 % Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Mixing Index} = 0.99 + 3.54E\text{-}004\ \text{RPM} + 6.63E\text{-}004T$$

Table 4.15: Effect of processing parameters on various responses during preparation of recombined milk (3.0 % Fat)

Run	Factor 1 A: RPM	Factor 2 B: Temp	Mixing Index	Mixing Time, s	Creaming Index	Power Cons., W	OA
1	15000	35	0.9999	150	36.98	152.11	7.66
2	20000	35	0.9999	150	28.35	192.98	7.9
3	10000	50	0.9998	210	45.85	94.96	7.99
4	20000	20	0.9996	270	61.96	193.18	5.9
5	15000	35	0.9999	180	36.68	156.28	7.7
6	15000	35	0.9991	210	35.45	155.47	7.8
7	20000	50	0.9999	90	25.69	195.65	8.11
8	15000	20	0.9983	300	64.58	153.75	5.42
9	10000	20	0.9978	300	74.15	95.263	5.4
10	15000	50	0.9999	150	34.15	157.85	8.04
11	10000	35	0.9998	180	55.18	92.52	7.25
12	15000	35	0.9999	180	32.15	154.29	7.4
13	15000	35	0.9999	180	42.15	150.35	7.7

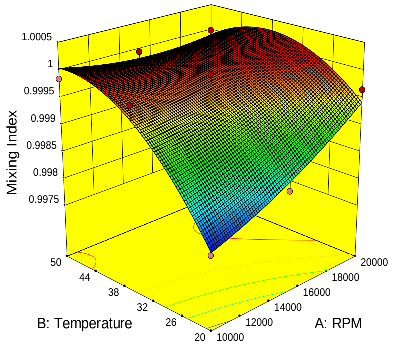


Fig. 4.43: Mixing index of recombined milk as influenced by temperature and impeller speed

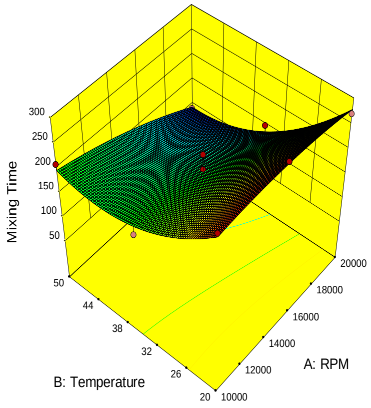


Fig. 4.44: Mixing time of recombined milk as influenced by temperature and impeller speed

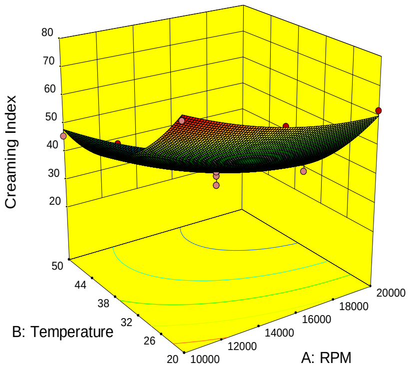


Fig. 4.45: Creaming index of recombined milk as influenced by temperature and impeller speed

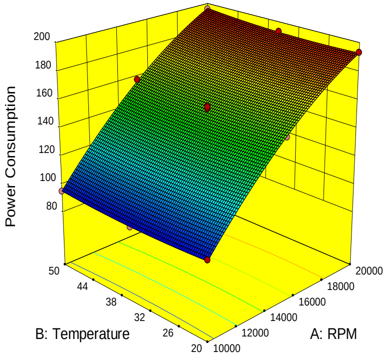


Fig. 4.46: Power consumption in preparation of recombined milk as influenced by temperature and impeller speed (RPM)

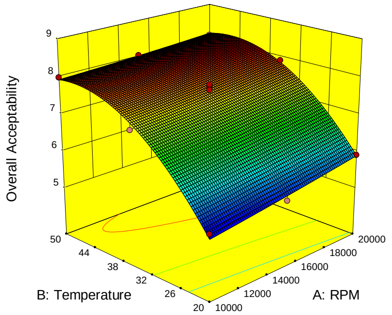


Fig. 4.47: Overall acceptability of recombined milk as influenced by temperature and impeller speed

Table 4.16: Regression coefficients and ANOVA of quadratic model of Mixing time, Mixing index, Creaming index, Power consumption and Overall acceptability for different levels of Impeller speed (RPM) (A) and Temperature (B) (3% Fat)

