

**FEASIBILITY STUDY ON MANUFACTURE
OF DANEDAR KHOA USING THREE
STAGE SCRAPED SURFACE HEAT
EXCHANGER**



**THESIS SUBMITTED TO THE
NATIONAL DAIRY RESEARCH INSTITUTE, KARNAL
(DEEMED UNIVERSITY)
IN PARTIAL FULFILMENT OF THE REQUIREMENT
FOR THE AWARD OF THE DEGREE OF**

**MASTER OF TECHNOLOGY
IN
DAIRYING
(DAIRY ENGINEERING)**

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KARNAL - 132001 (HARYANA), INDIA
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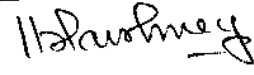
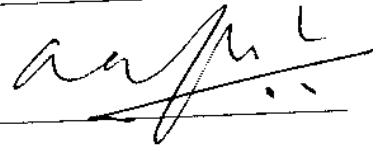
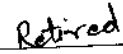
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This is to certify that the thesis entitled "**FEASIBILITY STUDY ON MANUFACTURE OF DANEDAR KHOA USING THREE STAGE SCRAPED SURFACE HEAT EXCHANGER**" submitted by **Mr. ANKIT DEEP** in partial fulfilment of the requirement for the award of the degree of **MASTER OF TECHNOLOGY** in **DAIRYING (DAIRY ENGINEERING)** of the **NATIONAL DAIRY RESEARCH INSTITUTE (DEEMED UNIVERSITY)**, Karnal (Haryana), India, is a bonafide research work carried out by his under my supervision and guidance and no part of the thesis has been submitted for any other degree or diploma.

Dated: 16th June 2009


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MAJOR ADVISOR & CHAIRMAN
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Dedicated to

Lord Shiva

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ABSTRACT

The present investigation was undertaken to explore the feasibility of three stage SSHE for manufacture of *danedar khoa*. Trials were conducted to optimize the process parameters such as initial acidity of milk, mass flow rate, steam pressure, and scraper speed. Initial acidity of milk was varied from 0.16 to 0.19 % LA. The mass flow rate was varied between 170 to 210 kg/hr. Three level of scraper speed were taken in the first, four levels in second stage and three levels in third stage i.e. 200,175,150 rpm; 200,175,150,125 rpm 25,20,15 rpm respectively. Steam pressure was fixed at 4 and 2 kg/cm² in first and second stage respectively and varied between 1.5 to 2 kg/cm² in third stage. The quality of *danedar khoa* so produced was evaluated in terms of sensory evaluation and textural profile analysis. Effect of scraper speed on different performance variables like sensory attributes, textural profile, overall heat transfer coefficient, steam and electricity consumption was also studied. Manufacture of *danedar khoa* using three stage TFSSHE was found out to be feasible. The best quality of *danedar khoa* as indicated by overall acceptability score in sensory evaluation was prepared by using standardised milk with 0.18% LA initial acidity & keeping scraper speed 175, 150, 15 rpm for first, second and third stage SSHE and flow rate 190 kg/hr and at steam pressures 4, 2 & 1.5 kg/cm². Comparative study was carried out with the market sample and *danedar khoa* made by using three stage TFSSHE. It was found out that product manufactured from TFSSHE was comparable with market samples with exception that it was softer and more adhesive as compared to market sample.

सारांश

वर्तमान जांच दानेदार खोआ के उत्पादन के लिए तीन चरण एस.एस.एच.इ. की व्यवहार्यता का पता लगाने के लिए की गई। प्रक्रिया मापदंड जैसे की दूध की आरंभिक अम्लता, द्रव्यमान प्रवाह दर, भाप का दबाव और खुरचनी की घूर्णक गति का अनुकूलन करने के लिए परीक्षण किए गए। दूध की आरंभिक अम्लता 0.16 से 0.19% एल. ए. तक विभिन्न की गई। द्रव्यमान के प्रवाह की दर 170 से 210 किग्रा./घंटा के बीच विभिन्न की गई। खुरचनी गति पहले चरण में तीन स्तर, दूसरे चरण में चार स्तर और तीसरे चरण तीन में स्तर अर्थात् 200,175,150; 200,175,150,125 और 25,20,15 प्रति मिनट परिभ्रमण ली गई। भाप दबाव पहले और दूसरे चरण में क्रमशः 4 और 2 किग्रा./वर्ग सेंटीमीटर पर तय किया और तीसरे चरण में 1.5 से 2 किग्रा./वर्ग सेंटीमीटर के बीच में विविध किया गया। दानेदार खोआ उत्पादन की गुणवत्ता का मूल्यांकन संवेदी मूल्यांकन और बनावट प्रोफाइल विश्लेषण की दृष्टि से किया गया। विभिन्न निष्पादन चर यथा संवेदन मूल्यांकन, बनावट प्रोफाइल विश्लेषण, समग्र ऊष्मा विनिमय गुणांक, भाप और बिजली की खपत पर खुरचनी की गति प्रभाव का अध्ययन किया गया। दानेदार खोआ के निर्माण के लिए तीन चरण टी.एफ.एस.एस.एच.इ के उपयोग को संभव पाया गया। सर्वोत्तम गुणवत्ता युक्त दानेदार खोआ का उत्पादन मानकीकृत दूध (0.18% एल. ए. प्रारंभिक अम्लता), पहले, दूसरे और तीसरे खुरचनी परिभ्रमण गति क्रमशः 175, 150, 15 प्रति मिनट और 190 किग्रा./घंटा प्रवाह दर का उपयोग करके किया गया। तीन चरण टी.एफ.एस.एस.एच.इ का सबसे अच्छा उत्पाद और बाजार नमूने का तुलनात्मक अध्ययन किया गया और यह पाया गया कि टी.एफ.एस.एस.एच.इ. का उत्पाद बाजार नमूने की तुलना में नरम और अधिक आसंजी था।

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LIST OF ABBREVIATIONS AND NOTATIONS

LIST OF ABBREVIATIONS

BIS	: Bureau of Indian Standards
DMB	: Dry Matter Basis
FFA	: Free Fatty Acids
g	: gram
IDF	: International Dairy Federation
IS	: Indian Standards
kg	: kilogram
LA	: Lactic acid
lps	: Litres per second
mg	: milligram
ml	: millilitre
MS	: Mild Steel
NPRT	: Normalized Particle Residence Time
°C	: Degree Celsius
PFA	: Prevention of Food adulteration Act
PV	: Peroxide Value
RO	: Reverse Osmosis
rpm	: Revolutions per minute
rps	: Revolution per second
RTD	: Residence time distribution
SD	: Standard Deviation
SNF	: Solid not fat
SS	: Stainless Steel
SSHE	: Scraped Surface Heat Exchanger
TFSSHE	: Thin Film Scraped Surface Heat Exchanger
TS	: Total Solid
UHT	: Ultra High Temperature
W	: Watts

LIST OF NOTATIONS

T	: Circumferential thickness of agitator nearest vessel wall ,m
C	: Minimum clearance between agitator and vessel ,m
C _m	: Maximum clearance between agitator and vessel, m
A	: C _m / C
B	: Number of blades
K	: Thermal conductivity of fluid ,W/mK
C _p	: Specific heat, kJ/kg °K
D	: Inside diameter of heat exchanger, m
P _c	: Power consumed in the clearance ,kgm/s

N	: Rotor speed ,rpm
S ₁	: Percent total solids in feed
S ₀	: Percent total solids at outlet
S	: Percent average total solids (S ₁ +S ₀)/2
E	: Percentage of feed evaporated or vapour fraction
h _s	: Scraped film heat transfer coefficient, W/m ² K
L	: Length of heat exchanger, m
π _m	: Criterion of film thickness
T _s	: Temperature of condensing steam, °C
ΔT	: Temperature difference between condensing steam and fluid saturation temperature
U	: Overall heat transfer coefficient, W/m ² K
G ₀	: Amount of feed, kg/s
V _c	: Circumferential velocity of rotor blades , m/s
μ	: Coefficient of viscosity, Pa-sec
ρ	: Density kg/m ³
σ	: Surface tension N/m
P	: Power consumption, Watts
m	: Average thickness of film, m
M	: Mass flow rate
R ₁	: Rotor rpm of first stage SSHE
R ₂	: Rotor rpm of second stage SSHE
R ₃	: Rotor rpm of second stage SSHE
P ₁	: Pressure in first stage SSHE
P ₂	: Pressure in second stage SSHE
P ₃	: Pressure in second stage SSHE

DIMENSIONLESS NUMBERS

π _{Re}	: Reynolds's number = ρVL / μ
N _u	: Nusselt number = hL / k
P _r	: Prandtl number = μCp / k
[N _{re}]G _e	: Generalized Reynolds's number
[P _r]G _e	: Generalized Prandtl number
T _a	: Taylor number
R _{ea}	: Axial Reynolds number

CHAPTER -1

INTRODUCTION

INTRODUCTION

1.1 Indian Dairy Industry – A Scenario

India has gained top position in milk production after white revolution with an average annual milk production of 101.2 MT against total world milk production around 632 MT in 2007, accounting for more than 16% of world's total production. It is estimated that about 50 – 55 % of Indian milk production is converted into milk products. As the growth rate of dairy industry in India is growing, the demand for energy efficient and highly sophisticated mechanized systems is also growing. Even today most of the traditional milk products are manufactured by conventional method, which suffers from many limitations such as low heat transfer rates, high fouling behaviour, batch to batch variation in product quality, poor hygienic, poor sanitary standards and lot of stress on the operator.

The traditional milk products provide a means of preserving precious milk solids for a comparatively longer time than the fluid milk, where the self life under tropical Indian condition is only 5-6 hrs at ambient temperatures. The manufacture of traditional milk products will enable the dairy plants to become economically viable.

These small-scale technologies cannot be exploited for large-scale production. Besides higher profitability, traditional dairy products have acquired interest in large-scale production of these products. Therefore the large-scale manufacture of traditional milk products will enable the dairy plant more economically viable due to their higher profitability and export potential. The GATT agreement from the time it has come into action facilitates free trade through the opening of potential market. It is therefore necessary to give top priority to work on design and development of mechanized systems for manufacture of traditional dairy products.

Khoa is partially dehydrated, heat desiccated milk product and it is widely used as a base material for preparation of numerous indigenous sweets. The increasing demand of *khoa* based indigenous sweets has created need for large industrial production ensuring uniform product quality, product safety, energy

conservation, etc. Development of an industrial scale *khoa* making plant has been a challenge to dairy scientists since several years. Many efforts have been made in mechanization of *khoa* making process to improve heat transfer and also to overcome the drawbacks of traditional methods as well as to commercialize the process for industrial requirements. Extensive studies were also carried out on the hydrodynamics and heat transfer of thin film scraped surface heat exchanger for processing of liquid, concentrated liquids, and particulate viscous foods. Studies were also undertaken on the applicability of thin film scraped surface heat exchanger (TFSSHE) for the mechanization of *khoa*.

1.2 Khoa

According to PFA rules, revised in 2002, *khoa* is a product obtained from cow or buffalo milk or a combination thereof by rapid desiccation and having not less than 30% fat on dry matter basis of the finished product.

According to Indian Standards (IS: 4883-1980), *khoa* shall be heat-coagulated milk-product obtained by partial dehydration of milk of buffalo, cow, sheep, and goat or their admixture. Milk solids suitably processed may also be used. It shall not contain any ingredient foreign to milk except citric acid in *danedar khoa* added to develop desirable characteristic. *Khoa* as presently marketed is designated as *pindi*, *dhap* and *danedar*.

Usually buffalo milk is preferred to cow milk in making *khoa* because besides giving a larger yield, it gives a product of soft body and smooth texture, which is highly desirable for *khoa* based sweets. A minimum fat level of 4 per cent in cow milk and 5.5 per cent for buffalo milk is essential for producing suitable body and texture in *khoa* to make it acceptable for use in sweet making.

A large variation in quality of market surplus indicates three major varieties of *khoa* viz. *pindi*, *dhap* and *danedar*. Chemical composition, sensory characteristics and end uses of such varieties are found to be different. These varieties of *khoa* are received in Delhi market, which is the biggest *khoa* marketing centre in the country today. These types of *khoa* differ in quality and also in price. All of these varieties are in demand and are required for specific types of sweets as shown below (De, 1983).

Table 1.1: Gross Composition and specific sweets prepared from different *khoa*

Type	Gross Composition		Specific sweets prepared
	Fat %	Moisture %	
<i>Pindi</i>	21-26	31-33	<i>Burfi, Peda</i>
<i>Dhap</i>	20-23	37-44	<i>Gulabjamun, Pantua</i>
<i>Danedar</i>	20-25	35-40	<i>Kalakand, Gourd Burfi, Milk cakes</i>

Conventionally it is prepared by continuous boiling of milk in an open kettle until desired concentration (normally 65-72% total solids) and texture is achieved. It has been estimated that about 5.5% of total milk production is converted into *khoa* (Banerjee,1997) and on the basis of present milk production of about 100 million tonnes per annum this, amount is equivalent to 15.17 million kilograms of *khoa* per day.

The preparation and use of *khoa* confined mostly to the northern and western regions of the country. By far the largest amount is contributed by Uttar Pradesh, where nearly 36% of the country's total *khoa* production takes place. About 15 plants in India have initiated in-line production of *khoa* with daily output of 1 to 4 tonnes. There are large numbers of *khoa* based sweets. These sweets are also gaining wide acceptance in South Asian and African countries, UK, Canada and the USA.

Khoa manufactured in jacketed kettles inherently suffers from several disadvantages.

1. Low heat transfer coefficients causing equipments to be bulky.
2. Insanitary operation as it is open to atmosphere.
3. Formation of tenacious scale of milk residues on the heating surface, adding poor performance of equipment and making cleaning and sanitization strenuous.
4. Equipment unsuitable for large volume of production.
5. Large residence time and product inventory in the equipment presenting greater risk of bulk spoilage of product.
6. Excessive strain and fatigue on the operator.
7. Batch to batch variation in product quality.

8. Under-utilization of capacity due to its foaming tendency.

All these problems can be overcome by using thin film scraped surface heat exchanger (SSHE) due to its unique performance characteristics. In this equipment, the heating surface is scraped continuously. By this technique, the slow moving layer of product at the heating surface which restricts the rate of heat transfer is quickly removed and mixed with bulk of liquid. Simultaneously, fresh product is brought in contact with surface. The scraping is achieved by a set of rotating blades. The action of blades substantially accelerates heat and mass transfer by creating turbulence and pumping action in liquid. To enhance heat transfer rates from condensing steam, horizontal configuration may be chosen. Some of the unique performance characteristics of thin film SSHE are:

1. Short residence time in heated zone, literally in seconds. Therefore, this type of heat exchanger is a logical choice for handling heat sensitive products.
2. High heat transfer and heat fluxes primarily due to thin layer of product and turbulence imparted by rotor. Hence, highly viscous material which tends to scale can be conveniently processed.
3. Higher yields due to short residence time fewer side reactions and less decomposition.
4. Product is confined as a thin film on the heating surface; consequently the hold-up volume is extremely small thereby minimum loss due to spoilage inside the heat exchanger, unlike in batch process where the loss would be total.
5. Improved flow characteristics of the product inside the equipment. The system can handle products even in semi-solid form without causing heat damage. Outlet to inlet viscosity ratio can be 1000 or more.
6. Adaptable to automation and cleaning in place.
7. Sanitary operation, as process takes place in a completely closed environment.
8. Low physical strain on operators. Only small valves have to be closed or opened by them.
9. Uniform product quality, because the process is continuous.
10. Low product inventory in process zone.

11. Once through processing with overhead to bottom splits as high as 99:1.
12. Negligible pressure drop.
13. High turn down capability.
14. Waste heat recovery is possible- energy conservation
15. It is possible to use concentrated milk as well as feed, which would increase the capacity substantially.
16. Narrow residence time distribution.
17. Minimum surface fouling.
18. Liquids with foaming tendencies can be easily handled.
19. Better to control and optimize the process.

The work on continuous *khoa* making machine gained momentum in recent years as a result of greater emphasis laid for the manufacture of indigenous milk products in the organized sector. For handling high viscosity products with or without particles, and for the products that tends to foul the heat transfer surface, the thin film scraped surface heat exchanger (TFSSHE) is most suitable. In TFSSHE, the working fluid is spread in the form of a film over the heat transfer surface by rotating blades. Each blade scoops a certain amount of fluid from the pool and accelerates it along the heat exchanger surface. At any given instant the fluid picked up by the blade is partly in the form of a film behind the blade and partly in the form of a fillet in front of the blade. The blade action, which is similar to that of a plough, causes part of the fluid in the film to mix with that in the fillet simultaneously restoring the film thickness by allowing an equal amount of fluid to squeeze past the tip of the blade.

Continuous *khoa* making machine developed as three stage Scraped Surface Heat Exchanger has been proved very successful. The state of the art technology has been provided in its design by incorporating variations in machine parameters. It is therefore proposed to study on manufacture of different types of *khoa* using three stage Scraped Surface Heat Exchanger.

1.3 Rationale and objectives

Significant portion of milk produced in India is used to manufacture a wide variety of indigenous sweets. *Khoa* is the basic ingredient in most of milk based sweets. However, no systematic attempt has been made in the development of

scientific methods for predicting equipment performance, suited to the formation of desirable texture of Indigenous dairy products. Since there is scanty knowledge of basic research data pertaining to the texture of the *khoa*, it has been difficult to make ameliorative effort to mechanize the process of *khoa* production with desirable texture. The equipment has been found very successful for manufacture of *khoa* using buffalo milk, but no attempt has been made yet to manufacture *danedar khoa*.

Hence the present dissertation work is envisaged to produce *danedar khoa* using thin film scraped surface heat exchanger. The operating parameters for formation of desired texture of the product would be investigated and optimized. Thus, the present dissertation programme has been formulated with the following objectives:

1. To establish process and machine parameters for manufacture of *danedar khoa*.
2. To study thermal performance of each SSHE.
3. To study the product quality in terms of textural attributes.

CHAPTER -2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The review of literature related to this investigation is here with presented under the following sub heads:

2.1 Khoa

2.1.1 Types of khoa

2.1.2 Legal Requirements for khoa

2.2 Equipment involved in manufacturing of khoa

2.2.1 Batch Type Equipments

2.2.2 Continuous-Operation Type Equipments

2.2.3 Multi-purpose Equipment

2.3 Texture and Microstructure of Traditional Dairy Products

2.4 Effect of various constraints on texture of khoa

2.5 Heat Transfer studies in SSHE

2.6 Arrangement of Rotor Blades and Power Consumption

2.6.1 Arrangement of Rotor Blades

2.6.2 Rotor Power Consumption

2.7 Inferences Drawn from Review of Literature

2.1 Khoa

Khoa, an important indigenous product prepared by partial desiccation of milk, is used as a base material in preparation of variety of popular milk sweets viz. *Burfi*, *Peda*, *Gulabjamun* and *Kalakand*. It is also known as *Khoya*, *Khava*, *Kava*, *Mava* or *Palghoa*. It is made by heating, evaporating and desiccation of milk at atmospheric pressure accompanied with continuous stirring until dough like consistency is achieved. According to Rajorhia (2002) about seven to eight per cent of country's milk is converted into *khoa* and annual production of *khoa* in India may be calculated at 1.5 million tones, valued at Rs. 1,05,00 crore at a present rate of Rs. 75/kg.

Khoa refers to the milk product prepared by partial dehydration of milk by heating under controlled conditions. According to PFA Rules revised in 2002, *khoa* is the product obtained from cow, buffalo, goat, or sheep milk/milk solids or

a combination thereof by rapid drying. The fat content shall not be less than 30% on dry weight basis of the finished product. It may contain citric acid not more than 0.1 % by weight. It shall be free from added starch, added sugar and added colouring matter.

According to Indian Standards: (IS: 4883-1980) *khoa* shall be heat-coagulated milk-product obtained by partial dehydration of milk of buffalo, cow, sheep, and goat or their admixture. Milk solids suitably processed may also be used. It shall not contain any ingredient foreign to milk except citric acid in *danedar khoa* added to develop desirable characteristic.

During the process of *khoa* production from milk, heat coagulation of milk proteins, especially the whey proteins occurs and the characteristics cooked flavour appears. Further the vigorous stirring of the hot mass exerts an appreciable homogenizing action, so that when the pat is formed, all the fat globules are entrained in the mass. The water is also dispersed as fine droplets in *khoa*.

Desirable characteristics of *khoa* refer to typically milk-cooked flavour, similar to that perceived from boiled milk are free from any objectionable or abnormal flavour, possessing uniform and slightly granular texture (Pal and Gupta, 1984). A good quality *khoa*, in general, should have a uniform whitish colour with perhaps a tinge of brown colour. *Khoa* made from cow milk, however, has slight yellow to deep yellow colour. A little release of free fat on surface is desirable. Chemical composition of *khoa* has been reported to vary widely in market samples. Percent moisture, fat, protein and lactose contents in laboratory samples were reported to be 33.20, 26.45, 18.60 and 19.85 respectively (Adhikari et al., 1994) whereas corresponding values for market samples varied from 9.9-39.5, 13.49-43.2, 18.99-34.6 and 9.88-39.50 (Mandkot and Garg, 1985). Shelf life of *khoa* is two to four days under ambient conditions and three weeks under refrigerated conditions. The *khoa* made from buffalo milk is considered distinctly superior, being whiter in colour and having soft smooth body and granular texture. These characteristics are considered desirable for making high quality sweets. Apart from this *khoa* made from buffalo milk gives higher yield as compared to that of cow milk. Since desiccation is done under open atmospheric

conditions, the microbiological quality of the product is open to environmental changes.

2.1.1 Types of *khoa*

Presently *khoa* being marketed is designated as follows:

Pindi – It is characterised as a circular ball of hemispherical pat with smooth and homogeneous body and texture. The product shall be free from burnt particles as well as from any browning defects. The product should possess characteristic cooked flavour and also should be free from objectionable odour and sour (acidic) taste.

