ENERGY CONSERVATION AND HEAT TRANSFER CHARACTERISTICS IN DAIRY PROCESSING

ARUNAVA DAS

DIVISION OF DAIRY TECHNOLOGY AND ENGINEERING
NATIONAL DAIRY RESEARCH INSTITUTE
(Indian Council of Agricultural Research)
KARNAL (Haryana) INDIA

1984

ENERGY CONSERVATION AND HEAT TRANSFER CHARACTERISTICS IN DAIRY PROCESSING

THESIS

SUBMITTED TO THE KURUKSHETRA UNIVERSITY, KURUKSHETRA
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF SCIENCE

IN

DAIRYING

(DAIRY ENGINEERING)

BY

ARUNAVA DAS

B.Sc. (Dairy Technology)

DIVISION OF DAIRY TECHNOLOGY AND ENGINEERING
NATIONAL DAIRY RESEARCH INSTITUTE
(Indian Council of Agricultural Research)
KARNAL (Haryana) INDIA

1984

Registration No. 81-DK-57

ENERGY CONSERVATION AND HEAT TRANSFER CHARACTERISTICS IN DAIRY PROCESSING

Thesis
Submitted to the Kurukshetra University, Kurukshetra
In partial fulfilment of the requirements for the
Degree of
MASTER OF SCIENCE IN DAIRYING
(DAIRY ENGINEERING)

By

ARUNAVA DAS
B.Sc. (Dairy Technology)
Regd. No. 81-DK-57

DIVISION OF DAIRY TECHNOLOGY AND ENGINEERING
NATIONAL DAIRY RESEARCH INSTITUTE
(Indian Council of Agricultural Research)
KARNAL-132001, INDIA

1984

Dedicated to
my beloved Parents

NATIONAL DAIRY RESEARCH INSTITUTE
(I.C.A.R.)
KARNAL (Haryana)

R.D. VERMA,
Scientist-2
(Dairy Engineering)

Division of Dairy Technology & Engineering

...

Dated: 1st June, 1984.

CERTIFICATE

This is to certify that the dissertation entitled "ENERGY CONSERVATION AND HEAT TRANSFER CHARACTERISTICS IN DAIRY PROCESSING" is a bonafide piece of research work carried out under my supervision by Shri ARUNAVA DAS towards the partial fulfilment of the requirements for the Degree of MASTER OF SCIENCE IN DAIRYING (DAIRY ENGINEERING) in the Faculty of Dairying, Animal Husbandry and Agriculture, Kurukshetra University, Kurukshetra. The assistance received during the course of investigation has been duly acknowledged.

R. Verma
1.6.84
(R.D. VERMA)

BIOGRAPHICAL SKETCH

Author was born in January 16, 1960 in Singur, West Bengal (India). He did his schooling, to the Higher Secondary level, in Singur, India. After completing schooling in 1976, he enrolled with Bidhan Chandra Krishi Viswa Vidyalaya (West Bengal) and was awarded the Bachelor of Science Degree in Dairy Technology in the year 1981. Before continuing his academic career, at National Dairy Research Institute, Karnal, he gathered Industry experience with "Milk Plant", Verka, Amritsar, Punjab. In 1981 he joined N.D.R.I. for his M.Sc. Dairying (Dairy Engineering) programme.

He has been awarded with Junior Indian Council of Agricultural Research Fellowship in Dairy Technology and Jr.National Dairy Research Institute Fellowship in Dairy Engineering.

*****

ACKNOWLEDGEMENT

It has been a rare privilege and pleasure to work with Mr. R.D. Verma, Scientist-2, Division of Dairy Technology and Engineering, National Dairy Research Institute, Karnal, who has been my guide during this investigation. An incisively knowledgeable mind, yet, he carries himself with such disarming humility. Without his able guidance and direction, this work would have yielded far less than it has. Rarer than all this has been the abundance of love and affection that I have received from him.