Factor	Mixing Index	Mixing Time	Creaming Index	Power Consumption	Overall Acceptability
Intercept	0.99	178.96	37.03	153.71	7.62
A	0.00035**	-30*	-9.86*	49.84*	0.21**
B	0.00066*	-70*	-15.83*	1.04^{NS}	1.23*
AB	-0.00042**	-22.5***	-1.99^{NS}	0.69^{NS}	-0.095^{NS}
A^2	0.00014^{NS}	-11.37^{NS}	3.85^{NS}	-10.99*	0.018^{NS}
B^2	-0.00060**	48.62*	11.45*	2.05^{NS}	-0.82*
R^2	0.87	0.94	0.96	0.99	0.98
Adj R^2	0.78	0.90	0.94	0.99	0.97
Adq. Pre.	10.79	15.60	20.48	77.03	27.23
Model F-value	9.60*	23.53*	39.37*	780.69*	95.13*
Lack of Fit	NS	NS	NS	NS	NS

*Significant at p <0.01, **Significant at 0.01<= p <.05, ***Significant at 0.05<= p <0.10, NS-Nonsignificant.

4.6.10.2 Mixing Time

The regression analysis of data on mixing time presented in Table-4.16 revealed that the coefficient of determination (R^2) for the quadratic model was 0.94 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of recombined milk made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 15.60, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (23.53) was significant ($p \leq 0.01$). The interaction among variables and their effect on mixing time is shown in 3-D graph (Fig.4.44).

Coefficients of estimated for mixing time model (Table-4.15) indicated that temperature and impeller speed had significant (p<0.01) negative effect on mixing time. It indicates that decreased in temperature and impeller speed, increased mixing time. The interaction found to have negative significant (0.05<= p <0.10) effect.

The mixing time of the recombined milk (3.0 % Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Mixing Time} = 178.96 - 30RPM - 69.99T - 22.50(RPM)(T) - 11.37(RPM)^2 + 48.62T^2$$

4.6.10.3 Creaming Index

The regression analysis of data on creaming index presented in Table-4.16 revealed that the coefficient of determination (R^2) for the quadratic model was 0.96 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing index of recombined milk made with any combination of the factors within the range evaluated. The 'adequate precision' was found to be 20.48, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (39.37) was significant ($p \leq 0.01$). The interaction among variables and their effect on overall acceptability is shown in 3-D graph (Fig.4.45).

The coefficient of estimates for creaming index model (Table-4.15) indicated that impeller speed and temperature had negative significant effect on creaming index. It revealed that decreased in temperature and impeller speed increased the creaming index. The interactions found to have no significant effect. The creaming index of the product (3.0 % Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Creaming index} = 37.03 - 9.86RPM - 15.83T + 11.45T^2$$

4.6.10.4 Power Consumption

The regression analysis of data on power consumption presented in Table-4.16 revealed that the coefficient of determination (R^2) for the quadratic model was 0.99 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing index of recombined milk made with any combination of the factors within the experimental range. The 'adequate precision' was found to be 77.03 which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (780.69) was significant ($p \leq 0.01$). The interaction among variables and their effect on power consumption is shown in 3-D graph (Fig.4.46).

The coefficient of estimates for power consumption model (Table-4.15) indicates that temperature and had significant ($p<0.01$) positive effect on power consumption while temperature found to have no significant effect. It indicates that increase in impeller speed increases power consumption. Interactive of the parameters were found to be insignificant.

The power consumption of the recombined milk (3.0 % Fat) could be predicted by the equation (for actual values of the variables) given below:

Power consumption = $153.71 + 49.84RPM + 1.04\,T + 2.058\,T^2$

4.6.10.5 Overall Acceptability

The regression analysis of data on overall acceptability presented in Table-4.16 revealed that the coefficient of determination (R^2) for the quadratic model was 0.98 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting overall acceptability of recombined milk made with any combination of the factors within the range evaluated. The 'adequate precision' was found to be 27.23, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (95.13) was significant ($p \leq 0.01$ and $p \leq 0.05$). The interaction among variables and their effect on overall acceptability is shown in 3-D graph (Fig.4.47).