Danedar – It is characterised by its granular texture and uneven body. The size of grains depends upon the amount of coagulant added and the quality of milk used. Citric acid when added should not exceed 0.1% of the product. This type of *khoa* is used as a base for the preparation of *kalakand*, cakes and pastries where granulation is valued to a greater extent.

Dhap (Kaccha Mawa) - It is characterised by loose and sticky body and smooth texture. It contains less than 60% by mass of total solids and higher moisture content than *pindi* and *danedar* types. *Dhap* is preferred for preparation of *gulabjamun* as it forms uniform balls with desired rheological qualities after frying and soaking in sugar syrup.

2.1.2 Legal Requirements for *khoa*

Only fresh, sweet, clean milk, free from colostrums and in every way fit for human consumption shall be used. The milk shall be free from adulterants, preservatives and any matter foreign to milk. The fat percentage of the milk shall be such that the final product conforms to the requirements given in Table 2.1.

Table 2.1: Requirements for *khoa*

Characteristic	<i>Pindi</i>	<i>Danedar</i>	<i>Dhap</i>
Total Solids, % by wt (<i>Min.</i>)	65	60	55
Fat, on dry basis, % by mass (<i>Min</i>)	37	37	37
Total Ash, on dry basis, % by mass (<i>Max</i>)	6.0	6.0	6.0
Titrateable Acidity, as lactic acid, % by mass(<i>Max</i>)	0.8	0.9	0.6
Coliform Count per gram, (<i>Max</i>)	90	90	90
Yeast and Mold Count per gram, (<i>Max</i>)	50	50	50

2.2 Equipment involved in manufacturing of *khoa*

For converting the milk into *khoa*, the processing operations like heating, concentration, evaporation, mixing and blending are carried out on milk. Several attempts have been made to design and develop equipments for manufacturing of *khoa*. These include batch type equipments, continuous operation type equipments and multi-purpose equipments. Each of these configurations has advantages in certain applications, while limitations in others. Some of these equipments have been discussed as below:

2.2.1 Batch Type Equipments

De and Ray (1952) described a method of *khoa* making by taking milk in a 'Karahi' to its 1/5th to 1/4th volume. Buffalo milk was standardized to 5% Fat and cow milk to 4% Fat. The average yield of *khoa* was found to be 21.6% and 18.3% respectively.

Sawhney *et al.* (1980) developed an improved village level pan to manufacture *khoa* consisting of a hemispherical milk steel pan joined to a cylindrical water jacket. Water in the jacket was converted into steam by placing the pan over a furnace. The steam exchanged heat with milk in the pan and returned to water phase by losing its latent heat content. The closed thermodynamic water-steam system in the jacket provided a mechanism for uniform heat supply for better quality product. A dead weight safety valve designed to be adjusted at an increment of 0.3 kg/cm² was provided to control water steam pressure in the jacket. This pan could also be used to manufacture other types of viscous dairy products.

Singh (1980) used atmospheric drum drier for large-scale production of *khoa* using evaporated milk having total solids ranging from 30% to 50% at three levels.

Sawhney *et al.* (1987) developed a mechanized *khoa* pan, having a provision for mechanized scrapping of contents in the *khoa* pan during desiccation process. The problem of foaming of milk during boiling was overcome by hinging a cylindrical foam column to the pan. In its jacket, water was filled up to 2/3rd of its height and then placed over furnace to generate steam. The

pressure of steam was controlled by safety valve from 0 to 4 kg/cm² as per the process requirement. The scrapping assembly consisted of an anchor type mechanism fitted with swinging blades attached to a central vertical shaft. The equipment could convert 5 litres of milk into *khoa* in 10 to 12 minutes at 2 kg/cm² pressure.

More (1987) designed and developed a batch type semi-mechanized SSHE. This system consisted of a jacketed drum, with vapour exhaust and scraper assembly. The system consisted of Scraper assembly with spring-loaded blades, rubber boots and central shaft. A gland packing is provided on auxiliary shaft in order to avoid the leakage of milk. Studies were carried out on the effect of scraper speed and heating temperature for better quality product. The results showed that the most suitable operating condition for dehydration of milk is to keep heating temperature at 121°C and scraper speed at 28 rpm. During the investigation, a batch size of 4 kg milk is used

2.2.2 Continuous-Operation Type Equipments

Banerjee *et al.* (1968) developed semi continuous *khoa*- making machine that was further modified by De and Singh (1970), and Srinivasan and Rajorhia (1975). The equipment consisted of a SSHE for pre concentrating the milk and two open semi jacketed pans in cascade fashion with reciprocating spring-loaded scrapers for continuous manufacture of *khoa*. During their investigation, initially milk having 12-13 % total solids, was pumped in the SSHE for pre-heating and concentrated to 30-35 % total solids in the SSHE followed by further heating and concentration up 50-55 % total solids in first open pan. The final concentration in the range of 70-75 % total solids achieved in second open steam jacketed pans where the burning of milk is prevented by scraping with power driven scraper. The whole assembly of equipment had a total capacity of 50 litres of milk per hour during smooth and uninterrupted running of the system.

Abhichandani (1985) claimed that the TFSSHE could be very effective used for continuous manufacture of Indigenous milk products. In this equipment, the heating surface was scraped continuously by a set of rotating blades, which causes the slow moving layer at the heating surface to be removed quickly and

mix with bulk of the liquid at the same time fresh liquid is brought in contact with heating surface.

Punj Rath *et al.* (1990) developed an inclined scraped surface heat exchanger (ISSHE) for continuous manufacturing of *khoa*. The heat exchanger comprised of inner cylinder, rotor drive and outer steam jacket. In this system, the scraper repeats the process of moving coagulated particles from heat transfer surface and mixing them back to the pool of heated milk. The wet coagulated particles are pushed ahead by the screw conveyor, provided as an integral part of the rotor for further evaporation and the concentrated milk flows back to the pool. The angle of inclination varied from 0 to 30°C. It permits the formation of pool of boiling milk critical for the formation of *khoa*. For the feed rates investigated during trials, rotor speed between 40 to 80 rpm found to be in the optimum range. It was found that steam pressures in the range of 1.0 to 2.0 Kg/ cm² were found to give best quality product. The limitation of the machine was that it requires pre concentrated milk around 45% TS.

Christie and Shah (1990) designed three stages unit for continuous manufacture of *Khoa* from whole milk. The machine had three jacketed cylinders placed in cascade arrangement with some slope. The slope allows the movement of contents in a longitudinal direction. The heat exchangers are partially open at both ends to provide a space for the vapours to escape thus water is evaporated at atmospheric pressure, to provide condition very similar to those of an open '*Karahi*' which is vital for the development of typical flavour as well as body and texture of *khoa*. The unit is provided with variable pulley drive so that speed adjustment is possible. The high speed in the first stage helps to achieve very high rates of water removal at low total milk solids level of the feed. Arrangements were also made at the end of each exchanger to facilitate effective transfer of contents into the next stage at the same time avoiding milk and solids spillage.

Jayendra (2000) reported that contherm-convap scraped surface heat exchanger system developed by Alfa-Laval has also been used to manufacture *khoa*. The process can be utilized for manufacture of *khoa* with sticky body or fine texture if the adequate precautions are taken to maintain uniform steam pressure

in the jacket and continuity of the flow of the product in the plant. In order to impart characteristic body and flavour, the concentrated mass at about 90°C, emerging out from convap is pumped into a long holding tube. This resulted in excessive power consumption. The cost of equipment is also very high. But the product obtained was criticized due to flavour lacking and being sticky and pasty consistency.

Dodeja *et al.* (1990) studied the performance of the thin film scraped heat exchanger for continuous manufacture of *khoa*. The study showed that increasing speed although enhanced the capacity but had an adverse effect on the product quality.

Dodeja *et al.* (1992) developed a continuous *khoa* manufacturing system. The system consisted of two scraped surface heat exchangers (SSHE) arranged in cascade fashion. The rotor of first SSHE is provided with four variable clearance blades and operated at 3.3 rps and the second SSHE with two variable clearance blades and two helical blades. It was operated at 2.5 rps. The steam pressure in the first stage jacket is maintained at 3-4 kg/cm² and in second stage at 1-2 kg/cm². The product obtained with this machine was comparable with traditional method.

2.2.3 Multi-purpose Equipment

Both the batch type and continuous operation type equipments for processing milk in to *khoa* met with limited success as each one of them had one or the other shortcoming. Moreover these equipments did not have multiuse capability.

Agrawala *et al.* (1987) developed mechanized conical process vat for preparation of *khoa*. This is batch type multipurpose equipment. This equipment consists of a stainless steel conical vat with cone angle 60° and steam jacket partitioned into 4-segments for efficient use of thermal energy and less heat loss. The mechanism is consisting of 3-equidistance arms supported at two points at shaft and each arm having three independent spring-loaded blades. A positive displacement roto-screw pump is connected to the outlet at the bottom of the vat for recirculation and spreading of the product over heat transfer surface. The design of the Conical Process vat was improvised from time to time to make it

suitable for processing various milk products such as *khoa*, *ghee*, *basundi*, *burfi* etc.

Jayendra (2000) redesigned and installed an improvised discharge mechanism for uninterrupted discharge of viscous dairy products at higher concentration from vat.

Dodeja *et al.* (2007) integrated a third stage to existing two stage SSHE in cascade fashion which is providing a great help for texture development in products manufactured by the machine.

2.3 Texture and Microstructure of Traditional Dairy Products

The unique feature of Indian traditional dairy products is that they are obtained by a wide variety of methods involving a range of unit operations. Obviously, this leads to a variety of product structures and textures. The chemical components of traditional dairy products including various additives and the processing conditions to which they have been subjected, determine the texture and microstructure of the products.

Texture perception begins with the structure of a food material (i.e. how the molecules or microstructures are arranged geometrically). When this structure is put in to the mouth or manipulated with our hands, it undergoes changes such as size reduction and moistening caused by salivation.

With the growing demand, there is a need for manufacture of traditional dairy products in modern dairy plants, without any compromise on the quality of the product. Retaining the product's complex texture, while following modified or new processes, is a real challenge to the manufacturer. Hence, characterization of a product's texture is valuable not only in process development studies but also in monitoring of textural quality in routine production.

2.4 Effect of various constraints on texture of *khoa*

Instrumental analysis of food texture has come of age as evinced by increasing application of various empirical and imitative methods towards measurements of texture for variety of food and food products both in research and quality control. Principally favoured due to their simplicity, versatility and

precision, these methods aim at replacing the sensory texture measurement which is time consuming and often less reproducible. Hence, despite the fact that texture is basically a sensory attribute which is perceived as a “response from different kinds of physical and physio-chemical stimuli”. Many attempts had been made to measure the kinesthetic properties of certain foods by instruments, and then to correlate them.

While these attempts had met with varying degrees of success, meaningful studies on psychorheology aspects of food products bringing out significant interrelationship between the sensory texture perception and instrumental measurement can potentially revolutionize the quality control programmes lending them greater reliability together with simplicity.

Instrumental devices such as the General Foods Texturometer, Ottawa Texture Measuring System, Universal Food Rheometer and Instron Universal Testing Machine had been found useful in texture assessment of various foods for research and quality control purposes. This would be particularly relevant to indigenous milk products such as *khoa* which, hitherto manufactured by traditional processes only on small scales, are proposed to be produced on large scales by introducing technological innovations.

De and Ray (1953) reported that the quality of *khoa* was better when made from buffalo milk as *khoa* from cow milk is inferior due to its moist surface, sticky and sandy texture.

Boghra (1988) reported that concentration of soluble calcium, magnesium, phosphorus and citrate had a positive correlation with hardness of *khoa*.

Garg *et al.* (1989) investigated the textural changes in *khoa* during holding. During the investigation, post-manufacture holding of *khoa* was investigated with respect to the textural changes in the product. Instron hardness, gumminess, chewiness and adhesiveness of *khoa*, particularly of low-moisture type, registered a definite rise during holding at 30°C for 72 hrs. Cohesiveness and springiness, however, remained largely unaffected. Dynamic viscosity of the product followed a similar trend as hardness. The moisture content unaltered during holding. The observed changes in texture of *khoa* were considered

attributable to probable changes in the physical status of the product constituents.

Gupta *et al.* (1990) studied the Instron texture profile parameters of *khoa* as influenced by composition. During their investigation, it was observed that an increase in TS was accompanied by considerable increase in Instron hardness, gumminess and chewiness, but decrease in cohesiveness. Water dispersible protein had the opposite effect although its effect on cohesiveness was non-significant. Milk acidity and free fat content of *khoa* did not show any significant correlations with texture profile parameters. Significant interrelationships among texture profile parameters, particularly between hardness and cohesiveness, gumminess and chewiness, and also between cohesiveness and other parameters indicated that one or two most important texture profile parameters could probably serve as an index for textural profile of *khoa*.

Patil *et al.* (1990) undertook the project to investigate the interrelationship between sensory and instrumental data on texture of *khoa*. During the course of study, the workers observed a significant correlation between Instron hardness and sensory firmness, crumbliness, stickiness and smoothness. While Instron gumminess and chewiness showed similar or even better correlations with different sensory texture descriptors, Instron springiness, cohesiveness and adhesive force exhibited relatively smaller correlations. Of all texture profile parameters, only adhesiveness bore a definite correlation ($P < 0.05$) with overall sensory texture score of *khoa* with relevant prediction equation explaining about 23% of overall sensory texture score. However, all texture profile parameters included in the multiple regression analysis could predict about 60% variation in overall sensory texture score, which could be considered substantial in view of the complexity of the product's texture. He reported that working of *khoa* significantly decreased the hardness and springiness but increased the adhesiveness and cohesiveness.

Rajorhia *et al.* (1990) studied the effect of quality of milk on chemical, sensory and rheological properties of *khoa*. During the study, the workers found that *khoa* samples prepared from fresh and slightly sour milk (up to 0.20% acidity) had similar sensory and rheological properties. Sour milk having more

than 0.25% acidity resulted in acidic smell and large grain formation in khoa. Such samples showed maximum hardness, springiness, gumminess and chewiness. Neutralization of sour milk with 20% sodium bicarbonate solution improved the flavour and smoothed the texture of khoa. The hardness *khoa* was observed to be increased from 19.47 mN to 22.85 mN and 28.44 mN due to increase in the acidity up to 0.19% and 0.27% lactic acid, respectively. Gumminess and chewiness of *khoa* was also increase due to the developed acidity in the milk and was reduced by neutralization of the same.

Rajorhia *et al.* (1990) studied the effect of composition on texture of *khoa* prepared from buffalo milk. *Khoa* with varying total solids (56.23-71.95%), fat (20.8- 28%) and protein (14.92 -18.87%) was evaluated. It was observed that with varying extent of heat treatment to milk during *khoa* preparation, WDP (water dispersible protein) varied from 8.54 -28.7%. They observed that crumbliness in *khoa* increased with increasing total solids, fat and protein and decreased with increase in WDP. Firmness increased with total solids, fat and protein and decreased with increase in WDP. On the contrary, stickiness increased with increased WDP.

Rajorhia *et al.* (1991) studied different mechanized systems (inclined scraped surface heat exchanger, contherm-convap system, roller dried and conical vat) were evaluated for the quality of *khoa* prepared thereof with regards to physico-chemical characteristics, sensory properties , rheological properties and operational features. During the course of investigation, the authors found that with regards to the sensory characteristics, chemical composition and rheological properties, the *khoa* prepared by ISSHE were similar to those prepared by traditional methods and were uniformly maintained in the whole process. On the basis of study, it was found that that amongst the four selected mechanized systems inclined scarped surface heat exchanger proved to be the most appropriate for continuous manufacture of *khoa*.

Patel *et al.* (1992) studied the effect of concentration condition on texture of *khoa* and reported that *khoa* made in steam kettle process was significantly harder, springy, gummy, and chewy but less adhesive than that prepared from

the simulated traditional process. However *khoa* made by later process was rated more desirable from the view point of overall textural quality.

Patil *et al.* (1992), studied the microstructure and texture of *khoa* and reported that *khoa* has a granular texture consisting of protein granules with several hundred of micrometers in diameter, the granules consists of intact and partially fused casein micelles and non micellar protein; the fresh product is slightly coarse in the mouth. Large aggregate of lactose crystals develops in the inter-granular space in un-worked *khoa* during storage. Working of *khoa* markedly reduces the dimensions of protein granules and the inter-granular wide space and produces large amount of fat globule membrane fragments. Individual lactose crystals in worked *khoa* stored at 20°C for 48 hours were uniformly distributed as compared to un-worked *khoa*. Storage did not increase the sandiness in worked *khoa* and sensory evaluation rated this product markedly smoother than the un-worked product.

Patel *et al.* (1993) studied the effect of addition of whey protein concentrate to cow milk prior to *khoa* making and developed desired grainy texture in cow milk *khoa*.

Adhikari *et al.* (1994) evaluated the interrelationships among Instron Textural Parameters with composition and microstructure of *khoa* and *gulabjamun* made from buffalo milk. The authors observed that Instron hardness, gumminess and chewiness were negatively correlate with moisture and fat contents, but positively with protein, lactose, added carbohydrates, ash and calcium contents for both *khoa* and *gulabjamun*. Cohesiveness was moderately influenced by the compositional characteristics, while no correlation was found between composition and springiness. Significant interrelationships were among hardness with cohesiveness and gumminess with chewiness were observed. Microstructure of *gulabjamun* revealed a loose protein matrix with carded- cotton appearance, while the star h particles had either thread or flower petal-like structure, interspersed loosely in the protein matrix.

Sindhu (1996) reported that the higher emulsifying capacity of buffalo milk fat due to the presence of larger proportion of butyric acid containing triglycerides

(50%) compared to only 37% in cow milk fat may be responsible for smooth and mellow texture of its *khoa*.

Bhadania *et al.* (2004) studied the effect of heat transfer on physico-chemical and sensory quality of *khoa* manufactured using SSHE.

2.5 Heat Transfer studies in SSHE

SSHEs are most often used for products that are highly viscous in nature. For evaporation, thin film operation is used where process liquid moves along the heat transfer surface as a thin film. The greatest advantage of SSHEs for either heating or cooling is the constant removal of the stagnant film near the wall and subsequent increase in the heat transfer coefficients and reduction in fouling at the wall. Investigations were also carried out to find the type of heat transfer mechanisms occurring in SSHEs during evaporation. Two types of mechanisms were suggested.

First mechanism was suggested by Kramers *et al.* (1955). On the basis of studies conducted it was concluded that heat transfer takes place by conduction across the vapour films combined with evaporation of the more volatile component at the surface of the film. During evaporation of liquid film in the SSHE, force of gravity, internal friction, and peripheral forces are the principal forces created by rotation acting on the film.

Lateinen (1958) applied the penetration theory to a two-bladed rotator type SSHE and arrived at an empirical relation for Nusselt number with limitation of heat transfer on viscosity and velocity of liquid through the exchanger.

$$Nu = 1.6 (Re)^{0.5} (Pr)^{0.5}$$

Krischbaum and Dieter (1958) conducted evaporation studies and showed that scraped heat transfer coefficient decreased with increasing ΔT at constant rotor speed, low flow rate and higher value of ΔT . The following correlation was observed.

$$h_s = 437 (N)^{0.33} \rho k / \mu$$

Skelland *et al.* in the late 1950s and early 1960s used dimensional analysis to derive empirical correlations for heat transfer coefficients that was

further modified by including parameters such as effect of rotation, number of blades, physical characteristics in the transition regime between full turbulent flow and laminar flow.

$$Nu = 4.9 (Re)^{1.0} (Pr)^{0.96} (DN_r / V_z)^{0.62} (D_s / s)^{0.55} (B)^{0.53}$$

Reay (1963) studied the relation between blade clearance and heat transfer in thin film evaporator with various fixed clearance blades. The study showed that, heat transfer coefficient dropped by 20% when clearance was doubled and increased by 20% when clearance was decreased by 80%.

The second mechanism explaining that heat transfer takes place due to vapour bubbles formation at heat transfer surface and at overheated spots inside the film was given by Ziolkowski and Skoczylas (1965). On the basis of trials conducted, the workers observed that the liquid film which is the resultant of forces of internal friction, gravitational force and the peripheral forces is affected by formation and release of vapour bubbles and is expected at higher values of specific heat flux and with turbulent flow of film.

Bott *et al.* (Azoory and Bott, 1970; Bott *et al.* 1968, Bott and Sheikh 1966) estimated heat transfer coefficients specifically for thin-film operation of SSHE using glycerol-water mixture. Experiments on water indicated that as rotor speed increased, film coefficient (h_s) was found to be nearly independent of temperature difference, partially at higher rotor speed. They suggested that axial flow velocities were a better marker of thin film operation than rotational velocities.

$$h_s \propto (N)^{0.37}$$

Abichandani (1985) conducted heat transfer studies in thin film evaporator using water, buffalo milk and cream as working fluids. Different process variables selected were in the range – flow rates 0.025 to 0.075 kg/s; scraped speed, 1.78 to 5.338 m/s ; number of blades 2,4,6 and 8 ; and temperature of steam 110⁰C , 120⁰C ,and 130⁰C. The conclusions drawn were:

1. Increase in mass flow rates caused overall heat transfer coefficients to increase for milk and cream only at low rotor speed (1.78 m/s). At higher rotor speed the effect of mass flow rates on overall heat transfer coefficient (U_0) was insignificant.