Mr.V.P. Aneja, Mr.H. Abichandani, Mr.R.K. Kohli, Mr.I.K. Sawhney, Mr. Bikram Kumar, Mr. A.K. Dodeja, Mr. G.R. Anap and all other staff members of Dairy Technology and Engineering, share with Mr.R.D. Verma that place of special respect due to their valuable help and guidance during my course work and this investigation.

Likewise, I appreciate all the assistance that I have received from the Head of the Division of Dairy Technology and Engineering and the Principal, Dairy Science College. I extend my thanks to them.

Thanks are also due to Mr.R.P. Chakraborty for his constant help during the progress of this investigation.

Financial assistance received from the Director, National Dairy Research Institute is duly acknowledged.

Karnal, (ARUNAVA DAS)

Dated: 1st June, 1984.

TABLE OF CONTENTS

				PAGE
LIST OF TABLES			.. ..	
LIST OF FIGURES			.. ..	
LIST OF SYMBOLS			.. ..	
LIST OF ABBREVIATIONS			.. ..	
CHAPTER	1.	INTRODUCTION	.. ..	1
	1.1.	CONCEPT OF ENERGY CONSERVATION	.. ..	2
	1.2.	CONCEPT OF HEAT TRANSFER MECHANISM	.. ..	4
CHAPTER	2.	REVIEW OF LITERATURE	.. ..	6
	2.1.	INTRODUCTION	.. ..	6
	2.2.	ENERGY REQUIREMENT, HEAT LOSSES AND CONSERVATION TECHNIQUES IN DAIRY PROCESSING	.. ..	7
	2.2.1.	Energy Consumption	.. ..	7
	2.2.2.	Energy Loss	.. ..	10
	2.2.3.	Energy Recovery and Conservation	.. ..	13
	2.3.	HEAT TRANSFER CHARACTERISTICS	.. ..	18
	2.3.1.	Heat Transfer Co-efficient of Condensing Steam	.. ..	19
	2.3.2.	Thermodynamic Expression for Heat Transfer in Free Convection	.. ..	21
	2.3.3.	Heat Transfer Co-efficient	.. ..	26
CHAPTER	3.	OBJECTIVES AND SCOPE	.. ..	30
	3.1.	OBJECTIVES	.. ..	30
	3.2.	SCOPE	.. ..	31

			PAGE
CHAPTER	4.	MATERIALS AND METHODS	 32
	4.1.	EXPERIMENTAL SET-UP	 32
	4.2.	SPECIFICATIONS OF INSTRUMENTS	 33
	4.3.	METHODS	 37
	4.3.1.	Steam Consumption in Khoa, Ghee and Paneer Processing	 37
	4.3.2.	Condensate Recovery and Reutilization	 37
	4.4.	MEASUREMENT OF TEMPERATURE	 37
	4.5.	CALIBRATION OF THERMOCOUPLE	 38
	4.6.	LOCATION OF THERMOCOUPLES	 38
	4.7.	GROSS ENERGY CONSUMPTION AND HEAT LOSSES DURING KHOA, GHEE AND PANEER PROCESSING	 38
	4.7.1.	Indirect Energy	 39
	4.7.2.	Direct Energy	 39
	4.8.	SAVING IN STEAM CONSUMPTION	 39
	4.9.	CALCULATION OF HEAT TRANSFER COEFFICIENT	 40
	4.10.	PRODUCT ANALYSIS	 40
	4.10.1.	Fat Content of Milk and Cream	 40
	4.10.2.	Moisture Content of Milk, Khoa and Paneer	 40
	4.10.3.	Moisture Content of Cream and Ghee	 41
	4.11.	OBSERVATION	 41
CHAPTER	5.	RESULTS AND DISCUSSION	 51
	5.1.	ENERGY CONSUMPTION, HEAT LOSSES, CONDENSATE RECOVERY AND REUTILIZATION IN KHOA PROCESSING	 51