The coefficients of estimates for overall acceptability model (Table-4.15) indicated that impeller speed had significant ($p<0.05$) positive effect and temperature had significant ($p<0.01$) effect on overall acceptability, while the interaction among them was nots significant effect. The overall acceptability of the recombined milk (3.0 % Fat) could be predicted by the equation (for actual values of the variables) given below:

Overall acceptability = $7.62 + 0.21RPM + 1.23T - 0.82T^2$

4.6.11 Optimization of Processing Parameters for Recombined Milk (3.0 % Fat)

Optimization of processing parameters were done as discussed in section 4.4.16. The upper and lower limits of the goal set for the constraints for optimization of processing parameters for recombined milk (3.0 % Fat) preparation is listed in Table-17. From amongst the suggestions given by the software after analysis, optimal combination of temperature and speed of impeller were identified. The solution with the most desirability factor (0.82) was chosen as the optimal point. Processing conditions of temperature 47 ^{o}C and speed of impeller 15701 rpm was identified as the most optimal process conditions to prepare the recombined milk (3.0 % fat) with saw tooth high shear impeller using universal disperser.

4.6.12 Validation of the Optimized Formulation

The process conditions optimized in the study was validated against experimental values obtained by preparing the recombined milk under the recommended process conditions (temperature – 48 ^{o}C, speed-15701 rpm) and recording the real time values of all the responses, i.e. mixing time, mixing index, creaming index, power consumption and sensory scores for overall acceptability.

The obtained values were compared with the predicted value (generated by the software) and statistical difference between the experimental and predicted values were tested using the Students' t-test ($\alpha = 0.05$). The results of validation are presented in Table-4.18. No significant difference was observed between the experimental and predicted values, confirming the adequacy of the developed model.

Table 4.17: Goal set for constraints for optimization process parameter for recombined milk (3.0 % Fat)

Parameter	Goal	Limits (Lower-Upper)	Importance
Temperature	In range	20 – 50	3
Speed of impeller, rpm	In range	10000 – 20000	3
Mixing Index	Maximize	0.9978 – 0.9999	3
Mixing Time, s	Minimize	90 – 300	3
Creaming Index	Minimize	25.69 – 74.15	3
Power Consumption, W	Minimize	92.52 – 195.65	2
Sensory Evaluation	Maximize	5.40 – 8.11	3

4.6.13 Effect of Processing Factors on Various Responses of Recombined Milk with 4.5 % Fat

The effect of the processing parameters during the recombination of milk in the universal disperser prepared with 4.5 % fat was evaluated in terms of its mixing performance and product quality and the results are discussed in this section.

Table 4.18: Comparison of predicted and observed values of responses to validate the optimized results (3.0 % F RM)

Parameter	**Predicted**	**Observed**	**Calculated *t value* (α = 0.05)**
Mixing index	1	0.9997	0.4685^{NS}
Mixing time, s	147	140.33±17.32	0.5225^{NS}
Creaming index	30.27	29±1.25	0.4^{NS}
Overall acceptability	8.0	7.87±0.24	0.3553^{NS}
Power consumption, W	162.9	163.62±1.19	0.4685^{NS}

NS: Non-Significant, (Mean±SD, n=3)

Table 4.19: Effect of processing parameters on various responses during preparation of recombined milk (4.5 % Fat)

Run	**Factor 1 A: RPM**	**Factor 2 B: Temp**	**Mixing Index**	**Mixing Time, s**	**Creaming Index**	**Power Cons., W**	**OA**
1	15000	35	0.9999	180	36.15	154.33	7.57
2	20000	35	0.9999	120	34.85	195.18	7.75
3	10000	50	0.9996	150	52.29	94.61	7.36
4	20000	20	0.9973	270	64.85	197.28	5.85
5	15000	35	0.9999	210	32.58	153.85	7.5
6	15000	35	0.9999	180	42.18	154.36	7.4
7	20000	50	0.9999	120	30.45	192.22	7.65
8	15000	20	0.9971	250	70.18	158.25	5.37
9	10000	20	0.9971	300	77.45	96.85	5.26
10	15000	50	0.9998	180	31.5	150.66	7.57
11	10000	35	0.9998	240	56.48	94.89	7.21
12	15000	35	0.9997	210	38.99	157.65	7.7
13	15000	35	0.9999	180	36.45	152.63	7.6

4.6.13.1 Mixing Index

The regression analysis of data on mixing index presented in Table-4.20 revealed that the coefficient of determination (R^2) for the quadratic model was 0.99 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing index of recombined milk made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 49.35, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (444.16) was significant ($p \leq 0.01$). The interaction among variables and their effect on mixing index is shown in 3-D graph (Fig.4.48)

Table 4.20: Regression coefficients and ANOVA of quadratic model of Mixing time, Mixing index, Creaming index, Power consumption and Overall acceptability for different levels of Impeller speed (RPM) (A) and Temperature (B) (4.5% Fat)