2. Overall heat transfer coefficient increased with increasing rotor speed especially in the range 100-150 rpm. Increasing the rotor speed beyond 150 rpm did not result in appreciable increase in overall heat transfer coefficient for fluids with fouling tendencies.
3. The overall heat transfer coefficient decreased with increasing ΔT at all rotor speed for milk and cream. It was mainly due to the formation of a tenacious layer of milk constituents on the surface of SSHE, which offered additional resistance.
4. The over all heat transfer coefficient was expressed by the relationship:

$$U_0 = 620.083 - 2.181 (E) - 32.313 (S) + 585.562 (V_c) + 133.336 (B) - 11.67 (\Delta T) - 0.234 (E)^2 + 0.483 (S)^2 - 73.616 (V_c)^2 - 6.293 (B)^2 - 0.168 (\Delta T)^2 - 0.246 (E)(S) + 0.641 (E)(V_c) - 0.029 (E)(B) + 0.706 (E)(\Delta T) + 2.242 (S)(V_c) + 0.758 (S)(B) - 0.21(S)(\Delta T) - 11.987 (V_c)(\Delta T) - 0.464 (V_c)(\Delta T) - 0.302 (B)(\Delta T).$$

It was inferred that the system could be suitably adopted for continuous manufacture of indigenous milk products.

Dodeja (1987) conducted the performance study of the thin film scraped surface heat exchanger for concentration of milk to higher concentration using parameters that were optimized by Abichandani (1985). Following conclusions are drawn:

1. Milk was concentrated upto 70 % total solid using thin film scraped surface heat exchanger. The obtained product was browning free. This inferred that thin film scraped surface heat exchanger could be successfully used for manufacture of indigenous milk products.
2. The data generated from experiments were analysed and following correlation was developed (Dodeja et al., 1990):

$$Nu = 6615.0619 (NRe)_{Ge}^{0.1331} (Pr)_{Ge}^{0.0764} (\Delta T/T_s)^{0.2843}$$

$$19 \leq So \leq 70 \%$$

$$\text{Number of blades} = 4$$

$$V_c = 3.558$$

Above correlation, which was found to predict the scraped film coefficient with reasonably accuracy must be useful in design the thin film scraped surface heat exchanger in applications such as concentration of milk to high solid contents and in manufacture of indigenous milk products.

3. The overall heat transfer coefficient decreased with increasing in steam condensing temperature. However the scraped film coefficient increased with increasing steam condensing temperature until the product attained concentration of about 45 per cent total solids. Beyond this concentration, scraped film coefficient decreased rapidly with increasing steam condensing temperature.

Abichandani and Sarma (1988) studied heat transfer coefficients for liquid of varying viscosity as a function of flow rate, rotor speed, number and mass of blades in thin film operation mode. The analysis was similar to the fluid-full operation except that surface tension forces corresponding to surface renewal were found to be significant.

De Goede and De Jong (1993), accounted for the deviation from the penetration theory included a period after the scraping action in which simple heat transfer under turbulent conditions in the absence of scraping occurred and based on their model they predicted higher heat transfer coefficients due to scraping action than predicted by penetration theory.

Badshah (1999) used a horizontal TFSSHE for evaporation under vacuum in the manufacture of sweetened condensed milk. A correlation was developed for evaporation of water in TFSSHE:

$$Nu = 0.1427 (Re_f)^{1.6527} (Re_r)^{0.1865} (P_r)^{-3.73} (\Delta T / T_s)^{-0.1121}$$

Dumont *et al.* (2000) studied the influence of flow regimes on temperature heterogeneity in a SSHE. Using non-Newtonian and Newtonian fluids, they observed large heterogeneities for laminar flow and progressive homogenization of temperature from inlet to outlet for high rotational speeds.

2.6 Arrangement of Rotor Blades and Power Consumption

2.6.1 Arrangement of Rotor Blades

In the thin film heat exchangers there are mainly two types of blades that can be used according to the investigation to be carried out:

1. Fixed clearance blades
2. Variable clearance blades

The overall thermal performance of the continuous *khoa* making unit is improved by increasing the heat transfer rate with the help of blades by violently

agitating the liquid, eliminating any channeling of liquid, decrease in apparent viscosity by shearing effect and forming a thin film of liquid on its heat transfer surface. To balance hydrodynamic force developed by liquid to the centrifugal force, the clearance of the blades should be selected.

The blade arrangement can be made in two fashions:

1. Straight blades
2. Staggered blades

Dodeja *et al.* (1987) investigate the effect of rotor blade arrangement on residence time distribution in SSHEs under a project. On the basis of studies the workers found that staggering of blades improved residence time distribution and reduced power consumption as the flow is very close to plug flow that is free from bypassing, short circuiting and channeling.

Kohli *et al.* (1993) worked on thin film scraped surface heat exchanger system for the concentration of milk and reported that, staggered blades are highly advantageous from viewpoint of heat transfer and hydrodynamics. It caused high turbulence due to more frequent interruption of fluid film by blades.

Bag *et al.* (1994) studied the influence of various parameters on quality and type of *khoa* in continuous *khoa* making unit. The workers varied the parameters like number of blades, rotation speed, mass flow rate and steam pressure. On the basis of study, the worker suggested that the performance of machine with regards to heat transfer and product outflow was better in case of 4-4 staggered blades compared to four straight blades.

2.6.2 Rotor Power Consumption

For handling high viscosity products with or without particles, the products that tend to foam and foul the heat transfer surface and heat sensitive products, the scraped surface heat exchanger is the most suitable. There are four major components of power consumption in SSHEs:

1. Shear stress created by the liquid for blade action and fluid pumping.
2. Scraping action of blades.
3. Friction of bearing.
4. The rotation of mass of the fluid within the inner cylinder and blades.

Traditionally, the factors emanating from shear stress created by liquid have been used theoretically to characterize power consumption. Due to inability

to distinguish between the individual, non- fluid related factors, they have not been used to characterize the power number.

Bolanowski and Lineberry (1952) studied power consumption during cooling of peanut butter in SSHE with eccentric and concentric arrangements. The workers found that eccentric design consumed on average 41% less power than concentric design, due to angle changed during each revolution and squeezing of product.

Trommelen and Boerema (1966) found that a significant amount of power was consumed by the scraping action and that the scraping caused heating of a thin film of fluid between the edge of the blade and the wall, which caused a decreased in viscosity.

Bhattacharya *et al.* (1970) in a study on hydrodynamics of film formation reported that, hydrodynamic force is a function of film thickness and the centrifugal force is a function of blade mass and speed. By equating these two forces for known value of film thickness, the required rotor speed can be attained for a definite system.

Practically, no appropriate design correlation is available for sizing a prime mover for horizontal TFSSHE. Only information available about power consumption in thin film SSHE is the work carried out by Bhattacharya (1970). Most of the work reported was based on slipper bearing theory, which does not seem adequate for predicting power consumption. On the basis of the studies conducted they arrived at the following expression for power consumption:

$$P_c = \pi^2 D^2 N^2 \mu L (t/c) [1/a - 1] [4 \ln a [6 (a-1) / (a+1)]]$$

The rotor power consumption is the largest single factor influencing operational cost, as there is hardly any pressure drop due to the fluid flow in TFSSHE. Abichandani and Sarma (1998 and 1989) studied that the power supplied to the rotor is consumed in:

1. Accelerating the product that enters the heat exchanger to the rotor speed (inertia forces).
2. Overcoming viscous and surface tension forces of the product in generating large surface.
3. Agitating the product film.

Abichandani and Sarma (1988 and 1989) studied power requirement in SSHE during thin film operation of milk and cream. During investigation the authors observed that most physically situations can usually be approximated by a quadratic function over a reasonable range of variables. Due to requirement of small number of tests and convenient computing properties, the authors developed an equation in Box-Wilson model to predict power consumption during evaporation in horizontal thin Film scraped surface heat exchanger, and also to examine the effect of process variables on power consumption involving process variables like percent average total solids, number of blades, circumferential speed of rotor. The following prediction model was developed with correlation coefficient 96.81%.

$$P = 189.67 - 3.86S - 36.42V_c - 16.66B + 0.09S^2 + 16.56V_c^2 + 1.35B^2 - 1.24S(V_c) - 0.41S(B) + 16.56V_c(B)$$

The following conclusions were drawn:

1. The effect of increasing mass flow rate on power consumption is insignificant.
2. The prime-mover for a straight sided horizontal thin film scraped surface heat exchanger should be selected on the basis of water as the working fluid, because for a given rotor speed, and geometry of the scraped surface heat exchanger, the power consumption for water was found to be highest due to higher surface tension.
3. Higher speeds resulted in more power consumption due to larger inertial forces without appreciable increase in overall heat transfer coefficient
4. Increasing the number of blades resulted in improved power consumption

Altiokka (1992) found that the contribution of friction in power consumption was estimated to be proportional to the rotational speed of the shaft. SSHE with no clearance had approximately 30% more power consumption than one with standard clearance.

2.7 Inferences Drawn from Review of Literature

The literature revealed that SSHEs are commonly used in food, chemical and pharmaceutical industries for heat transfer, crystallization, and other continuous processes. They are ideally suited for highly viscous, sticky, heat sensitive, that contain particulate matter. The thermal performance of the equipment has shown that it can handle wide viscosity range products without

appreciable falling in its heat transfer coefficient. The equipment has been found very successful for manufacture of *khoa* using buffalo milk, but no attempt has been made yet to manufacture *Danedar khoa*. Recently three stages SSHE has been designed and fabricated with the state of the art technology by incorporating various operating features. It may therefore felt to modify the equipment or process parameters for continuous manufacture of *Danedar khoa* and study its performance evaluation.

CHAPTER -3

MATERIALS AND METHODS

MATERIALS AND METHODS

The equipment used and methodology adopted for the preparation and analysis of *khoa* during present investigation is reported in this chapter and described under the following subheads:

3.1 Pilot plant and Accessories

3.1.1 Pilot plant used for experiments

3.1.1.1 Thin Film Scraped Surface Heat Exchangers

3.1.1.2 Variable speed drives

3.1.1.3 Balance Tank

3.1.1.4 Feed Pump

3.1.1.5 Valves for steam supply

3.1.1.6 Instrumentation

3.1.1.6.1 Magnetic flow meter

3.1.1.6.2 Pressure gauges

3.1.1.6.3 I/P converter

3.1.1.6.4 Transmitters

3.1.1.6.5 Pneumatic valves

3.1.1.6.6 Air pressure indicators

3.1.1.6.7 Digital panel meter

3.1.1.6.8 Process controller

3.1.1.6.9 Wattmeter

3.1.2 Experimental Accessories

3.1.2.1 Digital Thermometer

3.1.2.2 Container

3.1.2.3 Other material

3.2 Selection of Raw material

3.2.1 Milk

3.2.2 Caustic Solution

3.2.3 Water

3.3 Experimental Procedure

3.4 Measurement and Analysis

3.4.1 Analysis of milk

3.4.2 Analysis of *khoa*

3.4.2.1 Chemical analysis

3.4.2.2 Sensory Evaluation

3.4.2.3 Texture Profile Analysis

3.5 Process Parameters

3.1 Pilot plant and Accessories

3.1.1 Pilot plant used for experiments

The pilot plant was three stage scraped surface heat exchanger developed by Dodeja *et al.* (2007). The system includes:

3.1.1.1 Thin Film Scraped Surface Heat Exchangers

3.1.1.2 Variable speed drives

3.1.1.3 Balance Tank

3.1.1.4 Feed Pump

3.1.1.5 Valves for steam supply

3.1.1.6 Instrumentation

3.1.1.1 Thin Film Scraped Surface Heat Exchanger

The unit is consisted of three thin film scraped surface heat exchanger (TFSSHE). All heat exchangers are identical in length, diameter and effective heating length. The heat exchanger is made from SS 304 shell having 3.76×10^{-1} m inner diameter, 4.51×10^{-1} m outer diameter, 5×10^{-3} m wall thickness and 1.363×10^{-2} m length. Each heat exchanger is provided with MS jacket of 4.1×10^{-1} m inner diameter and 1 m length. The jacket of third heat exchanger is provided with partition at the middle. All the jackets are insulated with glass wool of thickness 4×10^{-2} m for minimizing the heat losses. All three TFSSHEs are provided with end covers fabricated from 7×10^{-3} m thick SS 304 sheet. Vapour outlet of 2.37×10^{-1} m diameter was provided on the top of all the three heat exchanger.

The rotor assembly of first two heat exchangers is identical but altogether different from rotor assembly of third TFSSHE. The scraper assembly consisted of solid SS shaft of 2.5×10^{-2} m diameter. The first and second stages TFSSHE had four variable clearance blades each of 1.332×10^{-2} m length, 5×10^{-3} m thickness and 4×10^{-2} m width and are hinged between cross supports in each

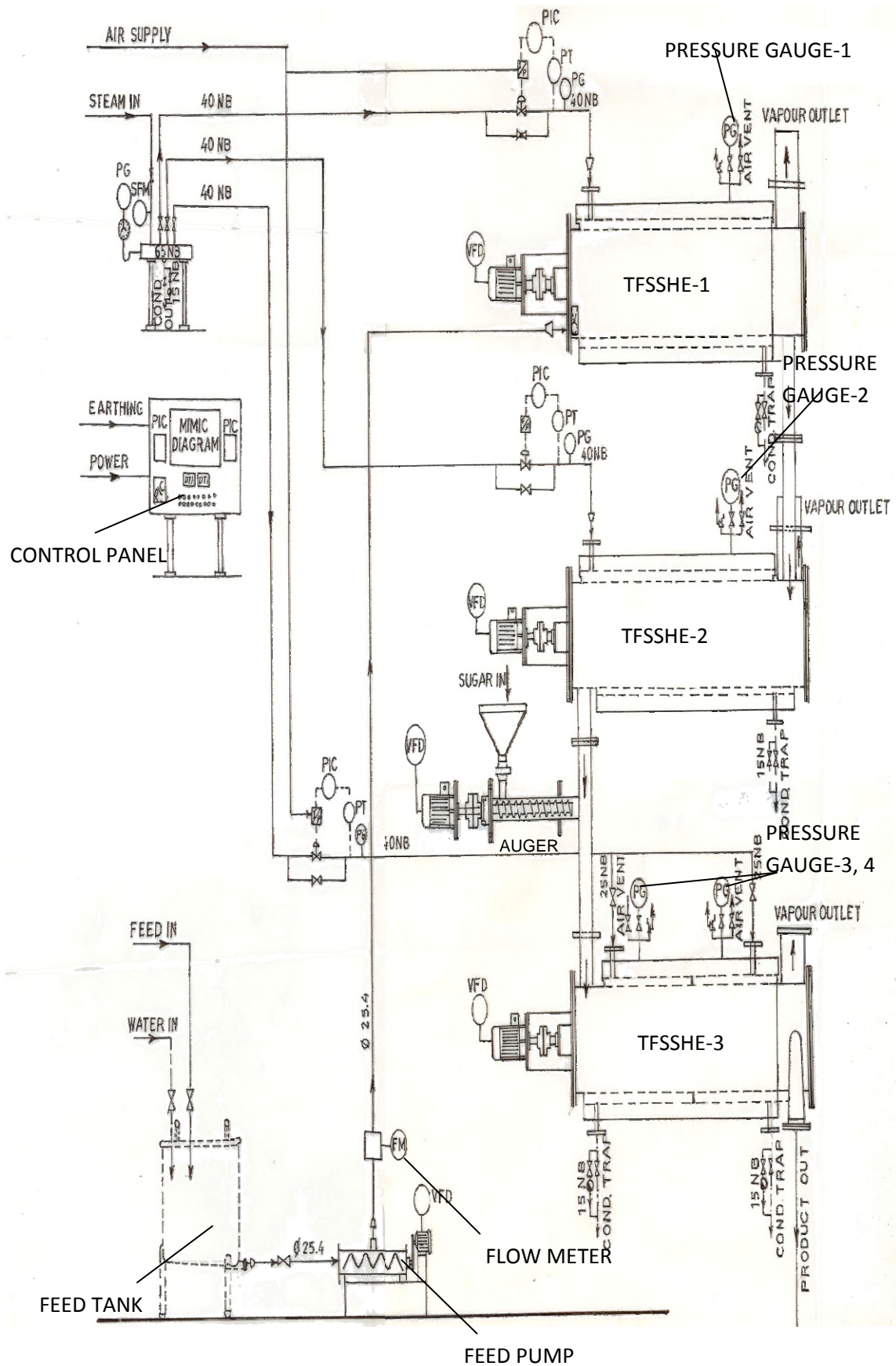


Figure 3.1.1: Schematic Diagram of Pilot plant used

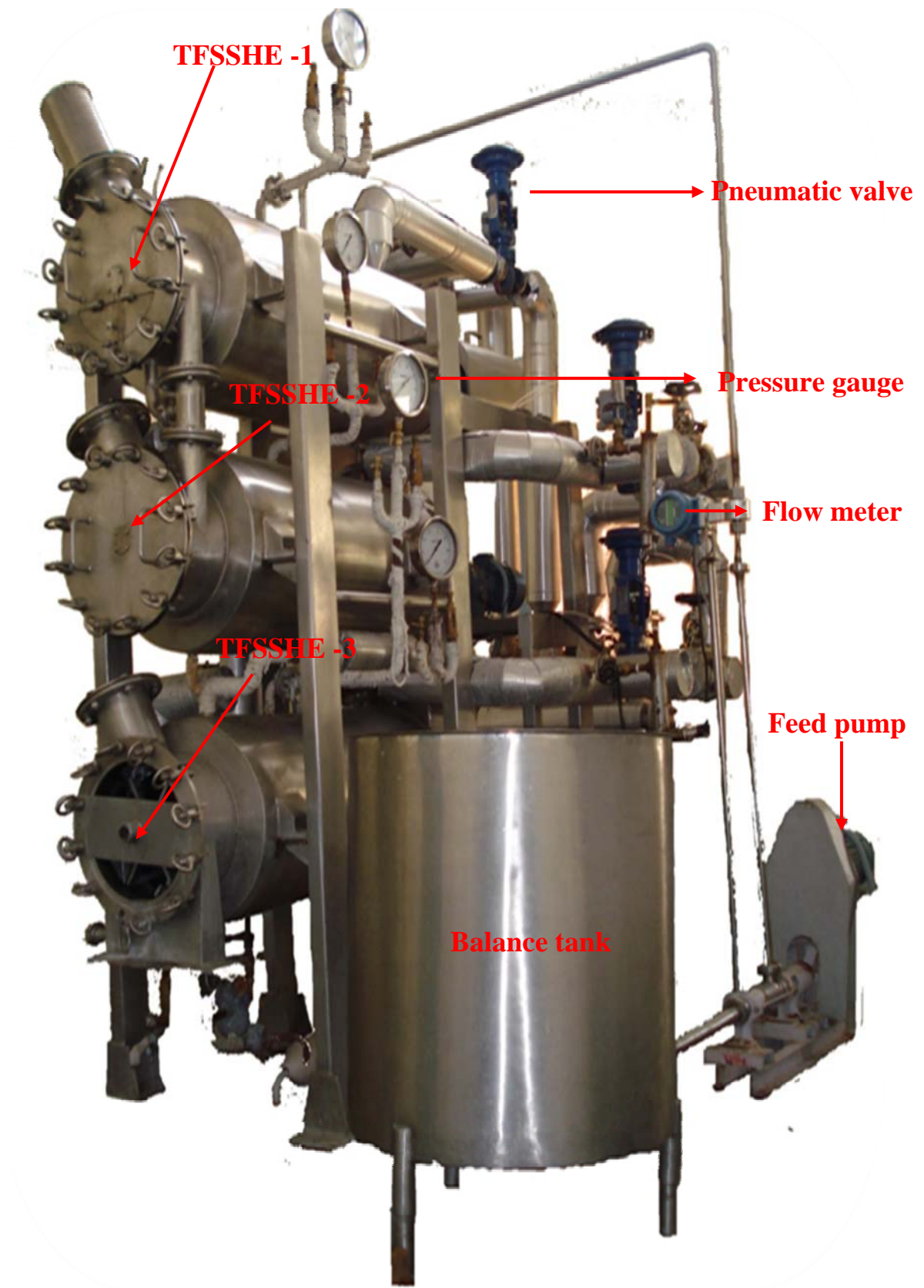


PLATE 3.1.1 a: Pilot plant – Three stage TFSSHE



PLATE 3.1.1 b: Pilot plant in operation



PLATE 3.1.1 c: Final product (*danedar khoa*)

scraper at 1.405×10^{-2} m distance from front end and 3.56×10^{-1} m from rear end. The rotor of third stage TFSSHE consisted of two variable clearance blades of size same as above and two skewed blades. In order to rotate two hinged blades as thin film formation mode at low rpm (0-100) a spring loaded support was incorporated. The scraper assembly was mounted on a type roller bearing housed in end cover of TFSSHE. The third stage TFSSHE is also provided with sugar with sugar dosing device. This consists of hopper and auger driven by variable speed drive for varying feeding rate. All TFSSHE's jackets are provided with spring loaded safety valves and vent cock on different desired locations.

3.1.1.2 Variable speed drives

The driven end of the scraper assembly was coupled to a variable speed drive through flexible coupling. The drive consisted of geared three phase, fan cooled induction motor. The required speed adjustment was done with the help of gear units, which are splash-lubricated. With the help of these arrangements, the rotor speed of first, second stage and third stage TFSSHE rotors as well as auger speed was adjusted from 20 to 200 rpm.

Specification of TFSSHE rotor motor of all three TFSSHE:

Make	:	REMI
Speed	:	303 rpm
KW	:	1.5
Power	:	3.71 A, 50Hz
Efficiency	:	77 %
Reduction gear box	:	used to reduce the motor rpm.

3.1.1.3 Balance Tank

A cylindrical SS tank with a capacity of 250 litres was used as the feed tank. It was connected to the feed pump through a SS pipe. The outlet of the pump is connected to the first TFSSHE.