			PAGE
	5.1.1.	Energy Consumption and Heat Losses	51
	5.1.2.	Condensate Recovery and Reutilization	53
	5.2.	ENERGY CONSUMPTION, HEAT LOSSES, CONDENSATE RECOVERY AND REUTILIZATION IN GHEE PROCESSING	55
	5.2.1.	Energy Consumption and Heat Losses	55
	5.2.2.	Condensate Recovery and Reutilization	57
	5.3.	ENERGY CONSUMPTION AND HEAT LOSSES IN PANEER PROCESSING	59
	5.4.	GROSS ENERGY CONSUMPTION	59
	5.5.	TEMPERATURE DISTRIBUTION CURVES FOR KHOA, GHEE AND PANEER	61
	5.5.1.	Khoa	61
	5.5.2.	Ghee	61
	5.5.3.	Paneer	62
	5.6.	HEAT TRANSFER CHARACTERISTICS DURING KHOA PROCESSING	62
	5.7.	HEAT TRANSFER CHARACTERISTICS DURING GHEE PROCESSING	63
CHAPTER	6.	SUMMARY AND CONCLUSIONS	65
	6.1.	SUMMARY	65
	6.2.	CONCLUSIONS	68
CHAPTER	7.	SUGGESTIONS FOR FUTURE WORK	69
CHAPTER	8.	BIBLIOGRAPHY	i-vi
		APPENDICES	A-B

LIST OF TABLES

TABLE	TITLE	PAGE
2.1.	Energy use profile in Indian Dairy Industry	9
2.2.	Energy losses in Indian Dairy Plants	12
4.1.	Observations: Khoa processing	43
4.2.	Observations: Khoa processing	44
4.3.	Observations: Khoa processing	45
4.4.	Observations: Ghee processing	46
4.5.	Observations: Ghee processing	47
4.6.	Observations: Ghee processing	48
4.7.	Observations: Paneer processing	49
4.8.	Observations: Condensate Recovery and Reutilization	50
5.1.	Energy consumption and heat losses in khoa processing	52
5.2.	Energy conservation with condensate reutilization with vaporizer and with insulated steam pipe in khoa processing	54
5.3.	Energy consumption and heat losses in ghee processing	56
5.4.	Energy conservation with condensate reutilization with vaporizer and with insulated steam pipe in ghee making	58
5.5.	Energy consumption and heat losses in paneer processing	60

LIST OF FIGURES

FIGURE	TITLE		PAGE
4.1.	EXPERIMENTAL SET-UP	.. ..	32
4.2.	CALIBRATION CURVE OF THERMOCOUPLE	.. ..	38
5.1.	STEAM CONSUMPTION AT DIFFERENT PRESSURES	.. ..	53,57
5.2.	VARIATION OF % SAVING IN STEAM CONSUMPTION WITH INSULATED STEAM PIPE VS. STEAM PRESSURE	.. ..	53,57
5.3.	% HEAT LOSS AND % HEAT UTILIZATION VS. STEAM PRESSURE (FOR KHOA)	.. ..	53
5.4.	VARIATION OF % ENERGY SAVING AND HEAT LOSS VS. STEAM PRESSURE (FOR KHOA)	.. ..	53
5.5.	% HEAT LOSS AND % HEAT UTILIZATION VS. STEAM PRESSURE (FOR GHEE)	.. ..	57
5.6.	VARIATION OF % ENERGY SAVING AND HEAT LOSS VS. STEAM PRESSURE (FOR GHEE)	.. ..	57
5.7.	GROSS ENERGY CONSUMPTION	.. ..	61
5.8.	TIME TEMPERATURE DISTRIBUTION DURING KHOA PROCESSING	.. ..	61
5.9.	TIME TEMPERATURE DISTRIBUTION DURING GHEE PROCESSING	.. ..	61
5.10.	TIME TEMPERATURE DISTRIBUTION DURING PANEER PROCESSING	.. ..	62
5.11.	HEAT TRANSFER CHARACTERISTICS FOR KHOA PROCESSING	... ..	63
5.12.	HEAT TRANSFER CHARACTERISTICS FOR GHEE PROCESSSING	.. ..	64