Factor	Mixing Index	Mixing Time	Creaming Index	Power Consumption	Overall Acceptability
Intercept	0.99	199.23	37.68	154.52	7.53
A	9.40E-005**	-30**	-9.345*	49.72*	0.23*
B	0.0013*	-61.66*	-16.37*	-2.48*	1.01*
AB	-1.06E-005^{NS}	-1.22E-014^{NS}	-2.31^{NS}	-0.70^{NS}	-0.07^{NS}
A^2	-8.49E-006^{NS}	-8.62^{NS}	6.95**	-9.37*	-0.009^{NS}
B^2	-0.0013*	26.37^{NS}	12.13*	0.04^{NS}	-1.019*
R^2	0.99	0.83	0.97	0.99	0.99
Adj R^2	0.99	0.71	0.95	0.99	0.98
Adq. Pre.	49.35	9.25	21.11	91.72	34.14
Model F-value	444.16*	7.10*	46.58*	1079.78*	160.20*
Lack of Fit	NS	NS	NS	NS	NS

*Significant at $p <0.01$, **Significant at $0.01<= p <.05$, NS-Nonsignificant.

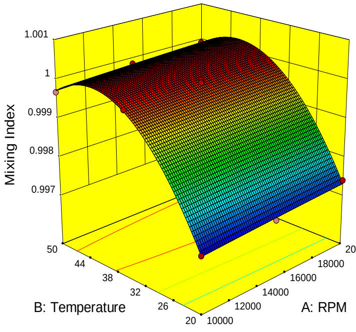


Fig. 4.48: Mixing index of recombined milk as influenced by the impeller speed and temperature

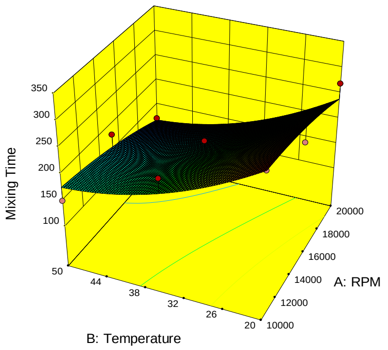


Fig. 4.49: Mixing time of recombined milk as influenced by the impeller speed and temperature

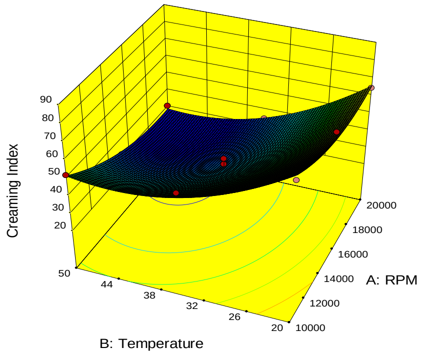


Fig. 4.50: Creaming index of recombined milk as influenced by the impeller speed and temperature

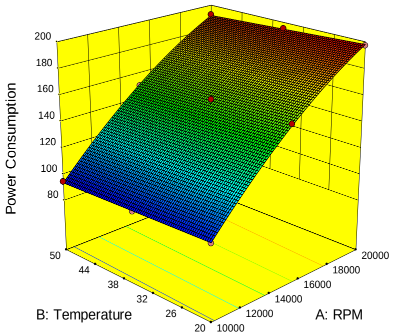


Fig. 4.51: Power consumption in preparation of recombined milk as influenced by the impeller speed and temperature

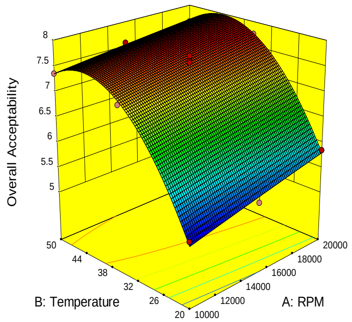


Fig.4.52: Overall acceptability of recombined milk as influenced by the impeller speed and temperature

The coefficient of estimates for mixing index model (Table-4.19) indicated that impeller speed and temperature had positive significant effect at $p<0.01$ and $p<0.05$, respectively. It indicates that, increased in temperature and impeller speed increased mixing index. Interaction had no significant effect.

The mixing index of recombined milk (4.5 % Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Mixing Index} = 0.99 + 9.40\text{E-}005\text{RPM} + 1.30\text{E-}003\text{T}\ ^{-}\ 1.39\text{E-}003\text{T}^2$$

4.6.13.2 Mixing Time

The regression analysis of data on mixing time presented in Table-4.20 revealed that the coefficient of determination (R^2) for the quadratic model was 0.83 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of recombined milk made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 9.25, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (7.10) was significant ($p\leq0.01$). The interaction among variables and their effect on mixing time is shown in 3-D graph (Fig.4.49).