3.1.1.4 Feed pump

Screw type 'FAS' Series ROTOMAC progressive cavity pump, a special type of positive displacement pump, in which flow through the pumping element is truly axial was used. It is ideal for handling viscous/ non-viscous fluids and pulped material in suspension, viz., milk, cream, sugar syrup, beverages, and

fruit juices. It has a uniform pulse-free output in strict linear dependence on the rotational speed. It is the intermeshing of the threads and close fitting of the surrounding housing, which create one or more sets of moving seals between pump inlet and outlet. These sets act as a labyrinth and provide the screw pump with its positive pressure capability. The successive sets of seals form fully enclosed cavities, which move from inlet to outlet. These cavities trap liquid at inlet and carry it along to the outlet, providing a smooth flow. They are accurate, compact, efficient and comparatively silent in operation. It has improved efficiency because of better volumetric and mechanical efficiency.

Flow of milk through the pump was regulated by varying the speed of feed pump with the help of frequency controller provided on the control panel.

Specification of feed pump motor:

Make	:	ABB
Type	:	3 phase induction motor
Efficiency	:	68.0 %
RPM	:	910
Weight	:	22 kg
Power	:	50 Hz, 2.1 A, 0.75 kW
Ambient	:	45° C

3.1.1.5 Valves for steam supply

Steam supply valves are provided at the inlet of each TFSSHE with following details:

Make	:	Micro valves India Pvt. Ltd, Noida
No	:	7
Size	:	40 mm
Type	:	globe valve
Spindle	:	13 % CR
Stopper	:	hard faced

3.1.1.6 Instrumentation

Instrumentation plays an important role in process control and automation for continuously monitoring the process variables. Following instruments were used in the set up to measure and control the process variables.

3.1.1.6.1 Magnetic flow meter

To measure the flow rate of the working fluid, a magnetic flow meter that works on the Faraday's Law of electromagnetic induction, which states that a voltage will be induced in a conductor moving through a magnetic field. The Rosemount magnetic flow meter specifically designed for food, beverages and pharmaceutical application. In Rosemount magnetic flow meter, the output voltage is directly proportional to the liquid velocity, resulting linear output. Following specification was used:

Make	:	Rosemount (Brazil)
Maximum power	:	input- 5W, output-1MW
Maximum current	:	input- 0.5 A, output- 0.20 mA
Maximum voltage	:	input- DC only, output- 5 volts
Maximum processing temp	:	160°C
Ambient temp limits	:	-34.0°C to +66°C
Maximum process pressure	:	2.06 MPa
Accuracy	:	± 0.005
Repeatability	:	±0.1 % of reading
Response time	:	0.2 seconds maximum response

3.1.1.6.2 Pressure gauges

Pressure gauges are used to indicate the steam pressure inside the shell maintained to carry out the present investigation at different locations of the three stage TFSSHE, with following specifications:

Make	:	H. Guru North
Range	:	0-7 kg/cm ²
Accuracy	:	± 1.0 % of range span
Dial size	:	150 mm
Dial marking	:	black and white
Standard fitments	:	Micro adjustable pointer, blow out disc
Tested against	:	Budden Berg Master Gauge
No of gauges	:	5

3.1.1.6.3 I/P converter

The electro pneumatic signal converter is used as a linking component between electric or electronic and pneumatic systems. It converts standard electric signals (mA) into standard pneumatic signals (psi/kg/cm²). Due to its innovative construction principle based on a fixed coil and a low- mass moving permanent magnet, it is highly resistant to shock and vibration and had following specification :

Make	:	ABB Limited, Faridabad
Input	:	4 – 20 mA
Output	:	0.2 – 1.0 kg/cm ²
Supply	:	20± 1.5 lb psi/1.4±0.1 kg/cm ²

3.1.1.6.4 Transmitters

The transmitter was used to transmit the converted pneumatic signals from I/P converter to the controller to convey the message for the variation of process variables to optimize the whole process with following details:

Make	:	WIKA Alexander Wigand GmbH
No	:	3
Pressure range	:	0 – 6 bar
Power	:	4 – 20 mA
Voltage	:	10 – 30 volts

3.1.1.6.5 Pneumatic valves

A control valve positioner is the heart of most accurate and efficient control systems, by ensuring the valve responds to the controller commands and adopts the precise position. It works on the principal of force balance to position the control valve stem in accordance to a pneumatic signal received from a controller or manual loading station. The instrument signal is applied to the signal diaphragm. An increasing signal will derive the diaphragm and flapper – connecting stem to the right. The flapper – connecting stem will then open the supply flapper admitting supply pressure into the output which is connected to the actuator diaphragm. The exhaust flapper remains closed when the flapper is connected to the right. The effect of increasing signal is to increase the pressure in the actuator. When the valve reaches the position called for by the controller,

the compression in the range spring will give a balance force resulting in the closure of both the flapper. It had the following specification:

Make	:	PNEUCON valves Pvt Ltd, Thane
No	:	3
Size	:	25 mm
Spring range	:	0.2 – 1.0 KSC
Travel	:	28 mm
Trim material	:	SS 316
Body material	:	WCB + 1 BR
Flange rating	:	150 ANSI
Characteristic	:	equal

3.1.1.6.6 Air pressure indicators

The air pressure indicators are used to indicate the pressure supplied to the pneumatic valves to regulate the steam pressure in the cylinder shell with following specifications:

Make	:	Denvar
Range	:	0 – 2.5 kg/cm ²

3.1.1.6.7 Digital panel meter

The digital panel meter was used to indicate the readings of RPM of all the three rotors of the three stage TFSSHE unit and had the following specifications:

Make	:	R/R electronics
Display	:	3.5 digits, 7 – segment red LED display
Supply	:	220 V AC
Input	:	10 V DC
Range	:	0 to 1500 rpm
Dimensions (W×H×D)	:	96 ×48 ×110 mm
Panel cut-out	:	92 ×44 mm

3.1.1.6.8 Process controller

The process controller of YOKOGAWA is an integral part of the automatic process control system assembled on the control panel of three stage TFSSHE. It had three different modes such as operator mode (standard controller,

heat/cooler controller, remote set point controller, profile controller), set up mode (level2 –tuning, level3 – set points, level4 – profile) and configuration mode and is used for observing the process variable value that was attained during investigation and control set point value that is fixed by the operator according to the requirement so that the process variable value can't exceed this limit.

3.1.1.6.9 Wattmeter

To note the power consumption by each scrapper in each stage at different rpm at different load, feed pump motor and sugar dosing motor a single phase wattmeter was used with following specifications:

Make	: Automatic Electric Pvt. Ltd., Bombay 31
Type	: 4P4C (Portable single phase wattmeter)
Model	: DVS 1065 (Class 2.5)
Principle of working	: Single element electrodynamicometer type
Full scale reading	: 0 to 156.25
Accuracy	: within 2.5% of full scale value
Insulation resistance	: above 20 MΩ
Breakdown voltage test	: 2000V AC for 1 min
Overload capacity	Potential Circuit : 50%
	Current Circuit : 50%
Ambient	: 27°C

Potential Circuit				Current Circuit	
62.5 V	4000 Ω	250 V	17300 Ω	2.5 A	0.66 Ω
125 V	8450 Ω	500 V	35000 Ω		

A circuit was prepared to connect this Wattmeter between control panel and motors of Feed pump, Sugar dosing mechanism, Scrapper-1, Scrapper-2, Scrapper-3 and one switch kept as a spare. Connections were made in such a manner that keeping the switches "ON" bypassed the power supply for sockets hence wattmeter if connected did not show power consumption reading. Power consumption was observed by first connecting wattmeter to socket and then switching related switch "OFF". During operation, all the switches were kept in 'ON' condition. Whenever the power consumption of any motor was to be observed, plug of wattmeter was inserted into respective socket and then switch

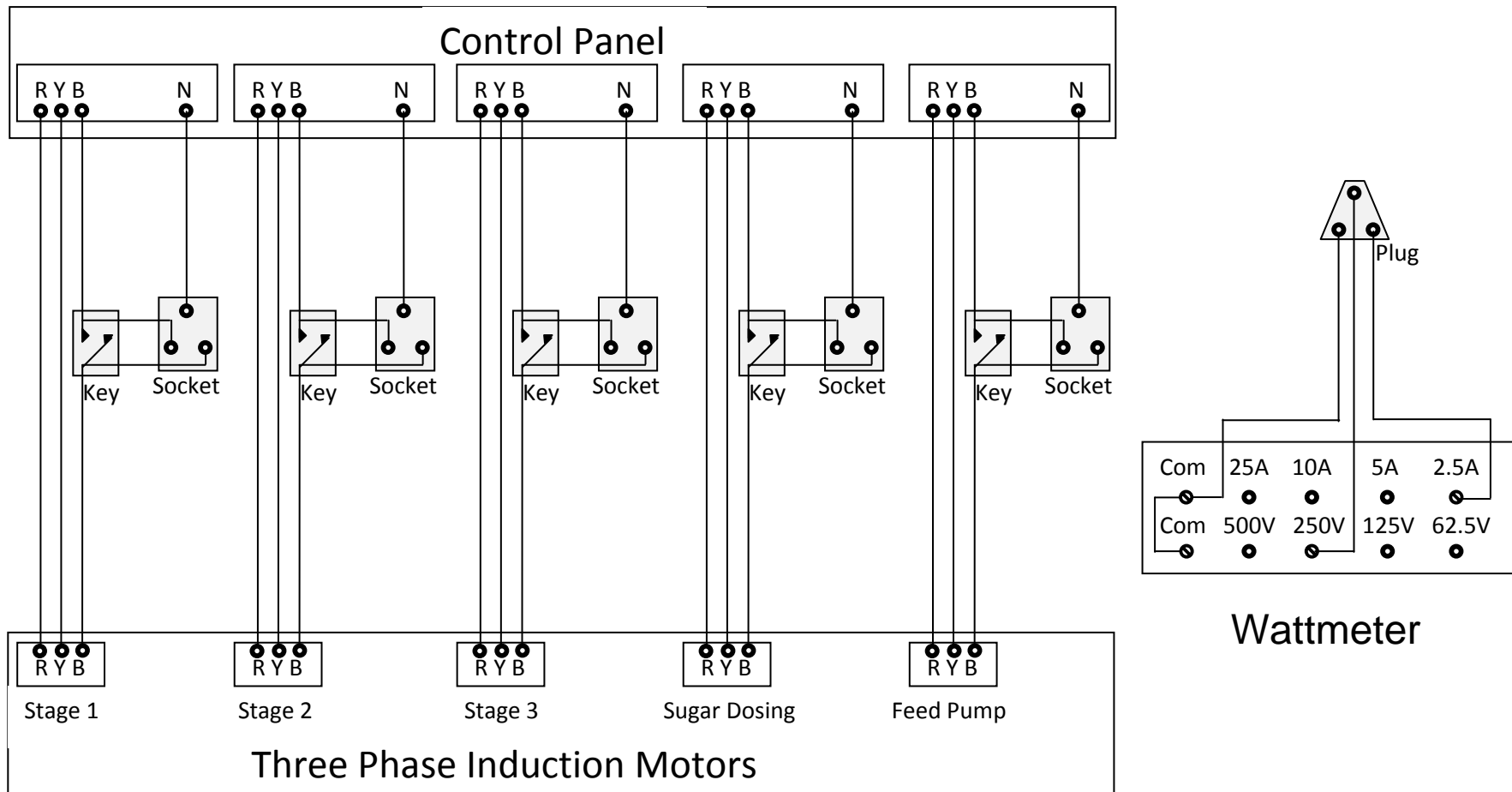


Figure 3.1.1.6.9: Circuit diagram for wattmeter connections to existing experimental setup of TSSHE for electrical performance evaluation

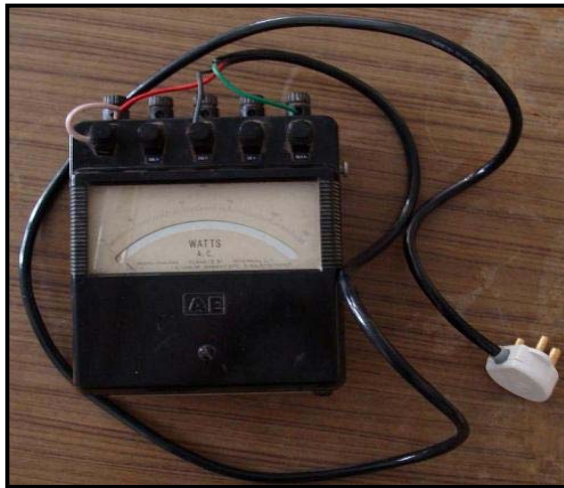
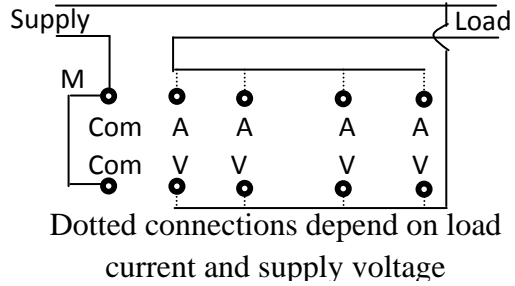


PLATE 3.1.1.6.9 a: Wattmeter

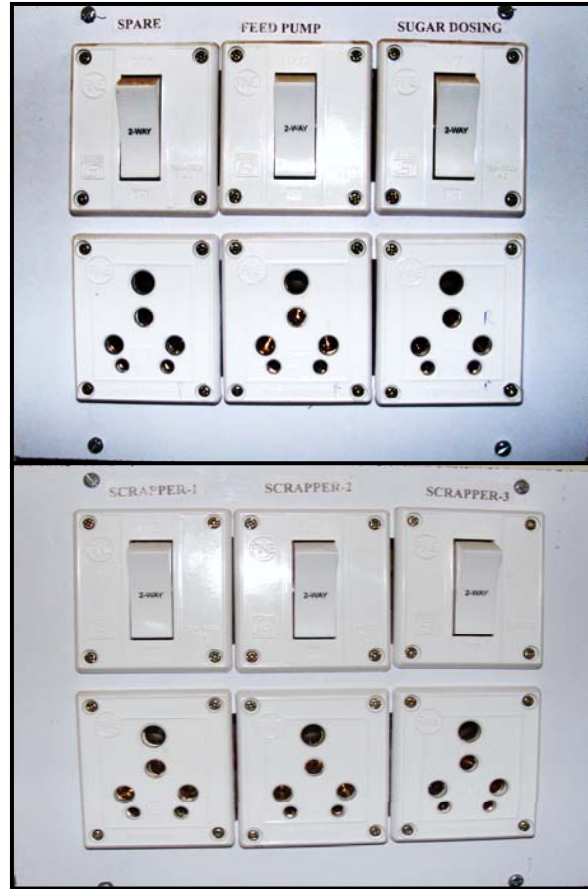


PLATE 3.1.1.6.9 b: Switch Board



PLATE 3.1.1.6.9 c: Wattmeter with Switch Board in working condition

was turned 'OFF'. After wattmeter reading was taken, switch was turned 'ON' and then plug of wattmeter was removed.

$$\begin{aligned}\text{Wattmeter factor} &= VIP/S \\ &= 12\end{aligned}$$

where,

$$V = \text{Voltage} = 250 \text{ V,}$$

$$I = \text{Current} = 2.5 \text{ A,}$$

$$P = 3 \text{ phase,}$$

$$S = \text{Full scale reading} = 156.25$$

3.1.2 Experimental Accessories

3.1.2.1 Digital Thermometer

To monitor the temperature change during the production process of *khoa*, a battery operated digital temperature indicator along with probe has been used.

3.1.2.2 Container

To collect condensate coming from each stage, to know steam consumption have been used as shown in Plate 3.1.2.2. Overall heat transfer can be calculated using following formula:

$$Q = U \times A \times \Delta T \quad \Rightarrow \quad U = Q / (A \times \Delta T)$$

Where,

U = Overall heat transfer coefficient

A = Heat transfer area of cylinder

ΔT = Temperature difference between steam and milk evaporation

Q = Quantity of heat used = condensate flow rate \times latent heat

3.1.2.3 Other material

Digital temperature indicator, Digital weighing balance, milk can, milk container, etc.

3.2 Selection of Raw material

3.2.1 Milk

Fresh buffalo milk and Skimmed milk was procured from Experimental Dairy NDRI, Karnal. Standardization was done to 6% Fat and 9% SNF. Acidity was increased up to 0.18% LA.

3.2.2 Caustic Solution

Caustic solution of 0.75% strength was prepared by using sodium hydroxide flakes LR grade for CIP of TFSSHE.

3.2.3 Water

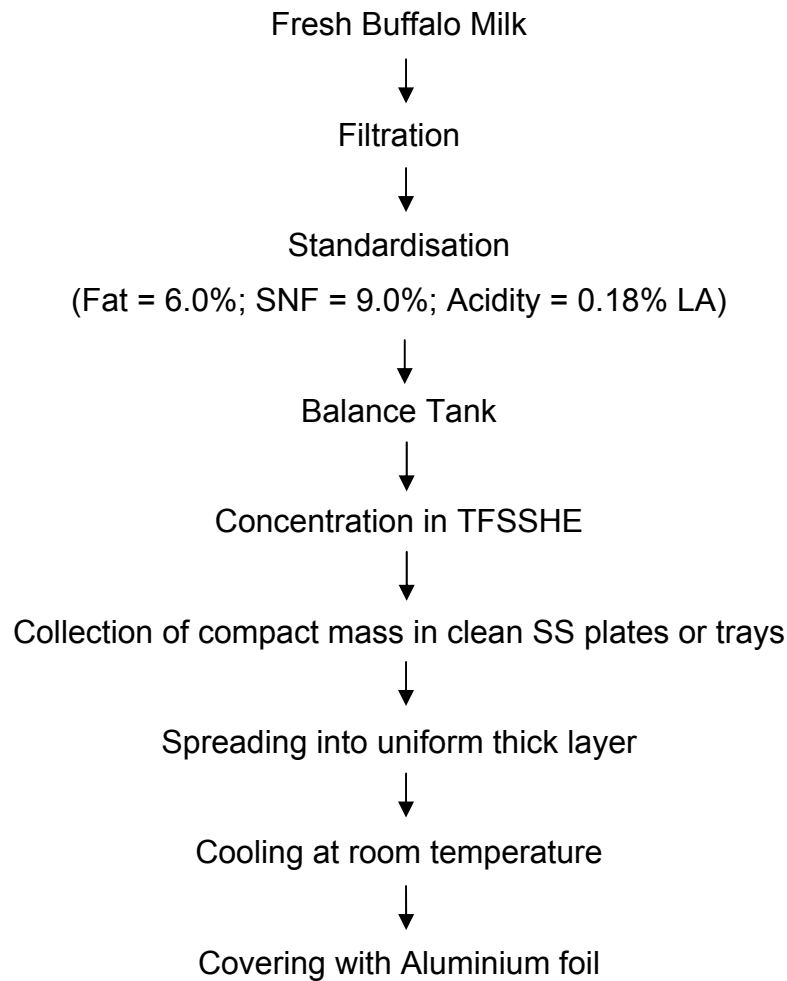
Potable water available at Dairy Engineering Division was used for washing and cleaning.



PLATE 3.1.2.2: Condensate collection

3.3 Experimental Procedure

Preparation of *khoa* in Three Stage Scraped Surface Heat Exchanger



First the steam valves of the steam header and three TFSSHEs, which were located at the rear side of three stage TFSSHE were opened manually. Then some water was filled in balance tank and feed pump started at full speed. Then air vents of all TFSSHEs were opened and steam pressure fixed at 0.8 kg/cm² in all TFSSHEs and all scrappers operated to initially flush the plant. Air vents were closed after all air was purged from the steam jackets. When water finished then standardised buffalo milk was poured into balance tank through sieve to filter any extraneous matter out. Then milk flow was varied between 170-210 kg/hr with the help of electromagnetic flow meter by controlling the rpm of feed pump from the control panel. The scrapper blade assembly of all TFSSHEs were set their pre-decided rpm by control panel. The Steam pressure in first and second stage was fixed at 4 kg/cm² and 2 kg/cm² respectively. The steam pressure was adjusted between 1.5 kg/cm² to 2.0 kg/cm² in third stage according

to observation of the body of product coming to third stage, from second stage. The milk flow rate was approximately so adjusted to get the consistency required in the product. Homogenous mixture of final product was obtained from outlet of third stage which was collected in trays and spread into uniform thick layer. Then product was covered with aluminium foil and cooled at room temperature. When product got cooled, it was cut into pieces and analysed as explained below.

3.4 Measurement and Analysis

3.4.1 Analysis of milk

Initially the raw milk was tested for fat, SNF and total solids (TS) by using gerber method (IS: 1224, 1977) and lactometer.

$$\text{Total solid (\%)} = \text{SNF} + \text{Fat}$$

Titrateable acidity was determined using the method described in IS: 1979 (Part-I)-1960.

3.4.2 Analysis of *khoa*

3.4.2.1 Chemical analysis

The *khoa* manufactured using three stage SSHE by selecting process variables under consideration was analysed for Moisture/TS by gravimetric method as per IS: 2785 (1964).

About 10 gm of previously dried sand in oven at 100°C was taken in to a dish and weight of dish with sand was recorded. Five gram of product sample was taken to the dish by spreading the sample over the sand. The dishes were then transferred to the hot air oven maintained at 105 ± 5°C.

The drying was continue till the solid mass in the dishes turns to be light brown and difference between the two successive weighting was not more than 1 mg.

$$\% \text{ Moisture} = \frac{W - (C - A)}{W} \times 100$$

Where,

W = Initial Weight of sample (gm)

C = Weight of dried sample + sand + dish (gm)

A = Weight of sand + dish (gm)

3.4.2.2 Sensory Evaluation

The *khoa* made from fresh standardized buffalo milk have typical sensory attributes, which depends on the process variables under study, viz. steam pressure, scrapper rpm and mass flow rate. The *khoa* samples were subjected for sensory evaluation by a panel of 5-7 judges selected from Dairy Technology and Dairy Engineering Division. A 25-point descriptive scale was used for sensory attributes like Flavour, Body & Texture and Colour & Appearance.