LIST OF SYMBOLS

SYMBOL	INTERPRETATION	UNIT
A	Area of heating surface	m^2
C	Coefficient	-
C_p	Specific heat	Kcal/kg.°C
D	Diameter	m
g	Acceleration due to gravity	m^2/sec
h	Convection heat transfer coefficient	Kcal/m^2hr-°C
h_p	Heat transfer coefficient of product	Kcal/m^2-hr-°C
h_s	Heat transfer coefficient of steam	Kcal/m^2-hr-°C
h_{fg}	Latent heat of vaporization	Kcal/kg
h'_{fg}	Modified latent heat of vaporization	Kcal/kg
K	Thermal conductivity	Kcal/m-hr-°C
L	Length of surface	m
m	Constant	-
m_w	Weight of moisture evaporated	kg
M	Mass	kg
n	Constant	-
Q	Heat transfer rate	Kcal/hr
Q_c	Heat loss due to convection	Kcal
Q_p	Heat of initial product	Kcal
Q_{ps}	Heat loss from product surface	Kcal
Q_r	Heat loss due to radiation	Kcal

SYMBOL	INTERPRETATION	UNIT
Q_s	Heat in steam	Kcal
Q_v	Heat utilized	Kcal
S	Specific heat	Kcal/kg.°C
t	Temperature	°C
T	Absolute temperature	°K
U	Overall heat transfer coefficient	Kcal/m^2-hr-°C
x	Dryness fraction of steam	kg/kg
X	Thickness	m
ρ	Density	kg/m^3
Δt_m	Log mean temperature difference	-
	Greek Alphabetes	
α	Angle of inclination	Degree
β	Coefficient of thermal expansion	/°C
Δ	Gradient	-
ϵ	Emissivity of body	-
θ	Angle of inclination	radian
μ	Absolute viscosity	kg/m-sec.
ν	Kinematic viscosity	m^2/sec
σ	Stefan Boltzman constant	Kcal/m^2-hr-°K

Suffix

a	-	Air	Cr	-	Critical
f	-	Fluid	g	-	gas
i	-	Initial	k	-	Khoa
o	-	Final	p	-	Product
s	-	Steam	v	-	Vapour
w	-	Wall	α	-	Ambient

LIST OF ABBREVIATIONS

Gr.	:	Grashof number
Nu.	:	Nusselt number
Pr.	:	Prandtle number
Ra.	:	Rayleigh number
Re.	:	Reynolds number

CHAPTER I

INTRODUCTION

1. INTRODUCTION

The dairy industry is developing at a rapid rate in our country. Almost in each state in our country dairy development in organised sector is taking place. With the expansion of dairy industry and other industries apart from mechanisation of agriculture in our country and mobility of peoples, the energy consumption has also increased tremendously. Though the Government is taking all necessary steps to enhance the generation of hydel/thermal electric power and oil/coal exploration to meet the increasing demand for more energy which is a necessity for a fast developing nation, yet the industry has to be energy conscious. In the recent past a lot of emphasis has been given to develop suitable mechanisms and gazets for utilizing alternative energy sources such as solar energy, biogas and wind power etc.

Due to the scarcity of fuel/oil, the dairy and food processing industry which consumes a large amount of such fuels for processing their products, have to become energy conscious. Otherwise due to constant increase in prices of fuel, the processing cost will also go on increasing in the same proportion. This will result in great hardship to the public because a stage would come when the prices of necessary commodities such as milk will be beyond their purchasing power. Therefore, to avoid such a situation, all necessary efforts have to be made to conserve energy to the maximum extent possible in processing. We have to collect a lot of data on energy consumption for manufacturing indigenous milk products such as khoa, ghee and paneer etc. The various heat losses during processing have to be estimated so that necessary precautions and modifications may be made in the processing equipments/techniques to minimise heat losses so as to achieve energy conservation in processing.

The indigenous milk products like khoa, ghee and paneer etc. are manufactured normally in jacketed vats as batch process. Therefore, to make these processes continuous, hygienic and economical, it is absolutely necessary to design and develop the continuous equipment for manufacture of these products. As the raw material is to be heated during processing for these products, therefore before designing the continuous equipments a lot of information is to be collected regarding the heat and flow characteristics of these products. The heat transfer coefficients of different products vary with temperature, composition, physical and thermal properties of the products at various stages during processing. A very little information is available in literature on heat transfer and heat transfer characteristics of indigenous milk products.