The coefficient of estimates for mixing time model (Table-4.20) indicates that impeller speed and temperature had negative significant effect at $p<0.01$ and $p<0.05$ respectively. It indicates that, decreased in temperature and impeller speed increased mixing time. Interaction found to have no significant effect.

The mixing time of the product prepared with 4.5 % Fat could be predicted by the equation (for actual values of the variables) given below:

$$\text{Mixing Time} = 191.03 - 30\text{RPM} - 61.66\text{T} - 8.62\text{RPM}^2 + 26.37\ \text{T}^2$$

4.6.13.3 Creaming Index

The regression analysis of data presented in Table-4.20 revealed that the coefficient of determination (R^2) for the quadratic model was 0.97 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting mixing time of recombined milk made with any combination of the factors within the experimental range. The ‘adequate precision’ was found to be 21.11, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (46.58) was significant ($p \leq 0.01$). The interaction among variables and their effect on creaming index is shown in 3-D graph (Fig.4.50).

The coefficient of estimates for creaming index model (Table-4.20) indicates that impeller speed and temperature had negative significant effect at $p<0.01$ and $p<0.05$ respectively. It indicates that decrease in temperature and impeller speed increases creaming index and interaction had no significant effect.

The creaming index of the high fat recombined milk (4.5 % Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Creaming Index} = 37.68 - 9.34\text{RPM} - 16.37\text{T} + 6.95\text{RPM}^2 + 12.13\text{T}^2$$

4.6.13.4 Power Consumption

The regression analysis of data on power consumption presented in Table-4.20 revealed that the coefficient of determination (R^2) for the quadratic model was 0.99 and the “lack of fit” test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting power consumption of recombined milk made with any combination of the factors within the range evaluated. The ‘adequate precision’ was found to be 91.72, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (1079.78) was significant ($p \leq 0.01$). The interaction among variables and their effect on power consumption is shown in 3-D graph (Fig.4.51).

The coefficient of estimates for power consumption model (Table-4.20) indicates that impeller speed had positive significant ($p<0.01$) effect while temperature had negative significant ($p<0.01$) effect. It indicates that, decreased in temperature increased power consumption while increasing impeller speed increases power consumption. Interaction found to have no significant effect.

The power consumption for preparation of the product (4.5 % Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Power Consumption} = 154.52 + 49.72\text{RPM} - 2.48\text{T} - 9.37\text{T}^2$$

4.6.13.5 Overall Acceptability

The regression analysis of data on overall acceptability presented in Table-4.20 revealed that the coefficient of determination (R^2) for the quadratic model was 0.99 and the "lack of fit" test which inversely measures the fitness of the model was not significant. This indicated that the model was sufficiently accurate for predicting overall acceptability of recombined milk made with any combination of the factors within the range evaluated. The 'adequate precision' was found to be 34.14, which is higher than the minimum desirable 4 (for high prediction ability). Further, the statistical analysis indicated that the model fitted the observed data well, the model F value (160.20) was significant ($p \leq 0.01$). The interaction among variables and their effect on overall acceptability is shown in 3-D graph (Fig.4.52).

The coefficient of estimates for overall acceptability model (Table-4.20) indicates that both impeller speed and temperature had significant ($p<0.01$) positive effect on overall acceptability. It indicates that, increase in temperature and impeller speed increases power consumption. Interaction among the factors had positive significant effect on overall acceptability on recombined milk (4.5% fat).

The overall acceptability of the recombined milk (4.5 % Fat) could be predicted by the equation (for actual values of the variables) given below:

$$\text{Overall acceptability} = 7.53 + 0.23\text{RPM} + 1.01\text{T} - 1.01\text{T}^2$$

4.6.14 Optimization of Processing Parameters for Recombined Milk (4.5 % Fat)

Optimization of processing parameters were done as discussed in section 4.4.16. The upper and lower limits of the goal set for the constraints for optimization of processing parameters for recombined milk (4.5 % Fat) preparation is listed in Table-4.20. From amongst the suggestions given by the software after analysis for the optimal combination of temperature and speed of impeller were selected. The solution with the most desirability factor (0.88) was chosen as the optimal point. Processing conditions of temperature 48 ^{o}C and speed of impeller 15459 rpm was identified as the most optimal process conditions to prepare the recombined milk (4.5 % fat) with saw tooth high shear impeller using universal disperser.