3.4.2.3 Texture Profile Analysis

Instrumental analysis of food texture has come of age as is evidenced by increasing application of various empirical and imitative methods towards measurement of texture of a variety of foods and food products in research and quality control. Due to their simplicity, versatility and precision, these methods aim at replacing the sensory texture measurements which is often time consuming and less reproducible. While these attempts have met with varying degrees of success, meaningful studies on psychorheology aspects of food products brining out significant interrelationship between sensory texture perception and instrumental measurement can potentially revolutionize the quality control programmes lending them greater reliability together with simplicity. So there is a need to consider the interrelationship between sensory descriptors and Instron texture parameters of *khoa*.

Khoa prepared was analysed for body and texture by using Texture Analyser (Model TAXT2i, double cycle compression) of Stable Micro Systems, U. K., combined with Texture Expert Exceed Software, installed in Dairy Technology Division, NDRI, Karnal. *Khoa* was evaluated for various rheological properties like hardness, adhesiveness, springiness, cohesiveness, gumminess and chewiness.

Initially the product sample was cut into a cylinder of height and diameter of 1 cm each. Product sample was kept on the Texture Analyser platform under the load cell. Load cell used was of 25 kg. Initially the Texture Analyser was calibrated for probe and then for force of 5 kg, before starting the analysis. Five samples of the product of parameters selected were analysed.

The test conditions (TA Settings) employed while testing the rheology of *khoa* samples were as under:

- **Sample size** : 1 cm diameter and 1 cm height cylinder
- **Compression** : 80 %
- **Load cell** : 25 kg
- **Probe speed** : pre test 5 mm/s, test 2.5 mm/s and post test 5 mm/s
- **Testing temperature** : 25± 1 °C
- **Probe name** : P75

3.5 Process Parameters

There are various process variables of three stage scraped surface heat exchanger that were selected for designed research project under study for manufacture of *khoa*:

Mass flow rate : 170 – 210 kg/hr

Ist Stage TFSSHE

Pressure : 4.0 kg/cm²

RPM : 150, 175, 200

IInd Stage TFSSHE

Pressure : 2.0 kg/cm²

RPM : 125, 150, 175, 200

IIIrd Stage TFSSHE

Pressure : 1.5 to 2.0 kg/cm²

RPM : 15, 20, 25

The quality of *khoa* so produced was evaluated in terms of sensory scores, textural profile analysis and TS/Moisture.



PLATE 3.4.2.3 a: Texture Profile Analyser with sample of *danedar khoa*



PLATE 3.4.2.3 b: TPA Probe P-75

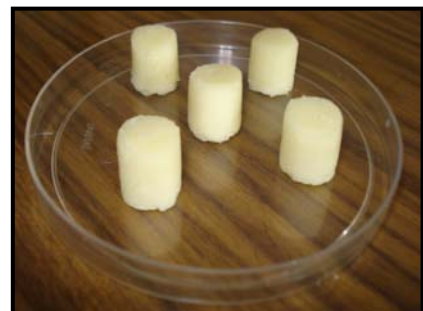


PLATE 3.4.2.3 c: Sample cutter with samples

CHAPTER -4

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

In the present Investigation systematic attempt has been made produce *danedar khoa* using thin film scraped surface heat exchanger. Product obtained was subjected to sensory evaluation using a panel of judges. Texture profile analysis was done by using a texture analyser. Instrumental texture profile analysis was used to compare the subjective sensory assessment of the textural attributes of the product. Based on these determinations, the operating parameter for formation of desired texture of the product has been optimized. The results obtained during present investigation are discussed in the proceeding text here under following heads:

4.1 Preliminary Studies

4.2 Effect of Scrapper speed on Sensory Attributes

4.2.1 Effect of Scrapper speed on Flavour

4.2.2 Effect of Scrapper speed on Body and Texture

4.2.3 Effect of Scrapper speed on Colour and Appearance

4.2.4 Effect of Scrapper speed on Overall Acceptability

4.3 Effect of Scrapper speed on Texture Profile

4.3.1 Effect of Scrapper speed on Hardness

4.3.2 Effect of Scrapper speed on Gumminess

4.3.3 Effect of Scrapper speed on Chewiness

4.3.4 Effect of Scrapper speed on Adhesiveness

4.3.5 Effect of Scrapper speed on Springiness

4.3.6 Effect of Scrapper speed on Cohesiveness

4.4 Effect of Scrapper speed on Overall Heat Transfer Coefficient

4.5 Effect of Scrapper speed on Electric power Consumption

4.6 Calculations for energy consumption using TFSSHE

4.7 Selection of optimal operating parameter combination

4.8 Comparative study

4.1 Preliminary Studies

Initially trials were conducted using standardised milk with different acidity levels (0.16, 0.17, 0.18, 0.19 %LA) by using TFSSHE and it was found that size and type of grains formed in final product was most suitable in case of using milk with 0.18% LA.

Acidity of milk was adjusted to predetermined value by using either natural souring by keeping it in unrefrigerated conditions for some time (if acidity was to be slightly raised) or by addition of small quantities of 10% citric acid solution in case acidity was to be raised quite a bit and measuring acidity after addition of citric acid solution. In no case milk was neutralised as milk received never exceed 0.16% LA initial acidity.

In case of milk with 0.16 % LA there were no grains and product was pasty in texture and with loose body. As acidity was increased to 0.17 % LA there was small grain formation but in pasty texture. In case of 0.18 % LA there was good amount of grain formation desired in *danedar khoa* and also product was not pasty in texture. As acidity was increased to 0.19 % LA grains formed were much harder and of large size. The product was having acidic off flavour and also definite wheying off was observed in the product which appeared as if milk was curdled a bit. Hence milk with 0.18 % LA was chosen for further studies for process optimization.

4.2 Effect of Scrapper speed on Sensory Attributes

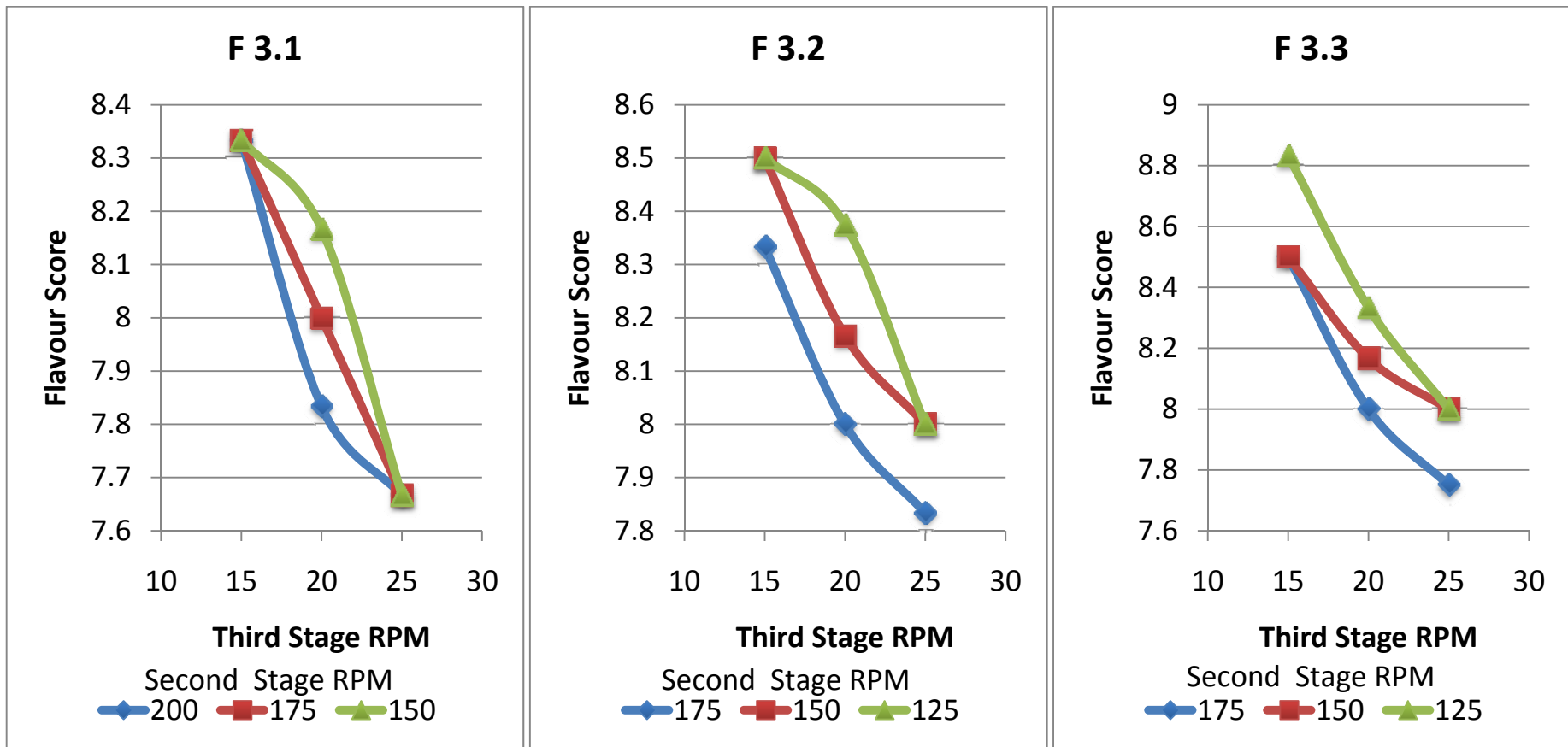
4.2.1 Effect of Scrapper speed on Flavour

Flavour is an important criterion for deciding the quality of any food product, which in turn, determines its acceptability.

Graph 4.1 and Table 4.1 indicates the effect of scrapper speed on flavour.

It is evident that as scrapper speed increases flavour scores decreases. It can be observed from graph that flavour scores are higher for lower speed in previous stage. This may be due to the fact that at the higher scrapper speed, the residence time of the product in the SSHE is reduced which leads to less release of flavouring compounds at higher speeds.

Table 4.1 reveals that flavour scores varied from 7.66 to 8.83.



Graph 4.1: Effect of Scrapper RPM on Flavour

F 3.1: Effect of Third Stage Scrapper RPM on Flavour keeping First Stage Scrapper at 200 RPM.

F 3.2: Effect of Third Stage Scrapper RPM on Flavour keeping First Stage Scrapper at 175 RPM.

F 3.3: Effect of Third Stage Scrapper RPM on Flavour keeping First Stage Scrapper at 150 RPM.

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip

4.2.2 Effect of Scrapper speed on Body and Texture

Body and texture is look and feel of how firm, loose or otherwise is the internal structure build up of the product. It is very important to have a good body and texture of the product as it would affect its application as each application has its own pre-requirements of body and texture like some applications require softer product some may require granular. Some others may require rather firm product to be used.

Graph 4.2 and Table 4.1 indicates the effect of scrapper speed on body and texture.

It is evident that as third stage scrapper speed increases body and texture scores decreases. It can be observed from graph that body and texture scores are highest when previous stage scrapper speed is kept at 172.945 m/s and decreases on either side of 172.945 m/s circumferential velocity (150 rpm). Also the body and texture scores are lowest at lowest or highest values of speed. This may be because at higher scrapper speeds the grains formed are broken by blade at higher scrapper speed, which results in a poor body and texture of the final product. The best results were observed at 172.945 m/s circumferential velocity for first and second stage scrapper assembly.

Table 4.1 reveals that body and texture scores varied from 6.83 to 8.5.

4.2.3 Effect of Scrapper speed on Colour and Appearance

Colour and appearance is a very important attribute of any food product as it is the first thing to be observed without any touch or feel from distance. Hence every food product is required to have a good colour and appearance in order to be further tested organoleptically as one would not feel like eating or even tasting a bad colour or bad appearing product.

Graph 4.3 and Table 4.1 indicates the effect of scrapper speed on colour and appearance.

It is evident that as third stage scrapper speed increases colour and appearance scores decreases. As first or second stage speed increases colour and appearance scores increases. It can be observed from graph that colour and appearance scores are higher for higher speed in previous stage. This may be because in third stage most of cooking occurs as speed is less and residence

time is more hence colour development can take place causing colour and appearance scores to rise with fall in third stage speed. But in first and second stage scrapper speed is on higher side hence residence time is much less hence no time for colour development but if scrapper speed of these stages is reduced then due to high steam pressure and increased residence time there would be more colour changes and heat damages which lower the colour and appearance scores.

Table 4.1 reveals that colour and appearance scores varied from 3.5 to 4.5.

4.2.4 Effect of Scrapper speed on Overall Acceptability

Overall acceptability indicates the consumer acceptance of the final product in the market i.e. whether the product manufactured was liked or accepted by the consumer or not? Hence overall acceptability is an important sensory characteristic of any product to be manufactured at commercial scale for consumer market.

Graph 4.4 and Table 4.1 indicates the effect of scrapper speed on overall acceptability.

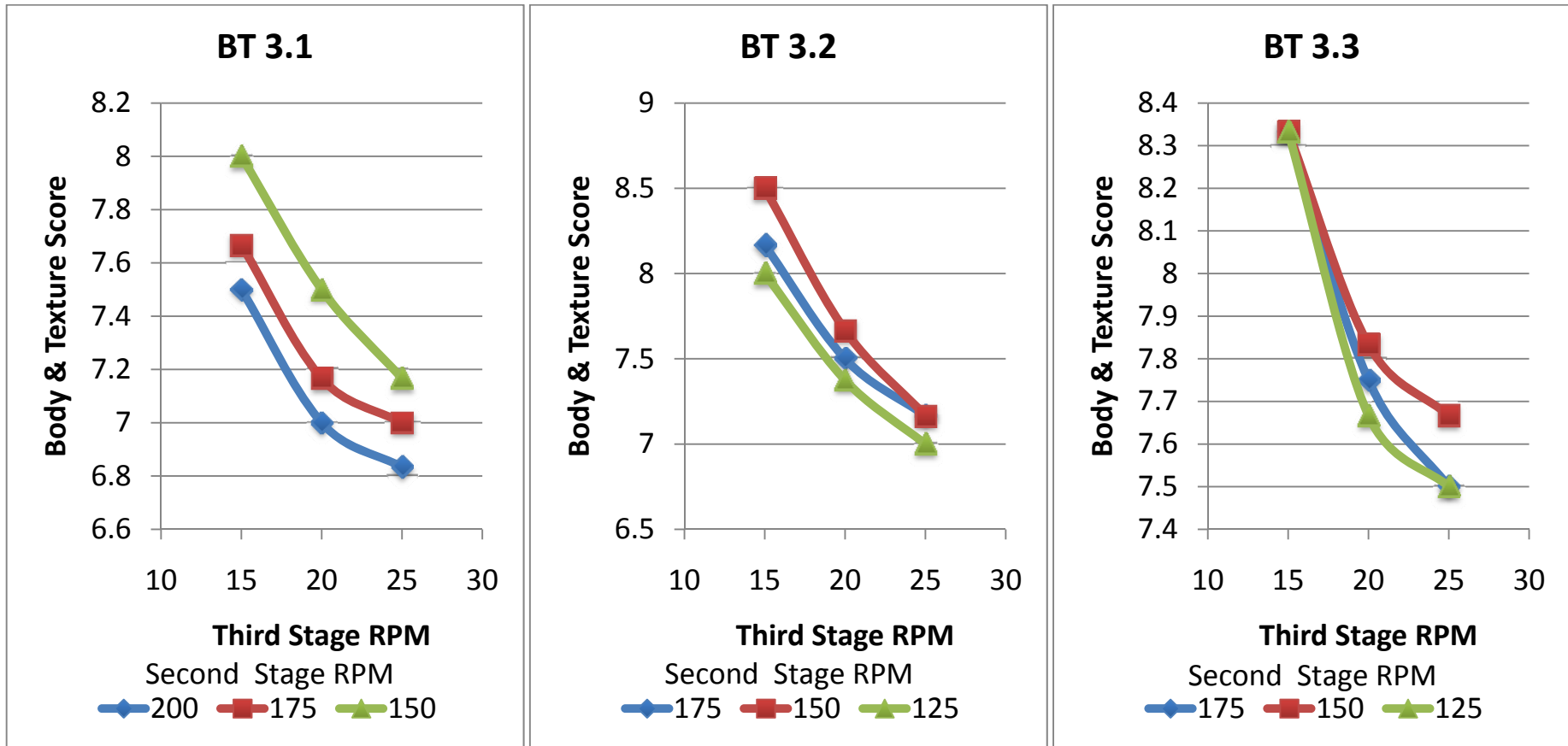
It is evident that as scrapper speed increases overall acceptability scores decreases. It can be observed from graph that overall acceptability scores are highest when scrapper speed is kept at 172.945 m/s and decreases on either side of 172.945 m/s circumferential velocity. Also overall acceptability scores are lowest at lowest or highest values of scrapper speed. This is obtained after summation of all three previous sensory scores hence it has all previous effects added linearly to give overall effect on acceptability of the final product.

Table 4.1 reveals that colour and appearance scores varied from 18.62 to 21.16.

4.3 Effect of Scrapper speed on Texture Profile

4.3.1 Effect of Scrapper speed on Hardness

Hardness is the force required to compress a substance between teeth and is indicated by the highest value of force on the force-time curve during first compression cycle. The hardness value represents firmness of the product and ease with which it will spread.



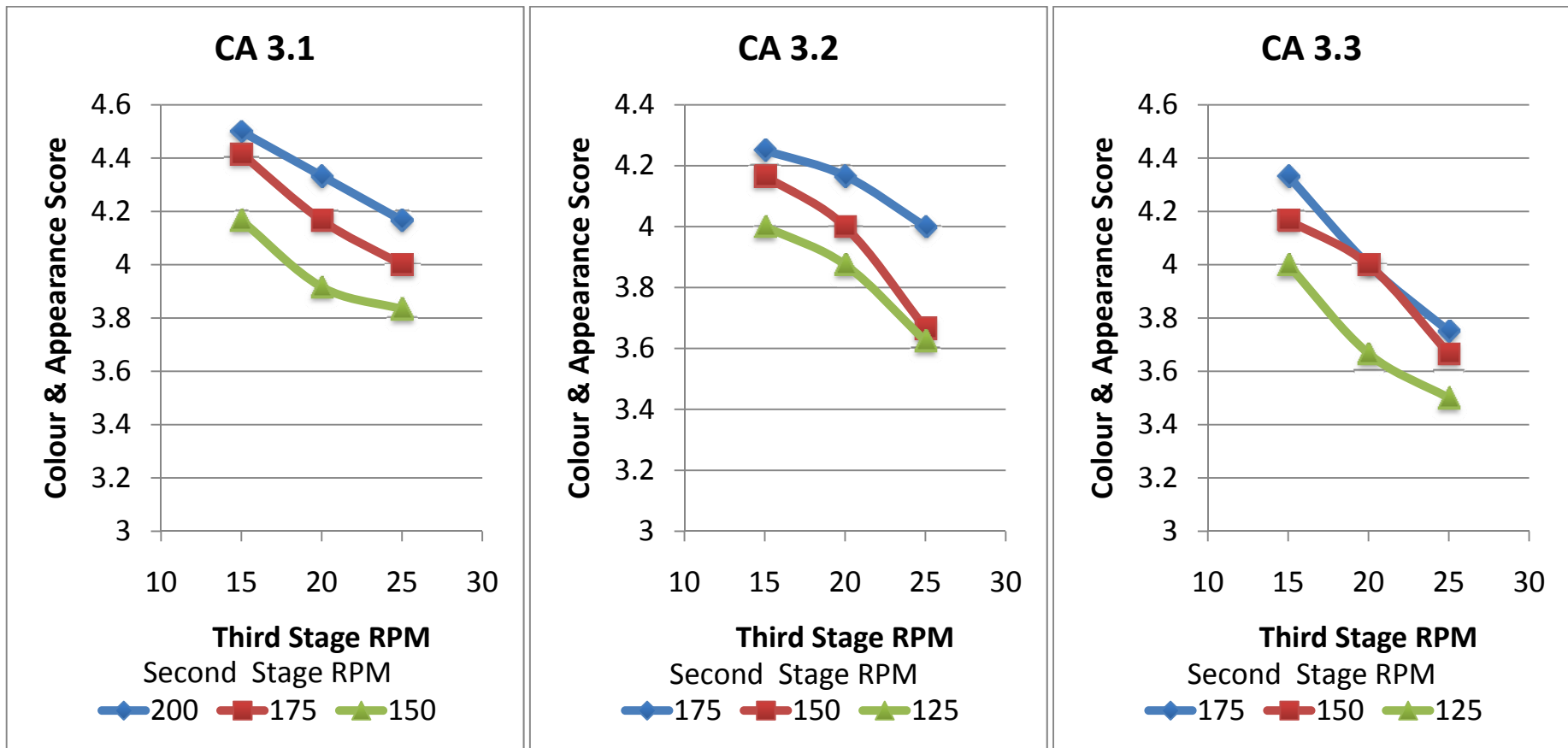
Graph 4.2: Effect of Scrapper RPM on Body and Texture

BT 3.1: Effect of Third Stage Scrapper RPM on Body and Texture keeping First Stage Scrapper at 200 RPM.

BT 3.2: Effect of Third Stage Scrapper RPM on Body and Texture keeping First Stage Scrapper at 175 RPM.

BT 3.3: Effect of Third Stage Scrapper RPM on Body and Texture keeping First Stage Scrapper at 150 RPM.