1.1. CONCEPT OF ENERGY CONSERVATION

The consumption of conventional energy sources has increased considerably due to automisation and mechanisation of various processes.

Electrical or thermal energy is required in each stage of milk product processing. Therefore, the utilization of techniques for energy conservation is very essential for keeping the processing cost to the minimum. Energy conservation can be achieved by reducing the heat losses and by increasing the efficient use of the waste heat. The optimisation of the available resources and sustaining reasonable levels of economic activity will help in energy conservation. The energy conservation technique proposed to be adopted must be technically and economically feasible and should not conflict with the present mode of processing.

There is very little information available on the energy requirements for indigenous dairy products. Therefore, it is necessary to first collect enough data on energy requirements and losses during processing of khoa, ghee and paneer. Then various alternatives can be adopted for energy conservation as suggested below:

1) By evaluating the energy utilisation efficiency of different processing plants or processing techniques and then adopting the process which is most energy efficient. If necessary, certain modifications in the processing technique may be made.

2) To evaluate the energy losses during processing and adopt techniques to minimise the same.

The following are some of the major energy conservation measures which could be evaluated and adopted by dairy industry:-

i) Condensate heat recovery.

ii) Heat recovery/recycle of hot water from pasteuriser.

iii) Heat recovery from exhaust air/flue gases.

iv) Heat recovery from vapours.

v) Insulation of process equipments, pipe lines and buildings.

vi) Heat recovery from refrigeration plant.

vii) Upgrading the efficiency of process and service equipments.

viii) Utilization of alternative energy sources namely, solar energy, energy from gobar gas.

1.2. CONCEPT OF HEAT TRANSFER MECHANISM

In dairy processing, the heating and cooling of the product is to be done at different stages during its manufacture. Thus this is one of the most important unit operation in dairy processing. The heat transfer takes place by all the three modes i.e. conduction, convection and radiation. In solid dairy products such as cheese, paneer, butter etc. heat transfer takes place by conduction. In liquid products such as ghee, fluid milk, whey etc. the heat transfer may take place by convection or by a combination of convection and radiation. However, within the fluid milk heat transfer by convection is more predominant in comparison to conduction. The heat transfer by convection within the fluid is dependent on the type of the system. If external forces such as pump, agitator etc. are used for the fluid to flow during processing the phenomenon is known as forced convection heat transfer. However, if the fluid flow is caused by density difference due to the temperature gradient the phenomenon is known as free or natural convection. During conversion of milk to khoa and paneer and cream to ghee, the fluid product is heated thus the heat transfer by convection is more predominant in these cases.

The heat transfer by convection from a solid surface to fluid is denoted by:

$$Q = h_c A.(T_s - T_d) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.1)$$

The value of h_c for these products can be determined either by Reynold's analogy or by dimensional analysis. The technique of dimensional analysis is convenient to be adopted for formulating the empirical relations for these products. They are given below:-

$$Nu = c\,(Re)^m\,(Pr)^n \quad - \text{(Forced convection)} \quad \ldots\ldots\ldots\ldots (1.2)$$

$$Nu = c\,(Gr.\ Pr.)^m \quad - \text{(Natural convection)} \quad \ldots\ldots\ldots\ldots (1.3)$$

Where, c, m and n are constants which are evaluated from experimental data.

*****

CHAPTER 2

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1. INTRODUCTION

The energy crisis is an universal phenomenon and the availability of non-renewable energy sources is limited. Therefore, there is necessity for critical evaluation of the energy requirements, losses and conservation techniques of the various unit operations in a processing plant. When the processing equipments were designed, the energy was plentiful, however now it is becoming expensive to operate at current energy costs which is increasing continuously and may touch the peak in near future. Hence, the various unit operations in a dairy plant must be critically analysed in terms of energy requirements.