4.6.15 Validation of the Optimized Formulation

The process conditions optimized in the study was validated against experimental values obtained by preparing the recombined milk under the recommended process conditions (temperature – 48 ^{o}C, speed -15459 rpm) and recording the real time values of all the responses, i.e. mixing time, mixing index, creaming index, power consumption and sensory scores for overall acceptability.

Table 4.21: Goal set for constraints for optimization process parameter for recombined milk (4.5 % Fat)

Parameter	Goal	Limits (Lower-Upper)	Importance
Temperature	In range	20 – 50	3
Speed of impeller, rpm	In range	10000 – 20000	3
Mixing Index	Maximize	0.9971 – 0.9999	3
Mixing Time, s	Minimize	120 – 300	3
Creaming Index	Minimize	30.45 – 77.45	3
Power Consumption, W	Minimize	94.61 – 197.28	2
Sensory Evaluation	Maximize	5.26 – 7.75	3

Table 4.22: Comparison of predicted and observed values of responses to validate the optimized results (4.5 % Fat)

Parameter	Predicted	Observed	Calculated *t value* ($\alpha = 0.05$)
Mixing index	1	0.9989±0.0009	0.9043^{NS}
Mixing time, s	142	140.33±17.32	0.5225^{NS}
Creaming index	24.6	32.41±1.04	0.9541^{NS}
Overall acceptability	7.65	7.38±0.33	0.3158^{NS}
Power consumption, W	156.7	157.33±0.90	0.2369^{NS}

NS: Non-Significant, (Mean±SD, n=3)

The obtained values were compared with the predicted value (generated by the software) and statistical difference between the experimental and predicted values were tested using the Students’ t-test ($\alpha = 0.05$). The results of validation are presented in Table-

4.22. No significant difference was observed between the experimental and predicted values, confirming the adequacy of the developed model.

4.6.16 Microscopic Analysis of High Shear Treated Recombined Milk

The ability of saw tooth high shear impeller to homogenize the fat in milk was determined by using optical microscope (Nikon YS100) under 40 X resolution. The raw unhomogenized milk was treated at 20000 rpm at 50°C for period of 5 min. Then the sample were analysed under optical microscope to understand the diameter size and increase in number of fat globules. Upon analysis, it can be seen that there was significant size reduction in the fat globules size. The comparison between untreated sample and treated samples showed in Fig. 4.53. It could be seen that there was increase in the number of fat globules than raw milk.

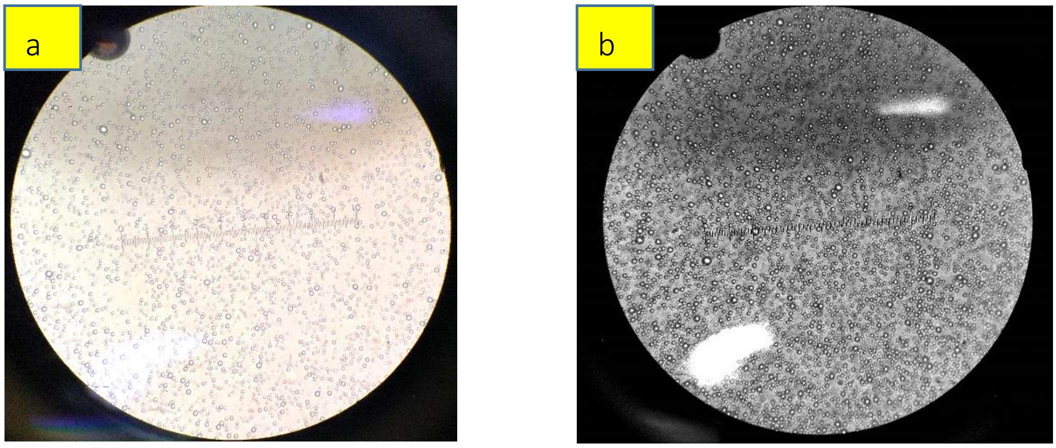


Fig. 4.53: Effect of high shear treatment on milk fat globule: a) Before high shear treatment b) After high shear treatment