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip



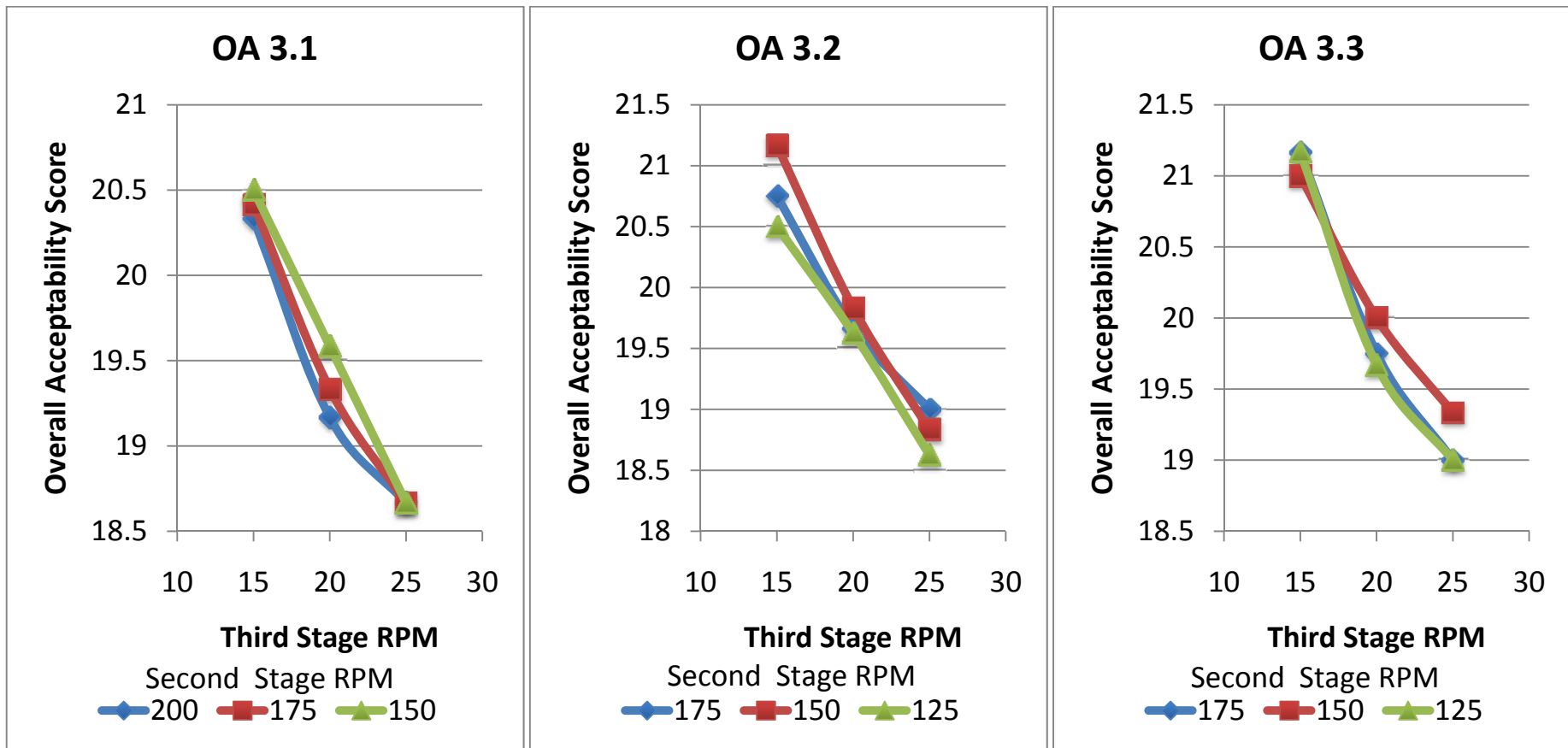
Graph 4.3: Effect of Scrapper RPM on Colour and Appearance

CA 3.1: Effect of Third Stage Scrapper RPM on Colour and Appearance keeping First Stage Scrapper at 200 RPM.

CA 3.2: Effect of Third Stage Scrapper RPM on Colour and Appearance keeping First Stage Scrapper at 175 RPM.

CA 3.3: Effect of Third Stage Scrapper RPM on Colour and Appearance keeping First Stage Scrapper at 150 RPM.

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip



Graph 4.4: Effect of Scrapper RPM on Overall Acceptability

OA 3.1: Effect of Third Stage Scrapper RPM on Overall Acceptability keeping First Stage Scrapper at 200 RPM.

OA 3.2: Effect of Third Stage Scrapper RPM on Overall Acceptability keeping First Stage Scrapper at 175 RPM.

OA 3.3: Effect of Third Stage Scrapper RPM on Overall Acceptability keeping First Stage Scrapper at 150 RPM.

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip

Graph 4.5 and Table 4.2 indicates the effect of scrapper speed on hardness.

It is evident that as third stage scrapper speed increases hardness decreases. As first or second stage speed increases hardness also increases. It can be observed from graph that hardness is higher for higher speed in previous stage. This may be because as third stage scrapper speed increases, the residence time of the product within the system decreases, resulting in higher moisture hence lowers hardness of the final product but in case of increasing scrapper speed of first and second stage hardness decreases because of higher steam pressures so high heat transfer rates so high evaporation rates hence lower moisture content leading to harder product.

Table 4.2 reveals that hardness varied from 10.23 N to 49.95 N.

4.3.2 Effect of Scrapper speed on Gumminess

Gumminess was defined as the product of hardness and cohesiveness (Bourne, 2002). In other words gumminess is the energy required to disintegrate a semisolid food to a state ready for swallowing, indicates the denseness that persists throughout mastication.

Graph 4.6 and Table 4.2 indicates the effect of scrapper speed on gumminess.

It is evident that as third stage scrapper speed increases gumminess decreases but as first or second stage speed increases gumminess also increases. It can be observed from graph that gumminess is higher for higher speed in previous stage. This may be because gumminess is product of hardness and cohesiveness hence gumminess varies directly as hardness does.

Table 4.2 reveals that gumminess varied from 2.06 to 8.85 N.

4.3.3 Effect of Scrapper speed on Chewiness

Chewiness was defined as the product of gumminess and springiness (i.e. hardness x cohesiveness x springiness) (Bourne, 2002). Chewiness is an important textural attribute of solid food materials.

Graph 4.7 and Table 4.2 indicates the effect of scrapper speed on chewiness.

It is evident that as third stage scrapper speed increases chewiness decreases but as first or second stage speed increases chewiness also

increases. It can be observed from graph that chewiness is higher for higher speed in previous stage. This may be due to fact that chewiness is directly proportional to hardness so it shows nearly same trends as hardness does.

Table 4.2 reveals that gumminess varied from 1.15 to 2.87 N.

4.3.4 Effect of Scrapper speed on Adhesiveness

Adhesiveness is the force required to remove the material that adhere to the mouth during eating and is indicated by the negative area of first decompression cycle in the force-time curve. It can also be explained as work necessary to overcome the attractive forces between the surface of the product and surface of the probe. The work of adhesion, which is related to stickiness, is also of relevance in context to textural quality of *khoa*.

Table 4.2 indicates the effect of scrapper speed on adhesiveness.

It is evident that no particular trend is observed between scrapper speed and adhesiveness. Hence we may assume adhesiveness to be uncorrelated to scrapper speed.

Adhesiveness of *khoa* made by TFSSHE is on higher side than that made by conventional method as indicated by Table 4.5. This may be due to salt imbalance of the milk during processing in TFSSHE. It supports the argument of earlier workers that conditions should be standardized during processing.

Table 4.2 reveals that adhesiveness varied from -1.26 N.s. to -0.14 N.s.

4.3.5 Effect of Scrapper speed on Springiness

The distance that the food recovered its height during the time that elapsed between the end of the first bite and the start of the second bite was defined as springiness originally called elasticity (Bourne, 2002).

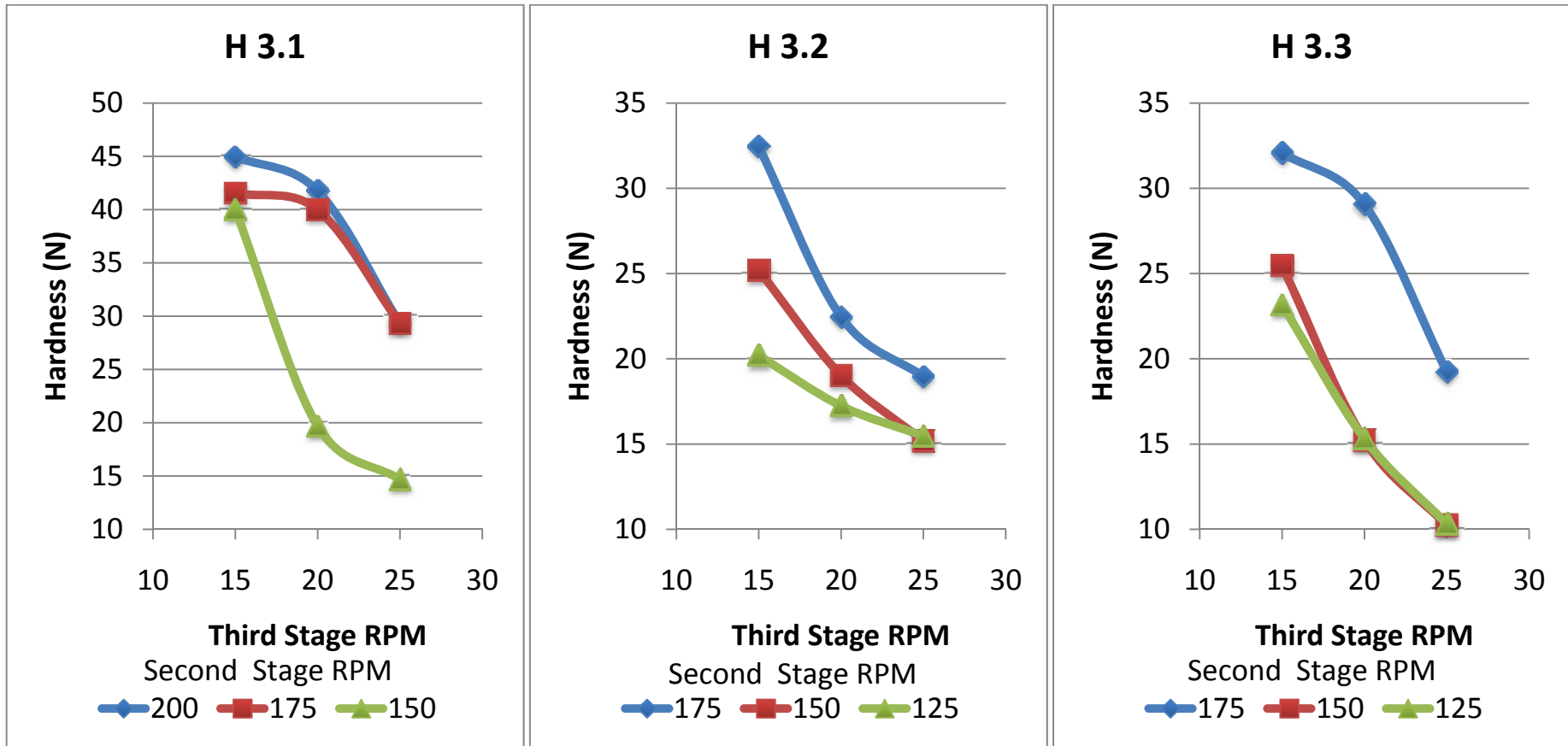
Table 4.2 indicates the effect of scrapper speed on springiness.

It is evident that no particular trend is observed between scrapper speed and springiness. Hence we may assume springiness to be uncorrelated to scrapper speed.

Table 4.2 reveals that springiness varied from 0.272 to 0.635.

4.3.6 Effect of Scrapper speed on Cohesiveness

The ratio of the positive force areas under the first and second compression was defined as cohesiveness (Bourne, 2002). In other words



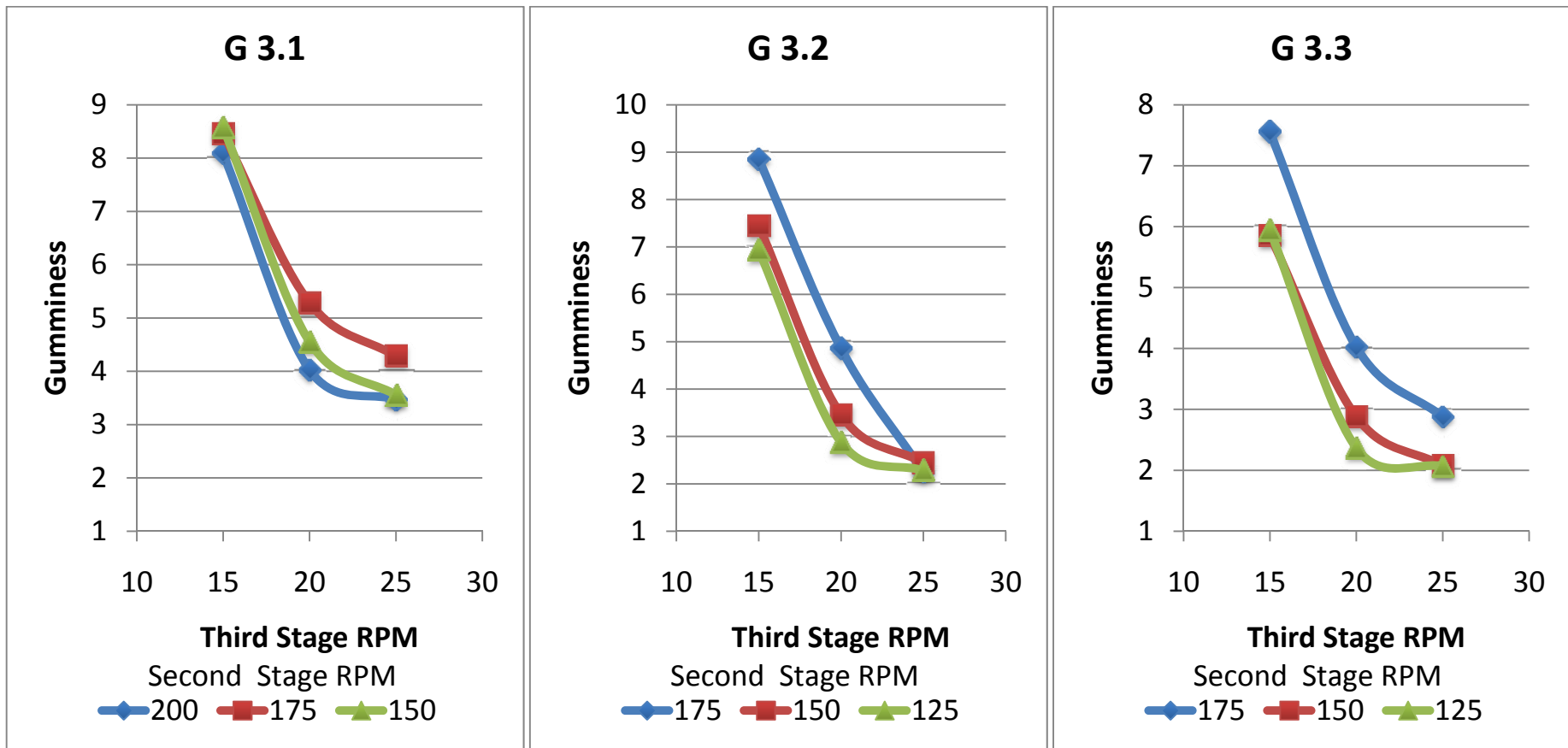
Graph 4.5: Effect of Scrapper RPM on Hardness

H 3.1: Effect of Third Stage Scrapper RPM on Hardness keeping First Stage Scrapper at 200 RPM.

H 3.2: Effect of Third Stage Scrapper RPM on Hardness keeping First Stage Scrapper at 175 RPM.

H 3.3: Effect of Third Stage Scrapper RPM on Hardness keeping First Stage Scrapper at 150 RPM.

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip



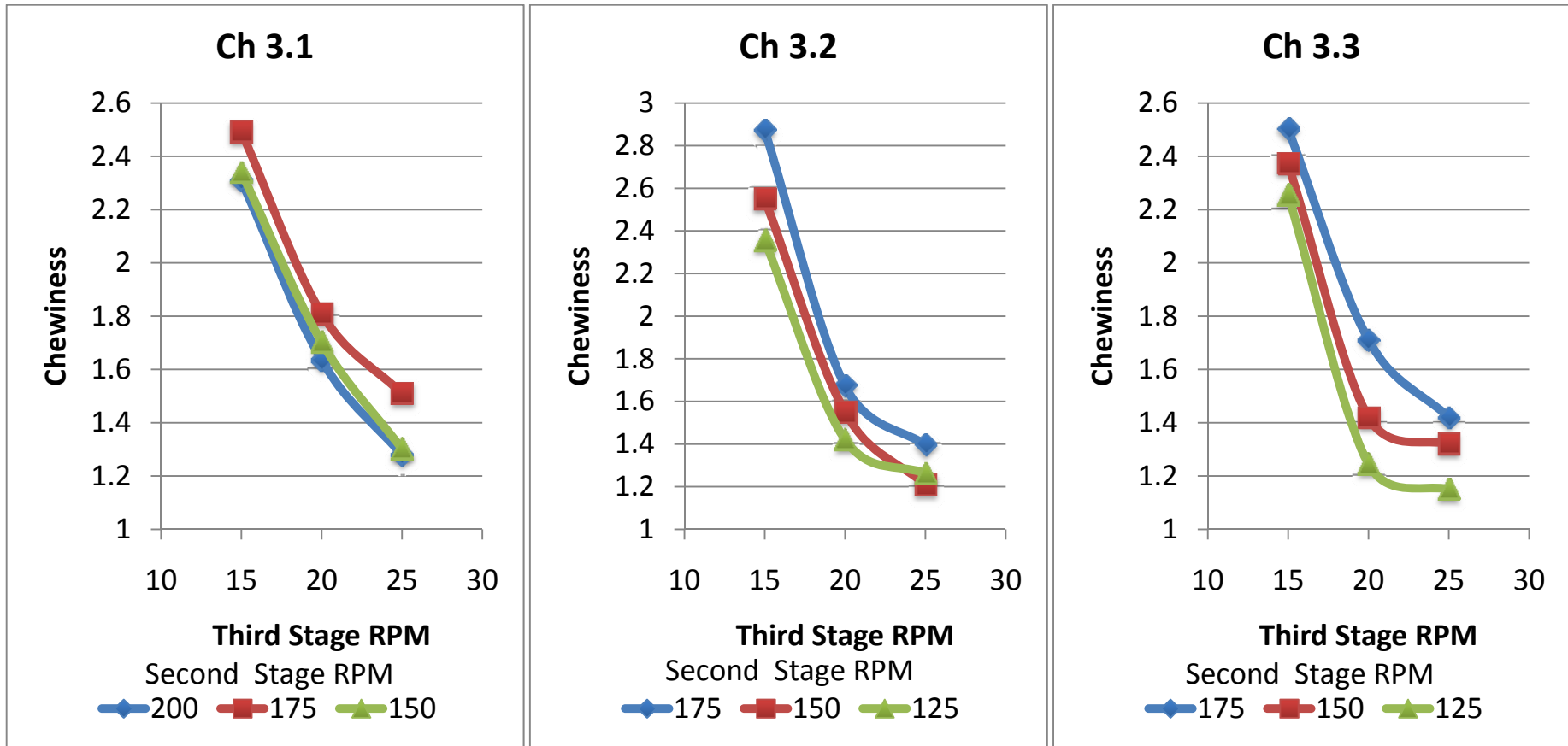
Graph 4.6: Effect of Scrapper RPM on Gumminess

G 3.1: Effect of Third Stage Scrapper RPM on Gumminess keeping First Stage Scrapper at 200 RPM.

G 3.2: Effect of Third Stage Scrapper RPM on Gumminess keeping First Stage Scrapper at 175 RPM.

G 3.3: Effect of Third Stage Scrapper RPM on Gumminess keeping First Stage Scrapper at 150 RPM.

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip



Graph 4.7: Effect of Scrapper RPM on Chewiness

Ch 3.1: Effect of Third Stage Scrapper RPM on Chewiness keeping First Stage Scrapper at 200 RPM.

Ch 3.2: Effect of Third Stage Scrapper RPM on Chewiness keeping First Stage Scrapper at 175 RPM.

Ch 3.3: Effect of Third Stage Scrapper RPM on Chewiness keeping First Stage Scrapper at 150 RPM.

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip

Cohesiveness is the degree to which a substance is compressed between teeth before it breaks, measures the disintegration of the sample and is the ratio of positive area A_2 to the positive area A_1 in force-time graph.

Table 4.2 indicates the effect of scrapper speed on cohesiveness.

It is evident that no particular trend is observed between scrapper speed and cohesiveness. Hence we may assume cohesiveness to be uncorrelated to scrapper speed.

The cohesiveness of the product made by TFSSHE was higher than that obtained from conventional method as indicated by Table 4.5. It indicates that the extent of deformation of the product before it ruptures is higher in the case of TFSSHE than made by conventional method.

Table 4.2 reveals that cohesiveness varied from 0.096 to 0.343.

4.4 Effect of Scrapper speed on Overall Heat Transfer Coefficient

Graph 4.8 and Table 4.3 indicates the effect of scrapper speed on overall heat transfer coefficient.

It is evident that as scrapper speed increases overall heat transfer coefficient also increases. It can be observed from graph that U value is higher for lower speed in previous stage. This is because increasing scrapper speed increases turbulence and hence led to higher heat transfer rates. But increasing scrapper speed in previous stage causes most of heat transfer to take place there only and much more concentrated and viscous product is delivered to next stage from which evaporation rate decreases due to high concentration and viscosity hence reduces heat transfer leading to comparatively lower overall heat transfer coefficient.

Table 4.3 reveals that U Value for first stage varied from 1431.994 W/m^2K to 1775.381 W/m^2K and for second stage it varied from 758.359 W/m^2K to 1385.504 W/m^2K and for third stage it varied from 126.577 W/m^2K to 567.584 W/m^2K .

4.5 Effect of Scrapper speed on Electric Power Consumption

Graph 4.9 and Table 4.4 indicates the effect of scrapper speed on electric power consumption.