Energy analysis of operation of the production of khoa, ghee and paneer is useful in two respects:-

1) It provides quantitative information on energy requirements of use in designing the energy generating and delivery system.

2) It evaluates the modes of energy losses and approaches adopted and suggested by different workers on energy conservation in dairy processing.

2.2. ENERGY REQUIREMENT, HEAT LOSSES AND CONSERVATION TECHNIQUES IN DAIRY PROCESSING

2.2.1. Energy Consumption

To carry out the energy conservation phenomena the total energy consumption as well as the sources of heat losses should be known. The following information in this respect is available in the literature.

Flink (1977) studied the energy consumption during dehydration processes of milk and found that energy required for spray drying is about 587 Kcal/kg water evaporated and for drum drying 618 Kcal/kg water evaporated.

Schwartzberg (1977) investigated the energy requirements for liquid food concentration as given below:-

Product	Annual production billion lbs	Water evaporated billion lbs	Energy required trillion BTU
Skim milk	0.445	0.26	3.08
Condensed milk	0.758	3.65	1.46
Evaporated milk	0.291	4.70	1.87
Whey	0.82	13.27	3.32
Dry whole milk	0.071	0.29	0.12
Dry butter milk	0.038	0.28	0.11

Goel (1978) carried out an extensive study on the energy use profile in Indian Dairy Industry, as shown in Table 2.1. Davis (1980) found that processing energy needed on a raw weight basis is 0.60 MJ/kg milk processed, whereas Elsy (1980) found it to the range of 0.99 MJ/ litre milk.

As far as indigenous dairy products are concerned, very limited information is available regarding energy requirement in khoa, ghee and paneer making. Sham Das et al. (1976) has studied steam requirement in ghee clarification from cream and butter. They observed that steam requirement varies as moisture per cent in butter varies from 11.5 to 16%. The average steam consumed is reported to be 0.48 kg/kg butter and 243 Kcal/kg ghee. Abichandani (1978) conducted the feasibility studies on direct contact heat exchanger for clarification of ghee from butter using hot nitrogen gas. He observed 132 Kcal/kg butter when clarification temperature was 115°C. It is also reported that the steam and electrical energy requirement in continuous ghee making machine per kg butter are 0.35 kg and 0.01 KWH, respectively.

Pandya (1978) reported that in cream butter method, the steam requirement varies from 0.34 to 0.39 kg/kg butter, 0.42 kg/kg ghee and 2.79 kg steam/kg water evaporated equivalent to 184.5, 218.7 and 1442.5 Kcal respectively. He also observed that the electrical and thermal energy required for converting milk into ghee in different methods are as follows:-

Goel, 1978

Table 2.1 : Energy Use Profile in the Indian Dairy Industry.

Source	Energy Use in BTU/LB Milk Processed					
	Plant A	Plant B	Plant C	Plant D	Plant E	Plant F
Direct Energy	926	804	3,637	3,086	1,818	3,309
Boiler	255	446	3,187	1,899	1,298	2,571
Electricity	669	351	437	1,181	517	734
Water	2	6	13	5	3	5
Indirect Energy						
Packaging	0	176	246	386	1,269	841
Transportation	281	143	268	123	247	284
Procurement	170	135	225	100	170	195
Distribution	111	8	43	23	77	83
Process Energy	1,207	1,123	4,152	3,597	3,335	4,389

Plant		Manufacturing	Plant		Manufacturing
A	-	Std. milk, toned milk, double-toned milk.	B	-	Std. milk, toned milk, lassi, ghee.
C	-	Milk powder, butter, ghee.	D	-	Milk powder, butter, ghee, fluid milk.
E	-	Milk powder, butter, ghee, fluid-milk, cheese, baby food.	F	-	Baby food, milk powder, fluid milk, butter, ghee.

Deshi method	-	1710 Kcal/kg ghee.
Direct cream method	-	1325 Kcal/kg ghee.
Cream butter method	-	414 Kcal/kg ghee.

Mregendra Kumar and Verma (1983) investigated that the energy requirement for khoa making is 1.06 to 1.3 kg steam/kg milk and for converting butter into ghee it is 0.59 to 0.68 kg/kg butter.