Summary and Conclusion

5. SUMMARY AND CONCLUSIONS

Milk production in India has been steadily on the rise and a significant quantity of the milk produced in the country has been converted by the Indian Dairy Industry (both organised and unorganised sectors) into a wide range of value-added products. With the advent of many food business startups and increased interest by MNCs in the dairy sector, coupled with the growing awareness on the goodness of milk and dairy products, a renewed impetus for organised procurement and processing is in the offing for this sector. Dairy processing involves the conversion of milk into two major categories of products, commonly classified as indigenous (*khoa*/*chhana* based sweets, *ghee*, *dahi*) and western (cheese, ice cream, butter) products. The processing involves multiple unit operations and the large organised dairies have the sophisticated infrastructure including process machinery for the same. At the same time, there is also a need to develop versatile equipment suited to small and medium scale processing to cater to new market entrants operating on smaller product volume. Further, it is well established that the value-added dairy product industry in India is still driven by local *halwais*, who would also benefit to upgrade their operations through such versatile equipment. In this context, a multifunctional equipment, capable of delivering mechanical unit operations such as mixing, blending, dispersion, etc. across a wide range of rpm, in combination with heat transfer operations (heating and cooling) presents a pragmatic option for the small and medium scale units involved in product development and marketing in the areas of dairy processing.

Keeping in view the above considerations, the present study was undertaken to develop a universal disperser with following objectives:

(1) Design and fabrication of universal disperser for dairy processing operations
(2) Evaluation and selection of suitable attachments for universal disperser
(3) Performance evaluation of the developed universal disperser for performing different unit operations in dairy products processing

The following methodology was adopted to conduct the experiments as per the above objectives:

- The universal disperser was designed as a concentric cylinder comprising of the inner process vessel, with a jacket to contain the heat transfer medium and external insulation. The material of construction, vessel dimensions, jacket volume, thickness of insulation, multiple impellers, heater rating and motor selection were finalized based on basic engineering principles.
- Fabrication drawings of the designed unit were prepared in 2-D and 3-D using AutoCAD and bought out items were sourced as per the design specifications. The designed unit was fabricated and assembled as per the prepared design.
- The assembled unit was tested using a CMC solution as a test fluid for its mixing performance using acid-base neutralization (discoloration) test and electrical conductivity measurement.
- The developed unit was evaluated for the preparation of *lassi* using the multivane churn impeller fixed at different off-bottom clearance (3, 6, and 9 cm) and impeller speeds (300,400 and 500 rpm). The mixing performance was recorded in terms of the mixing index, mixing time, and power consumption, while product characteristics was monitored in terms of its viscosity and sensory quality.
- The preparation of processed cheese spread (PCS) in the developed unit using the saw tooth disc impeller was attempted by combining the mixing unit operations with heat transfer. The process parameters identified for the evaluation included the process temperature (50, 65 and 80 ^{o}C) and impeller speed (10000, 15000 and 20000 rpm). Both mixing performance indices and product quality characteristics (spreadibility and sensory scores) were investigated.
- The efficacy of the developed unit to recombine milk at three fat levels (1.5, 3.0 and 4.5 %) was studied using the saw tooth disc impeller as a high shear impeller. The process parameters identified for the study were temperature (20, 35, 50 ^{o}C) and impeller speed (10000, 15000 and 20000 rpm). The recombination was monitored in terms of the mixing indices, power draw as well as creaming index, viscosity and sensory profile of the recombined milks.
- Experiments were designed for the identified process parameters for each product (lassi, processed cheese spread and the three recombined milks) based on a Face Centered Composite Rotatable Design and 13 runs of experiments were carried out. For each experimental run, the respective identified responses were recorded and

analysed.

- Based on the statistical analysis of the observed responses, quadratic models were fitted to each of the response. The optimal combination of process parameters for preparing each of the selected products in the universal disperser was determined using Response Surface Methodology for set goals for the responses. The obtained optimal process parameters were then validated through real time evaluation.

The salient results obtained in this study are presented below.

- The developed universal disperser could be successfully applied for multiple unit operations in the batch mode preparation of the selected products. Based on the envisaged applications, three impellers of different geometry viz. multivane churn impeller, pitched blade and saw tooth disc impeller were identified and selected as the multifunctional attachments for the unit. The unit was also integrated with an electric heater (2 kW) and two independent motors to provide the mechanical drive for low speed (<2000 rpm) and high speed (<25000 rpm) applications, respectively.
- CMC solution was successfully tested as a simulant fluid for the performance evaluation of the developed unit at different off-bottom clearance levels and impeller speed for the three impeller designs.
- Multivane churn impeller was identified as the more suitable impeller for the preparation of *lassi* in the developed unit. Both off-bottom clearance and impeller speed were significant in their influence on the mixing performance and product quality and acceptability.
- The optimal combination of process parameters for preparation of *lassi* using the developed disperser were obtained using Response Surface Methodology. The impeller placed at an off-bottom clearance of 4.84 cm at an impeller speed of 389 rpm provided the optimal combination. The mixing time for the optimised process conditions was obtained as 168 s with a power draw of 34.47 W, resulting in a product with overall acceptability score of 8.16.
- Preparation of processed cheese spread was successfully achieved in the universal disperser using the saw tooth disc impeller with assisted heating. The process temperature (50-80 ^{o}C) and impeller speed (10000-20000 rpm) were deduced to be significant in their influence on the process and product quality.