It is evident that as scrapper speed increases electric power consumption also increases. It can be observed from graph that electric power consumption is higher for higher speed in previous stage. This is because increasing scrapper speed increases work load on scrapper motor and hence led to higher power consumption. But increasing scrapper speed in previous stage causes more heat transfer to take place in that stage and much more concentrated and viscous product is delivered to next stage hence increasing density (due to rise in TS) of product so it becomes more heavy to be handled (scrapped and conveyed) and increasing power consumption.

Table 4.4 reveals that electric power consumption for first stage varied from 360 to 480W and for second stage it varied from 348 to 876W and for third stage it varied from 60 to 144W with and for feed pump it varied from 228 to 300W.

4.6 Calculations for energy consumption using TFSSHE

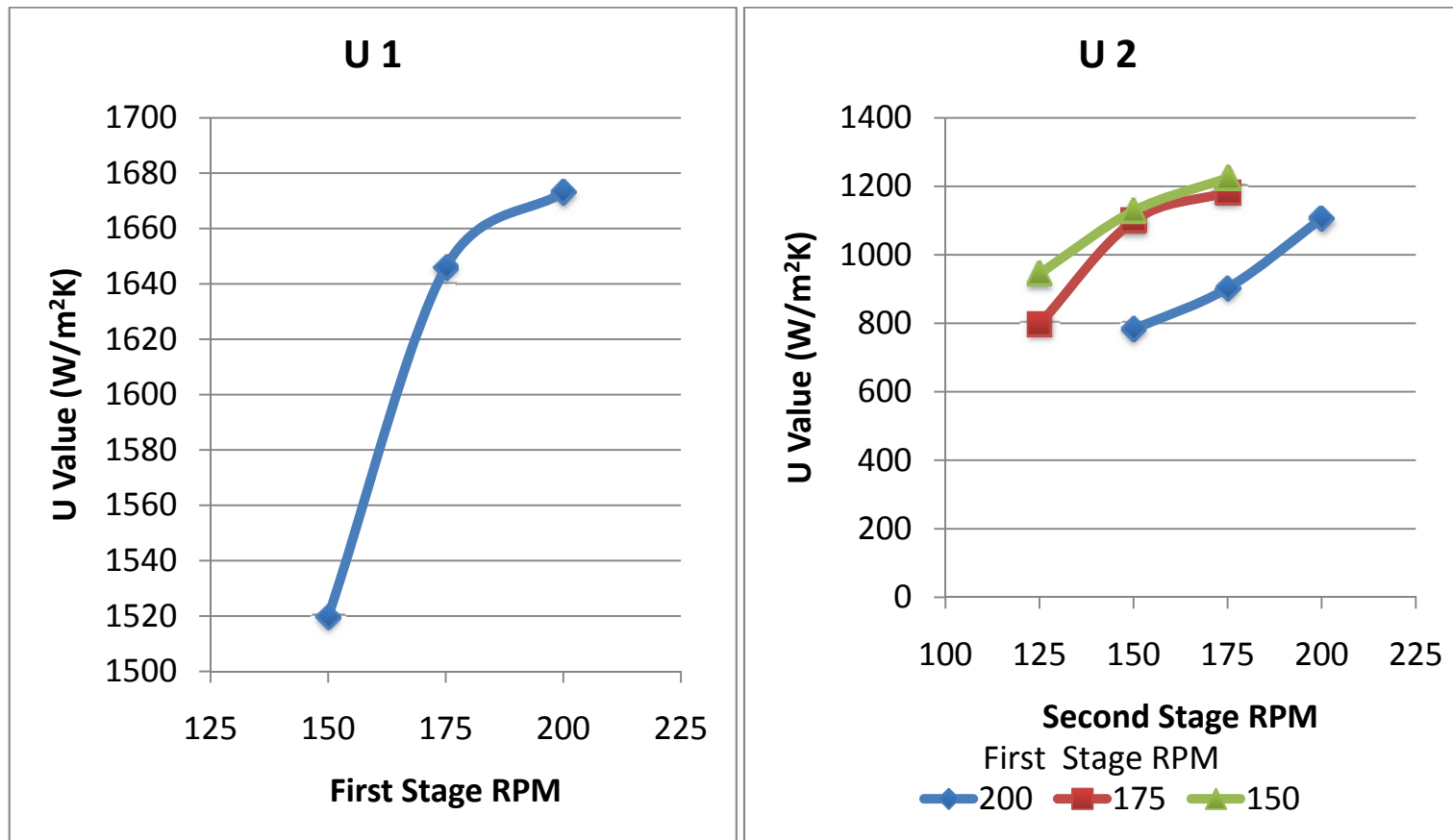
Table 4.3 and 4.4 indicates the calculations made for computing energy consumption in terms of steam and electricity in processing one kilogram of milk.

Table 4.3 summarises on steam consumption. Total condensate flow rate (kg/hr) was calculated by summing up condensate flow rate from all stages which was divided by mass flow rate (kg/hr) to obtain steam requirement (kg steam per kg milk).

Table 4.3 reveals that steam consumption for processing milk into *danedar khoa* using TFSSHE varied from 0.925 to 1.131 with an average of 1.017 kg steam used per kg of milk processed.

Table 4.4 summarises on electric power consumption. Total wattage (kW) consumption was calculated by summing up power consumption from all motors (namely scrapper1, 2, 3, feed pump motors) in kilo watts which was divided by mass flow rate (kg/hr) to obtain specific electric power consumption (kilo-Watt-hour).

Table 4.4 reveals that electric power consumption for processing milk into *danedar khoa* using TFSSHE varied from 5.55×10^{-3} to 8.76×10^{-3} with an average of 6.69×10^{-3} kWh used per kg of milk processed.

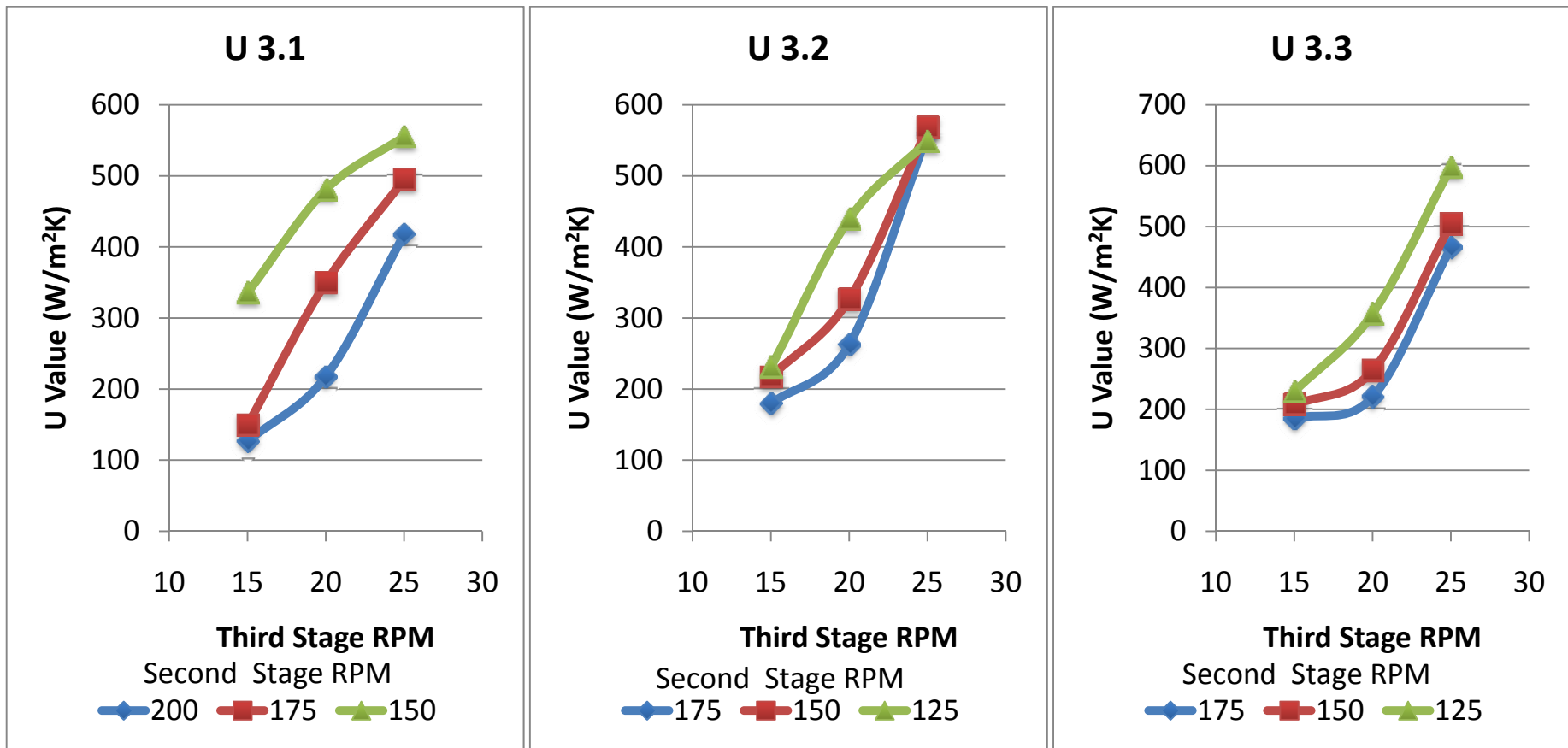


Graph 4.8 a: Effect of Scrapper RPM on Overall Heat Transfer Coefficient (U)

U 1: Effect of First Stage Scrapper RPM on Overall Heat Transfer Coefficient.

U 2: Effect of Second Stage Scrapper RPM on Overall Heat Transfer Coefficient.

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip



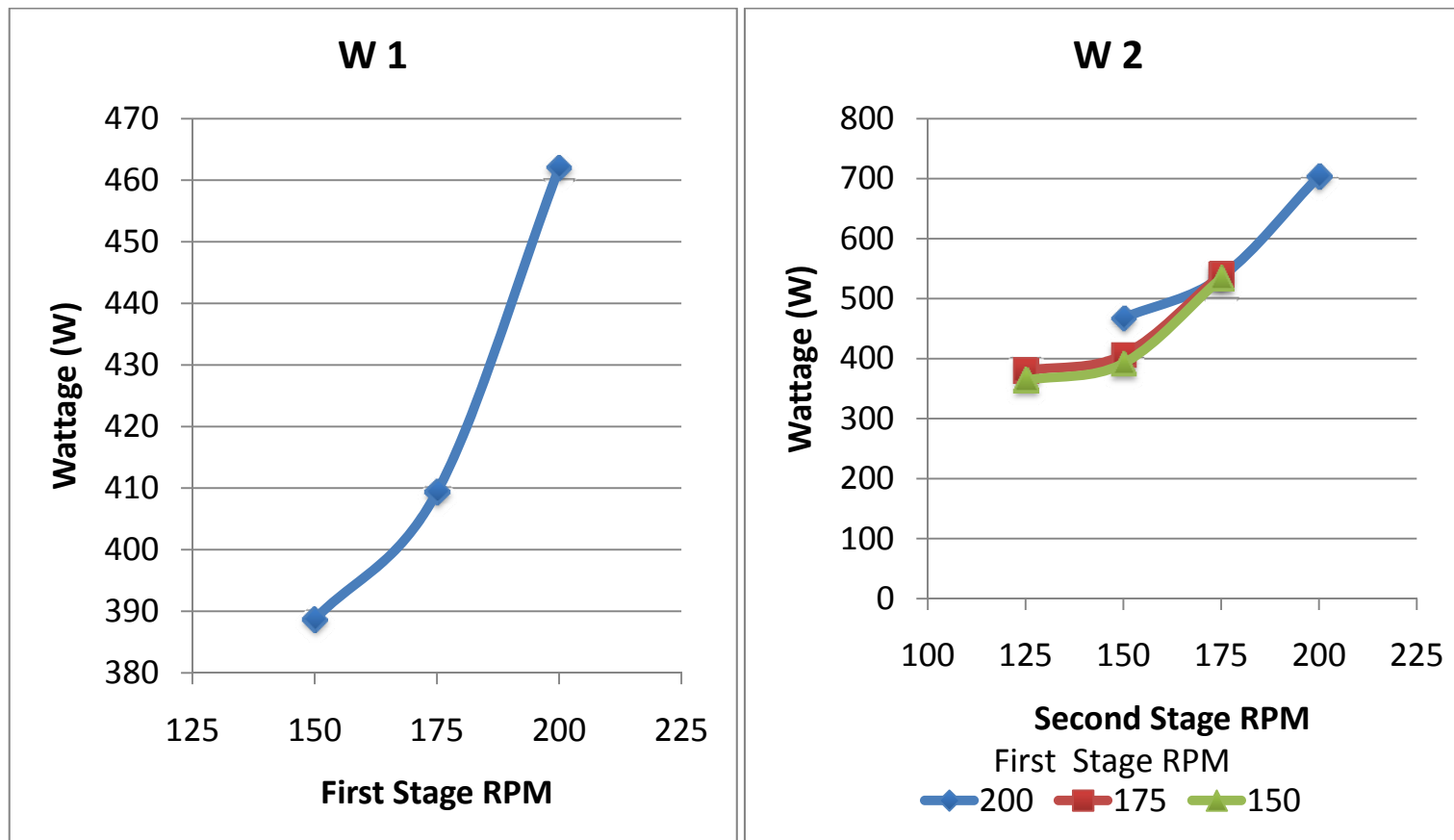
Graph 4.8 b: Effect of Scrapper RPM on Overall Heat Transfer Coefficient (U)

U 3.1: Effect of Third Stage Scrapper RPM on Overall Heat Transfer Coefficient keeping First Stage Scrapper at 200 RPM.

U 3.2: Effect of Third Stage Scrapper RPM on Overall Heat Transfer Coefficient keeping First Stage Scrapper at 175 RPM.

U 3.3: Effect of Third Stage Scrapper RPM on Overall Heat Transfer Coefficient keeping First Stage Scrapper at 150 RPM.

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip

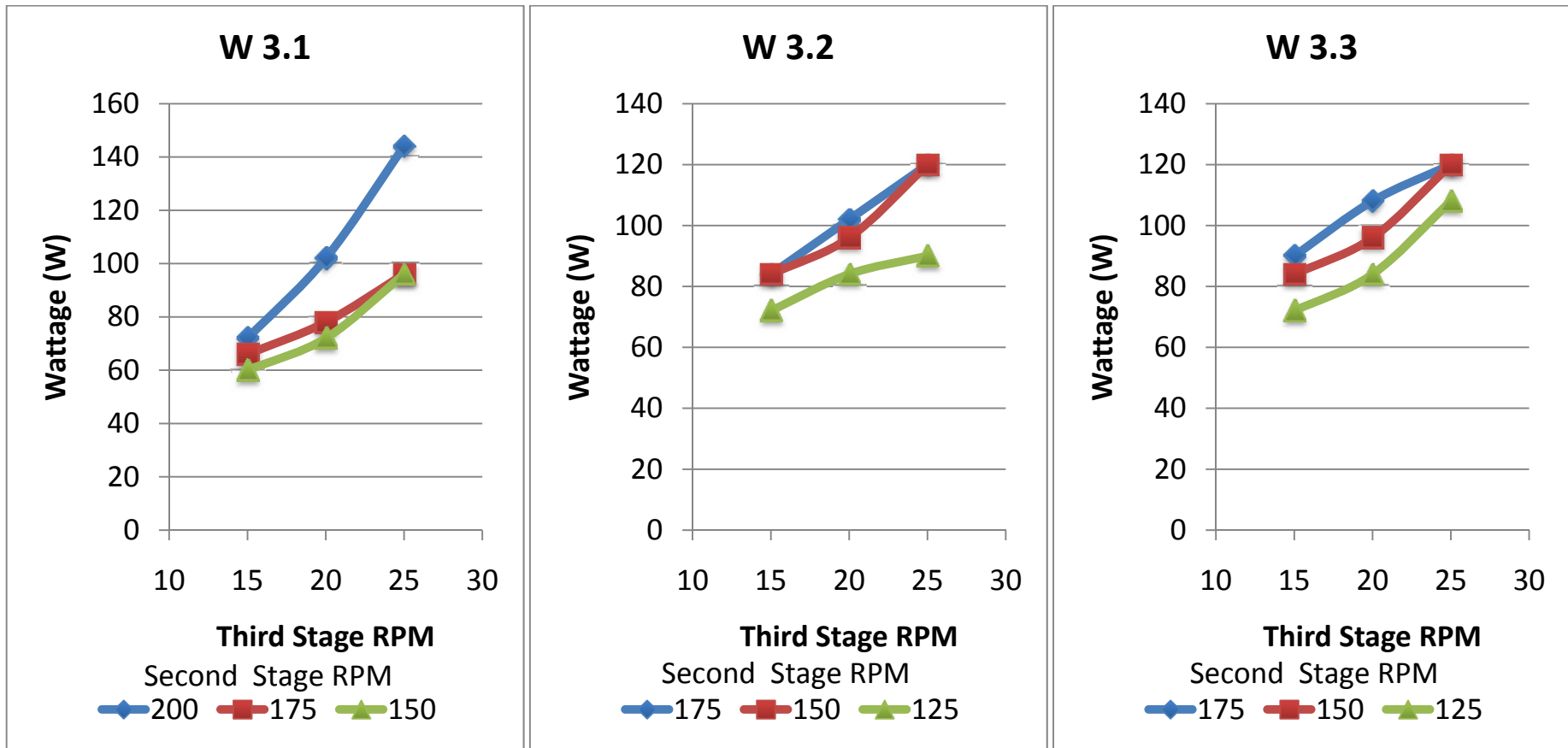


Graph 4.9 a: Effect of Scrapper RPM on Electric power Consumption

W 1: Effect of First Stage Scrapper RPM on Electric power Consumption.

W 2: Effect of Second Stage Scrapper RPM on Electric power Consumption.

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip



Graph 4.9 b: Effect of Scrapper RPM on Electric power Consumption

W 3.1: Effect of Third Stage Scrapper RPM on Electric power Consumption keeping First Stage Scrapper at 200 RPM.

W 3.2: Effect of Third Stage Scrapper RPM on Electric power Consumption keeping First Stage Scrapper at 175 RPM.

W 3.3: Effect of Third Stage Scrapper RPM on Electric power Consumption keeping First Stage Scrapper at 150 RPM.

Table 4.1: Average sensory evaluation scores

Code	RPM			Flow Rate	Sensory Evaluation			
	RPM 1	RPM 2	RPM 3		Flavour (10)	Body and Texture (10)	Colour and Appearance (5)	Overall Acceptability (25)
T 1	200	200	25	215	7.667	6.833	4.167	18.667
T 2	200	200	20	195	7.833	7.000	4.333	19.167
T 3	200	200	15	200	8.333	7.500	4.500	20.333
T 4	200	175	25	200	7.667	7.000	4.000	18.667
T 5	200	175	20	200	8.000	7.167	4.167	19.333
T 6	200	175	15	205	8.333	7.667	4.417	20.417
T 7	200	150	25	190	7.667	7.167	3.833	18.667
T 8	200	150	20	185	8.167	7.500	3.917	19.583
T 9	200	150	15	180	8.333	8.000	4.167	20.500
T 10	175	175	25	200	7.833	7.167	4.000	19.000
T 11	175	175	20	190	8.000	7.500	4.167	19.667
T 12	175	175	15	190	8.333	8.167	4.250	20.750
T 13	175	150	25	190	8.000	7.167	3.667	18.833
T 14	175	150	20	190	8.167	7.667	4.000	19.833
T 15	175	150	15	190	8.500	8.500	4.167	21.167
T 16	175	125	25	175	8.000	7.000	3.625	18.625
T 17	175	125	20	180	8.375	7.375	3.875	19.625
T 18	175	125	15	190	8.500	8.000	4.000	20.500
T 19	150	175	25	185	7.750	7.500	3.750	19.000
T 20	150	175	20	175	8.000	7.750	4.000	19.750
T 21	150	175	15	175	8.500	8.333	4.333	21.167
T 22	150	150	25	175	8.000	7.667	3.667	19.333
T 23	150	150	20	180	8.167	7.833	4.000	20.000
T 24	150	150	15	180	8.500	8.333	4.167	21.000
T 25	150	125	25	175	8.000	7.500	3.500	19.000
T 26	150	125	20	180	8.333	7.667	3.667	19.667
T 27	150	125	15	180	8.833	8.333	4.000	21.167

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip

Table 4.2: Average texture profile analysis results

Code	RPM			Flow Rate	Texture Profile Analysis					
	RPM 1	RPM 2	RPM 3		Hardness (N)	Adhesiveness (N.s)	Springiness (1)	Cohesiveness (1)	Gumminess (N)	Chewiness (N)
T 1	200	200	25	215	29.3215	-0.778	0.368429	0.118394	3.471	1.279
T 2	200	200	20	195	41.7510	-0.530	0.405862	0.096429	4.026	1.634
T 3	200	200	15	200	44.9570	-1.053	0.285555	0.179861	8.086	2.309
T 4	200	175	25	200	29.3215	-1.053	0.352077	0.146173	4.286	1.509
T 5	200	175	20	200	40.0000	-1.053	0.342225	0.132150	5.286	1.809
T 6	200	175	15	205	41.5500	-0.968	0.294751	0.203562	8.458	2.493
T 7	200	150	25	190	14.6860	-0.897	0.366348	0.241999	3.554	1.302
T 8	200	150	20	185	19.6860	-0.897	0.373738	0.231332	4.554	1.702
T 9	200	150	15	180	40.0000	-0.290	0.272791	0.214450	8.578	2.340
T 10	175	175	25	200	18.9490	-1.267	0.619450	0.118845	2.252	1.395
T 11	175	175	20	190	22.4610	-0.543	0.344458	0.216108	4.854	1.672
T 12	175	175	15	190	32.4610	-0.543	0.324373	0.272758	8.854	2.872
T 13	175	150	25	190	15.2090	-0.901	0.493268	0.161155	2.451	1.209
T 14	175	150	20	190	19.0300	-0.968	0.448236	0.181713	3.458	1.550
T 15	175	150	15	190	25.2090	-0.901	0.342236	0.295569	7.451	2.550
T 16	175	125	25	175	15.4800	-0.269	0.553266	0.147351	2.281	1.262
T 17	175	125	20	180	17.2390	-0.561	0.493398	0.166947	2.878	1.420
T 18	175	125	15	190	20.1830	-0.140	0.339435	0.343755	6.938	2.355
T 19	150	175	25	185	19.2390	-0.561	0.493399	0.149592	2.878	1.420
T 20	150	175	20	175	29.0510	-0.301	0.425199	0.138515	4.024	1.711
T 21	150	175	15	175	32.0710	-0.897	0.331215	0.235540	7.554	2.502
T 22	150	150	25	175	10.2390	-0.561	0.635227	0.202950	2.078	1.320
T 23	150	150	20	180	15.2390	-0.561	0.493399	0.188858	2.878	1.420
T 24	150	150	15	180	25.4610	-0.543	0.405193	0.229920	5.854	2.372
T 25	150	125	25	175	10.3130	-0.993	0.556363	0.200427	2.067	1.150
T 26	150	125	20	180	15.3130	-0.993	0.525983	0.154575	2.367	1.245
T 27	150	125	15	180	23.1830	-0.140	0.379757	0.256136	5.938	2.255