2.2.2. Energy Loss

A considerable amount of heat is lost during manufacture of dairy products. The major sources of heat losses are buildings, equipment surface, pipe lines and hot water. Studies aimed at determining the magnitude of energy losses in dairy processing are important because they can be used to develop energy conservation programme.

Sampson (1953) reported that only 16.7 per cent of the steam supplied to the stationary retort was used in heating the can and contents. The remainder was lost as follows: 36.4 per cent passed out of vents, 16.4 per cent was used to heat the retort and crates, 11.2 per cent was used to heat the condensate in the botton of the retort, and 19.3 per cent was lost through radiation.

Rippen (1974) observed that a single-pane window will lose 1.13 BTU/hr-ft^2 of glass per 1^{o}F. He also observed that a bare 2 inch uninsulated steam pipe of 100 ft length operating at 100 psi will lose 1,250,000 BTU in 24 hours. Helamma (1975) has reported 14 per cent energy loss in a dairy was due to heat losses from buildings. Goel (1978) observed that the heat losses from dairy buildings ranged from 2.6 to 21.6% of boiler energy consumption.

Dave et al. (1979) observed that the heat losses through exhaust air were 24.7% of total heat added to a spray drier. Rao et al. (1976) has studied that the heat losses from preheater, cooler in different food processing plants. The heat losses in condensate was 13.6 to 21.6% and losses from equipment by convection and radiation was 2.0 to 2.8%.

Rao et al. (1976b) observed that heat losses with hot water varies from 13 to 22 per cent. Flink (1977) reported that about 20-90 Kcal/kg of water removed of heat is lost with exit air from a spray drier and 2-7 Kcal/kg of water removed with exit product from a drum drier.

John (1977) reported that a 30 gallon jacketed pan, unlagged, taking steam at 60 psi, lost heat equivalent to 10 lb steam/hr, through its bare jacket.

Goel (1978) observed that energy losses through steam condensate, heat losses from uninsulated steam pipe, total loss from hot water steam and from pasteurizer are 840, 85 and 1,254 million BTU/ lb of milk processed. The observed values of different energy losses in Indian Dairy Plants are shown in Table 2.2.

McAdams (1954) has evaluated some dimensional equations as given below to find out the heat losses.

Table 2.2 : Energy Losses in Indian Dairy Plants.

Source	Energy Losses in Million BTU*					
	Plant A	Plant B	Plant C	Plant D	Plant E	Plant D
Boiler condensate	840 (7.9)	989 (7.6)	11,935 (7.9)	567 (2.7)	28,612 (7.4)	3,102 (7.9)
Pasteurizer	324 (3.0)	76 (0.6)	151 (0.1)	27 (0.1)	833 (0.2)	46 (0.1)
Vapours	-	-	2,336 (1.5)	361 (1.7)	11,312 (2.9)	649 (1.6)
Steam pipes	85 (0.8)	97 (0.7)	125 (0.1)	59 (0.3)	195 (0.1)	117 (0.3)
Milk pipes	5	3	10	15	46	8
Equipments	N.A.	27 (0.2)	1,539 (1.0)	1,284 (6.2)	9,652 (2.5)	1,400 (3.6)
Total	1,254 (11.7)	1,192 (9.2)	16,096 (10.6)	2,313 (11.2)	50,650 (13.1)	5,322 (13.5)

* Numbers in parenthesis are percentages of the corresponding losses expressed in boiler energy basis.

N.A - Not available.