- Process optimization using Response Surface Methodology revealed that the optimal quality processed cheese spread (overall acceptability score 8.3) with desired mixing performance could be prepared using the universal disperser fitted with the saw tooth disc impeller operated at 19124 rpm and process temperature of 80 ^{o}C. The process time obtained was 326 s for a mixing index of 0.975 and the power consumed was obtained as 295.96 W
- The developed universal disperser fitted with the saw tooth disc blade was also successfully tested for recombination of milk from SMP, butter oil and water at three different levels of fat, viz., 1.5, 3.0 and 4.5 %. Impeller speed and process temperature were observed to be significant in their effect on the process and product parameters.
- The process conditions were optimized using Response Surface Methodology for recombination at each level of the fat in milk in terms of process temperature and impeller speed. The optimized conditions for satisfactory recombination was 48 ^{o}C at 17820 rpm (for 1.5 % fat milk), 15701 rpm (for 3.0 % fat milk) and 15459 rpm (for 4.5 % fat milk). The mixing index for the recombined milk at all levels of fat prepared under the optimized process conditions were near unity with an overall acceptance score >8.0.
- Realtime validation of the optimised process for all the three tested products (*lassi*, processed cheese spread and recombined milk) indicated that the observed values of the responses for each product were in good agreement with the predicted values.

The study was an action-based research, to develop a universal disperser for dairy processing operations, which was successfully demonstrated. The process profile of the selected test products i.e. *lassi*, processed cheese spread and recombined milk encompassed different processing operations including stirring, agitation, mixing, size reduction, dispersion and emulsifications. The developed unit demonstrated versatility in its applications to perform multiple unit operations during processing of dairy products.

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Appendix

APPENDIX-I

Sensory Evaluation of Product on 9-Point Hedonic Scale

Name of the judge: **Date:**

Name of the product: Lassi

Attributes / Sample code	Color and Appearance	Mouthfeel	Taste and Flavour	Overall acceptability
Control				
S1				
S2				
S3				

(9-Like Extremely, 8-Like Very Much, 7-Like Moderately, 6-Like Slightly, 5-Neither Like nor Dislike, 4-Dislike Slightly, 3-Dislike Moderately, 2-Dislike Very Much, 1-Dislike Extremely)

Remarks if any:-

Signature

APPENDIX-II

Sensory Evaluation of Product on 9-Point Hedonic Scale

Name of the judge: **Date:**

Name of the product: Processed Cheese Spread

Attributes / Sample code	Color and Appearance	Flavour	Consistency and Spreadibility	Overall acceptability
C1				
C2				
C3				
C4				

(9-Like Extremely, 8-Like Very Much, 7-Like Moderately, 6-Like Slightly, 5-Neither Like nor Dislike, 4-Dislike Slightly, 3-Dislike Moderately, 2-Dislike Very Much, 1-Dislike Extremely)

Remarks if any: -

Signature

APPENDIX-III

Sensory Evaluation of Product on 9-Point Hedonic Scale

Name of the judge: **Date:**

Name of the product: Recombined Milk

Attributes Sample code	Color and Appearance	Consistency	Flavour	Overall acceptability
R1				
R2				
R3				
R4				

(9-Like Extremely, 8-Like Very Much, 7-Like Moderately, 6-Like Slightly, 5-Neither Like nor Dislike, 4-Dislike Slightly, 3-Dislike Moderately, 2-Dislike Very Much, 1-Dislike Extremely)

Remarks if any: -

Signature

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- Rupesh P. Datir, Anant V. Dhotre, Prashant G. Wasnik & Gajanan P. Deshmukh (2017) Feasibility Study of Self-Heating Container For Cooking of Noodle Using Exothermic Reaction. International J. of Pure Applied Biosciences, 2017, 5(5):1099-1107.
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