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip

Table 4.3: Overall heat transfer coefficient (U) and Steam Consumption

Code	RPM			Flow Rate	U Value (W/m ² K)			Steam Consumption (kg/hr)			Total Condensate Flow Rate per hour	Steam Requirement
	RPM 1	RPM 2	RPM 3		U 1	U 2	U 3	SC 1	SC 2	SC 3		
T 1	200	200	25	215	1672.955	1385.504	417.440	134.238	72.524	8.963	215.7248	1.003371
T 2	200	200	20	195	1775.381	974.0792	217.737	142.457	50.988	5.103	198.5483	1.018197
T 3	200	200	15	200	1657.022	957.0927	126.578	132.960	50.099	3.086	186.1443	0.930722
T 4	200	175	25	200	1657.022	858.0505	494.632	132.960	44.914	10.620	188.4943	0.942471
T 5	200	175	20	200	1657.022	858.0505	349.614	132.960	44.914	7.506	185.3807	0.926903
T 6	200	175	15	205	1672.955	991.9477	149.340	134.238	51.923	3.908	190.0701	0.927171
T 7	200	150	25	190	1633.684	781.5346	555.052	131.087	40.909	11.917	183.9137	0.967967
T 8	200	150	20	185	1633.684	781.5346	480.588	131.087	40.909	10.318	182.3149	0.985486
T 9	200	150	15	180	1697.438	784.9841	335.344	136.203	41.089	7.200	184.4926	1.024959
T 10	175	175	25	200	1681.037	830.8711	558.906	134.887	43.492	12.000	190.3785	0.951893
T 11	175	175	20	190	1689.198	1358.808	262.686	135.542	71.126	5.640	212.3080	1.117410
T 12	175	175	15	190	1689.198	1358.808	179.648	135.542	71.126	3.857	210.5251	1.108027
T 13	175	150	25	190	1633.684	1099.030	567.585	131.087	57.528	12.186	200.8019	1.056852
T 14	175	150	20	190	1633.684	1099.030	326.361	131.087	57.528	7.007	195.6227	1.029593
T 15	175	150	15	190	1633.684	1099.030	217.574	131.087	57.528	4.671	193.2870	1.017300
T 16	175	125	25	175	1689.198	758.3595	548.950	135.542	39.696	14.367	189.6050	1.083457
T 17	175	125	20	180	1581.703	817.7011	439.141	126.916	42.802	9.428	179.1471	0.995262
T 18	175	125	15	190	1581.703	817.7011	230.599	126.916	42.802	6.035	175.7539	0.925020
T 19	150	175	25	185	1431.995	1228.126	465.621	114.904	64.286	9.997	189.1865	1.022630
T 20	150	175	20	175	1431.995	1228.126	220.308	114.904	64.286	5.765	184.9554	1.056888
T 21	150	175	15	175	1431.995	1216.540	184.918	114.904	63.679	3.970	182.5532	1.043161
T 22	150	150	25	175	1512.933	1140.717	504.350	121.398	59.710	13.200	194.3086	1.110335
T 23	150	150	20	180	1512.933	1144.664	263.638	121.398	59.917	6.900	188.2152	1.045640
T 24	150	150	15	180	1539.711	1098.567	207.416	123.547	57.504	4.453	185.5042	1.030579
T 25	150	125	25	175	1641.390	1021.882	596.912	131.706	53.490	12.816	198.0117	1.131495
T 26	150	125	20	180	1641.390	1005.130	356.684	131.706	52.613	7.658	191.9770	1.066539
T 27	150	125	15	180	1532.928	808.4888	229.250	123.003	42.320	6.000	171.3226	0.951792

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip

Table 4.4: Electric power consumption

Code	RPM			Flow Rate	Wattage (W)				Total Wattage (kW)	Electric energy consumption (kWh)
	RPM 1	RPM 2	RPM 3		W 1	W 2	W 3	W FP		
T 1	200	200	25	215	456	636	144	288	1.524	0.007088
T 2	200	200	20	195	468	876	102	264	1.71	0.008769
T 3	200	200	15	200	480	600	72	270	1.422	0.00711
T 4	200	175	25	200	468	528	96	252	1.344	0.00672
T 5	200	175	20	200	468	528	78	252	1.326	0.00663
T 6	200	175	15	205	450	552	66	264	1.332	0.006498
T 7	200	150	25	190	456	468	96	264	1.284	0.006758
T 8	200	150	20	185	456	468	72	264	1.26	0.006811
T 9	200	150	15	180	456	468	60	252	1.236	0.006867
T 10	175	175	25	200	408	624	120	288	1.44	0.0072
T 11	175	175	20	190	420	600	102	264	1.386	0.007295
T 12	175	175	15	190	420	396	84	300	1.2	0.006316
T 13	175	150	25	190	420	402	120	300	1.242	0.006537
T 14	175	150	20	190	420	408	96	300	1.224	0.006442
T 15	175	150	15	190	420	408	84	300	1.212	0.006379
T 16	175	125	25	175	408	396	90	228	1.122	0.006411
T 17	175	125	20	180	408	396	84	228	1.116	0.0062
T 18	175	125	15	190	360	348	72	276	1.056	0.005558
T 19	150	175	25	185	366	534	120	264	1.284	0.006941
T 20	150	175	20	175	366	534	108	264	1.272	0.007269
T 21	150	175	15	175	366	534	90	264	1.254	0.007166
T 22	150	150	25	175	372	396	120	264	1.152	0.006583
T 23	150	150	20	180	372	384	96	264	1.116	0.0062
T 24	150	150	15	180	378	396	84	252	1.11	0.006167
T 25	150	125	25	175	450	360	108	240	1.158	0.006617
T 26	150	125	20	180	450	372	84	240	1.146	0.006367
T 27	150	125	15	180	378	360	72	270	1.08	0.006

Refer appendix-IV for conversion of rpm to circumferential velocity or velocity at tip

Table 4.5: Comparison between Market sample and *danedar khoa* from TFSSHE

Instrumental Textural Parameters	<i>Danedar khoa</i> from three stage TFSSHE	Market Sample (<i>Danedar khoa</i>)
Hardness (N)	25.209 ± 6.801	33.553 ± 10.605
Adhesiveness(N.s)	-0.901 ± 0.553	-0.311 ± 0.389
Springiness	0.342 ± 0.115	0.349 ± 0.172
Cohesiveness	0.295 ± 0.095	0.222 ± 0.055
Gumminess (N)	7.451 ± 2.419	7.448 ± 3.304
Chewiness (N)	2.55 ± 1.099	2.59 ± 2.184

4.7 Selection of optimal operating parameter combination

The optimal combination of operating parameter for production of *danedar khoa* with desirable textural attributes has been selected on the basis of overall acceptability of the product including all the sensory attributes of *khoa*. Table 4.1 represents the average sensory score allotted to different trial codes. It was found that the *khoa* produced by using trial code T15 had all desired sensory attributes. Hence in the present investigation, the operating parameter combination of T15 is selected as optimum operation parameters for the production of *danedar khoa* using TFSSHE. Hence optimum operating parameters for production of *danedar khoa* using TFSSHE are:

Initial Acidity of standardised milk	:	0.18 % LA
Flow rate of milk through feed pump	:	190 kg/hr
RPM of First Stage SSHE	:	175 rpm (201.769 m/s)
RPM of Second Stage SSHE	:	150 rpm (172.945 m/s)
RPM of Third Stage SSHE	:	15 rpm (17.294 m/s)
Steam Pressure in First Stage SSHE	:	4 kg/cm ²
Steam Pressure in Second Stage SSHE	:	2 kg/cm ²
Steam Pressure in Third Stage SSHE	:	1.5 kg/cm ²

Values in brackets represent circumferential velocity or velocity at tip of scrapper blade.

4.8 Comparative study

Comparative study was carried out with the market sample and *danedar khoa* made by using three stage TFSSHE with combination code T15 (Table 4.1). Table 4.5 represents comparison between the instrumental textural parameters of market sample and product made by using TFSSHE with 69.01 ± 1.89 percent total solid contents. All the textural parameters except hardness and adhesiveness of product made by using TFSSHE and Market sample having around same total solid content were not significantly different from each other. Hence it is concluded that product manufactured from TFSSHE was comparable with market samples with exception that it was softer and more adhesive as compared to market sample.

CHAPTER -5

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSION

The Indian dairy industry is rapidly growing, trying to keep pace with the galloping progress around the world with annual production more than 100 million tonnes. Significant portion of milk produced in India is used to manufacture a wide variety of indigenous milk sweets. *Khoa* is an important indigenous milk product, is used as a base material for a variety of sweets, such as *burfi*, *peda*, *gulabjamun*, milk cake, *kalakand*, *kunda* etc. Conventionally it is prepared by continuous boiling of milk in an open kettle until desired concentration (normally 65-72% total solids) and texture is achieved. This product is mainly prepared by unorganized dairy sector using traditional processing equipments and techniques.

Continuous *khoa* making machine based on the principle of thin film scraped surface heat exchanger was developed in Dairy Engineering Division of NDRI (Dodeja *et.al*, 1992). It manufactures *khoa* from standardized buffalo milk. It was felt that machine may get wider acceptability in market if it can manufacture different types of *khoa* so that it can be used for production of *khoa* on application specific uses like different sweets require different textural qualities of *khoa*. Hence the present dissertation work is envisaged to study feasibility of production of *danedar khoa* using three stage TFSSHE.

Trials were conducted with milk having 6% Fat, 9% SNF, 0.18% LA for manufacture of *danedar khoa* to optimize the process parameters such as mass flow rate, initial acidity of milk, steam pressure and scrapper rpm. The quality of product so obtained was established in terms of sensory and textural profile analysis and was compared with product made by using conventional method. Based on these determinations, the operating parameters for formation of desired texture of the product has been investigated and optimized.

It was concluded that:

1. Manufacture of *danedar khoa* using three stage scraped surface heat exchanger was found out to be feasible.

2. On the basis of preliminary studies it was observed that optimum type and size of grain size was obtained in final product by using standardised milk with 0.18% LA initial acidity.
3. On the basis of overall acceptability of the product including all sensory attributes, *danedar khoa* produced by using trial code T15 (i.e. at 175, 150, 15 RPM) has most desirable sensory and textural characteristics as compared among all trial codes.
4. The process parameter optimization study has indicated that the best quality *danedar khoa* can be produced by keeping following parameters as:
 Flow Rate = 190 Kg/Hr $R_1 = 175$ RPM $R_2 = 150$ RPM $R_3 = 15$ RPM
 Acidity = 0.18% LA $P_1 = 4$ Kg/cm² $P_2 = 2$ Kg/cm² $P_3 = 1.5$ Kg/cm²
5. Flavour scores increases with decrease in scrapper speed in all stages.
6. Body & texture scores decrease as third stage scrapper speed but are highest when previous stage scrapper speed is kept at 150 and decreases on either side of 150 rpm.
7. Colour and appearance scores decreases as third stage scrapper speed increases but as first or second stage speed increases colour and appearance scores also increases.
8. Overall acceptability scores decreases as scrapper speed increases but overall acceptability scores are highest when scrapper speed is kept at 150 and decreases on either side of 150 rpm.
9. The sensory characteristic scores namely flavour, body and texture, colour and appearance, overall acceptability of *danedar khoa* produced by TFSSHE using all trial codes varied from 7.67 to 8.83; 6.83 to 8.5; 3.5 to 4.5 and 18.625 to 21.167 respectively.
10. Hardness, Gumminess and Chewiness decreases as third stage scrapper speed increases but increases as first or second stage speed increases.
11. Adhesiveness, Cohesiveness and Springiness showed no particular trend with scrapper speed.
12. The hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness values of *danedar khoa* made by using all combination codes varied from 10.239 to 44.957 N; -1.267 to -0.14 N.s; 0.272 to 0.635; 0.096 to 0.343; 2.067 to 8.854 N and 1.15 to 2.872 N respectively.

13. Product manufactured from TFSSHE was comparable with market samples with exception that it was softer and more adhesive as compared to market sample.
14. Overall heat transfer coefficient for first, second and third stage of TFSSHE varied from 1431.994 to 1775.381 W/m²K; 758.359 to 1385.504 W/m²K and 126.577 to 567.584 W/m²K respectively.
15. Electric power consumption for first, second, third stage and feed pump motor of TFSSHE varied from 360 to 480W; 348 to 876W; 60 to 144W and 228 to 300W respectively.
16. Steam consumption for processing milk into *danedar khoa* using TFSSHE varied from 0.925 to 1.131 with an average of 1.017 kg steam used per kg of milk processed.
17. Electric power consumption for processing milk into *danedar khoa* using TFSSHE varied from 5.55×10^{-3} to 8.76×10^{-3} with an average of 6.69×10^{-3} kWh used per kg of milk processed.

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APPENDICES

KHOA SCORE CARD

Please give the score and mark the defects in the space allotted for the sample.

Perfect score	Criticism	Sample Number			
		1	2	3	4
Flavour (10)	Judge's score				
	Burnt				
	Stale				
	Salty				
	Oxidized				
	Rancid				
	Sour				
	Flat/Lacking				
	Metallic				
	Any other				
Body & Texture (10)	Judge's score				
	Weak/Loose				
	Grainy				
	Sandy/Gritty				
	Hard				
	Brittle				
	Sticky/Pasty				
	Chewy				
	Any other				
Colour & Appearance (5)	Judge's score				
	Uneven/ Mottled				
	Moist/Wet				
	Dry				
	Mouldy				
	Oily				
	Any other				
Total score (25)					

SCORE GUIDE FOR KHOA

Intensity of Defects	Score to be assigned	
	Flavour & Texture	Colour & Appearance
Slight	> 7-9	>3-4
Moderate	>5-7	>2-3
Pronounced	3-5	1-2
Unacceptable	<3	0

Date:**Comments:****Signature**

Sensory Evaluation of *Khoa* (9 point Hedonic scale)

Date: _____

Please rate the Product for quality attributes according to 9 point Hedonic scale (Please tick ✓ which you like)

- a) Liked extremely.
- b) Liked very much.
- c) Liked moderately.
- d) Liked slightly.
- e) Neither liked nor disliked.
- f) Disliked slightly.
- g) Disliked moderately.
- h) Disliked very much.
- i) Disliked extremely.

9	
8	
7	
6	
5	
4	
3	
2	
1	

Characteristics:

Please give marks for following characteristics according to above hedonic scale

- a) Flavour: _____
- b) Body and Texture; _____
- c) Colour and appearance: _____

Remarks:

Signature: _____

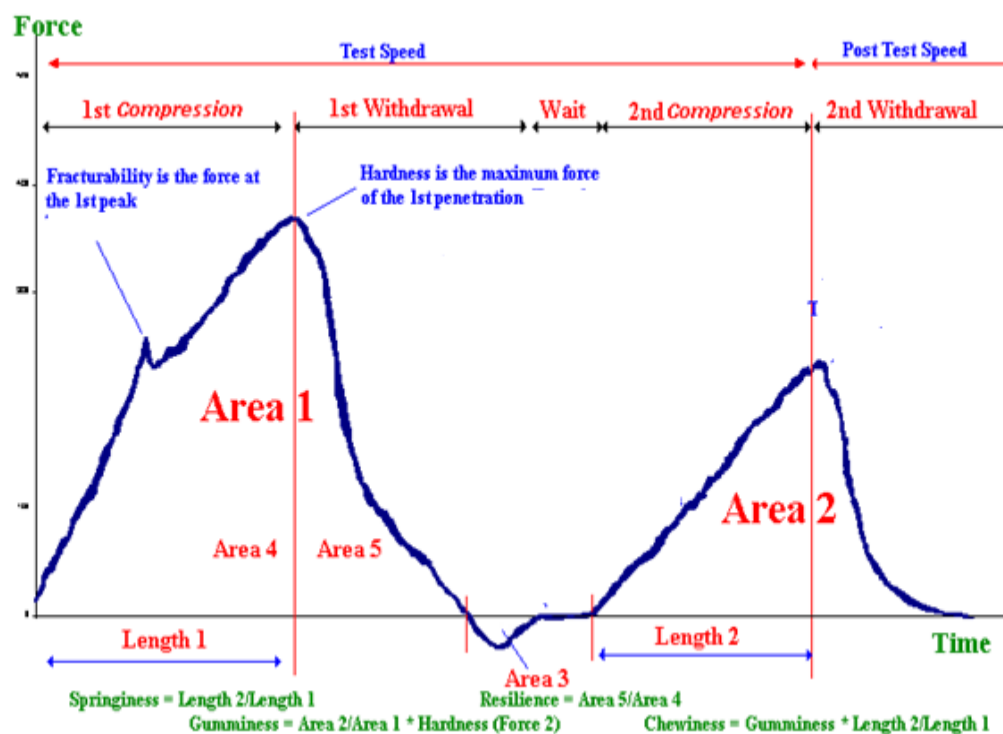
Name: _____

Texture Profile Analysis

Texture refers to sensory perception of the force-deformation relationship in a product. Instrumental measurements provide objective information about the subjective properties. Texture profile analysis (TPA) refers to identification and quantification of various constituent perceptions of texture which give the overall texture impression, i.e. the individual texture attributes such as hardness, gumminess, chewiness, etc. In TPA, sample is usually subjected to large deformation (in the destructive range) primarily to simulate the chewing action (Bourne, 1978). In the recent times, with the advent of modern texture analysers facilitated with software, most instrumental measurements on traditional dairy products have been made using the TPA approach.

Interpretation of texture profile parameters from texture profile curve

A typical force – deformation curve for double cycled compression is given in following figure.



A typical force–deformation curve for double cycled compression

Hardness (N): The hardness value is the peak force of the first compression of the product. The hardness need not occur at the point of the deepest compression, although it typically does for most products.

Fracturability (N): Not all products fracture but when they do fracture the fracturability point occurs where the plot has its first significant peak (where the force falls off) during the probe's first compression of the product.

Cohesiveness: Cohesiveness indicates as to how well the product withstands a second deformation relative to how it behaved under the first deformation. It is measured as the area of work during the second compression divided by the area of work during the first compression (i.e. Area 2/ Area 1)

Adhesiveness (N.s): The negative force area of the first bite represented the work necessary to pull the compressing plunger away from the sample.

Springiness: Springiness means how well a product physically springs back after it has been deformed during the first compression. The spring-back is measured at the down stroke of the second compression, so the wait time between two strokes can be relatively important. In some cases, an excessively long wait time will allow a product to spring-back more than it might do under the conditions being researched (e.g. one would not wait 60 seconds between successive chews). Springiness is measured several ways, but most typically, by the distance of the detected height of the product on the second compression divided by the original compression distance (i.e. Length 2 /Length 1). The original definition of the springiness used the length 2 only, and its units were mm or other unit of distance. It might be better not to subscribe to that original description of springiness since the springiness value can only be compared among products which are identical in their original shape and height. Many TPA users compress their products a % strain, and for those applications a pure distance value (rather than a ratio) is too heavily influenced by the height of the sample. By expressing springiness as a ratio of its original height, comparisons can be made between a more broad set of samples and products.

Chewiness (N): Chewiness only applies for solid product and is calculated as gumminess x springiness (i.e. Length 1 / Length 2). Chewiness is mutually

exclusive with gumminess since a product would not be both solid and semi-solid at the same time.

Gumminess (N): Gumminess only applied to semi-solid products and is hardness x cohesiveness (i.e. Area 2 / Area 1). Gumminess is mutually exclusive with chewiness since a product would not be both a semi-solid and a solid at the same time.

Resilience: Resilience shows as to how well a product “fight to regain its original position”. It may be regarded as instant springiness, since resilience is measured on the withdrawal of the first penetration, before waiting period is started. It can be calculated as area during the withdrawal of the first compression divided by the area of the first compression (i.e. Area 5 / Area 4). Resilience can be measured with a single compression. However, the withdrawal speed must be the same as the compression speed.

CONVERSION OF RPM TO CIRCUMFERENTIAL SPEED

Revolutions per minute may be converted into circumferential speed by using the following formula:

$$\text{Circumferential speed} = \pi Dn$$

Where,

$$D = \text{Diameter of each SSHE} = 367\text{mm} = 0.367\text{m}$$

$$\pi = 3.14$$

$$n = \text{Revolution per minute (rpm)}$$

Scrapper speeds used in this dissertation work have been calculated in terms of circumferential speed in the following table:

RPM	Circumferential speed (m/s)
200	230.593
175	201.769
150	172.945
125	144.121
25	28.824
20	23.059
15	17.294