(N.B. - Please refer Table 2.1 on page 9 for plants; A, B, C, D, E and F)

Goel

Geometry	Equation	Range of validity	
	For Process Equipment		
Horizontal cylinder	$h = 0.18\ (\Delta T)^{1/3}$	$10^9 \leq Gr.Pr. \leq 10^{12}$	.. (2.1)
Vertical cylinder	$h = 0.22\ (\Delta T)^{1/3}$	$2x10^7 \leq Gr.Pr. \leq 10^{10}$	.. (2.2)
	For Steam Pipeline		
Horizontal cylinder	$h = 0.27\ (\Delta T)^{0.25}$	$10^3 \leq Gr.Pr. \leq 10^8$	.. (2.3)
Vertical cylinder	$h = 0.29\ (\Delta T)^{0.25}$	$10^4 \leq Gr.Pr. \leq 10^9$	.. (2.4)

Rao and Katz (1976) have proposed a computer programme, named CNSRV to estimate heat losses from building, equipment surface, hot water and steam pipes. Singh (1977) outlined a method for accounting energy losses during sterilization. Singh (1978) formulated the energy accounting process to find out energy requirement as well as losses.

2.2.3. Energy Recovery and Conservation

The concept of energy conservation contributes towards alleviating the energy dilema. Conservation of energy in food production, processing and transportation has been the subject of several students.

2.2.3.1. Pasteurization:

On account of regeneration, there is saving in heating and cooling medium.

Walzholz (1957) has studied the heat energy requirement in different types of pasteurizing equipments with or without regeneration and observed that the steam requirement was 37, 25 and 20 kg at 65, 75 and 80% regeneration.

Andree (1974) observed 300 kg steam/hr and 220 kg steam/hr at 55 and 68% regeneration for a 4400 L/hr cheese milk pasteurizer. Heckenbury (1975) observed that using a heat pump with a 3 heat exchangers can save 21 to 25 per cent energy.

Leistra (1975a) reported that by installing a pre-heating section and larger regeneration section in a 40,000 L/hr H.T.S.T. pasteurizer saved 2780 tons of steam per hour in a cheese plant.

Rippen (1975) has reported that when the regeneration efficiency increased from 80 to 90%, the steam requirement is reduced to half.

Hille _et_ _al._ (1977) has reported the reduced steam consumption from 264 kg/hr to 189 kg/hr by increasing regeneration upto 90% in 10,000 L/hr HTST plant.

Rippen (1977) has reported a considerable energy saving by collecting steam condensate. The condensate obtained at 195°F, from HTST pasteurizer, is stored in an insulated tank at 130°F and used as wash water or as feed water of boiler.

Varshney et al. (1979) has designed a regeneration section of a HTST cream pasteurizer with 70% regeneration efficiency which saves 40% energy or Rs.210 per day.

2.2.3.2. Evaporation and Drying:

Jelson et al. (1975) observed that 80% of the steam requirement can be saved with a two stage compressor attached to a multiple effect evaporator. This could be increased to 90 - 100% when cooling water from the compressor engine was used to preheat the milk supply to the evaporator.

Kessler (1978) estimated that under optional conditions mechanical vapour compression in evaporator plants can give the same energy saving as would be achieved by increasing the number of effects to 15.

Morlok (1978) observed that the thermal economy can be achieved by recovery surplus heat from sterilized milk by means of a heat exchanger.

Varshney (1978) reported that use of mechanical vapour compressor with single effect evaporator is 9 times more economical in energy requirement than a 4 effect evaporator. He also observed that if a four effect evaporator is used to concentrate milk to 60% moisture, 150 Kcal/kg water evaporated is required whereas in conventional spray dryer, it is 1200 Kcal/kg water evaporated.

Annon (1979) observed that heat recovery by preheating the ingoing air to a drier using outgoing air in an air to air heat exchanger and save 20 - 25% steam consumption.

Dave et al. (1979) reported that steam consumption in a two stage drying plant is 15 - 20% lower as compared to equivalent conventional spray drying.

Vautrin (1979) observed using hot water instead of steam in cheese making and recovery of condensate from evaporators can save 20 - 25% thermal energy.

Christenser (1982) reported that a three effect evaporator with a heat pump gives energy saving of 98% and water saving of 94% compared with a single effect evaporator used without a heat pump.

2.2.3.3. Heat Recovery from Whey:

Leistra (1975b) reported savings in steam of about 2780 t/yr and savings in refrigeration (whey cooled to 8°C) of 232 million Kcal/yr by means of heat exchange between cheese milk and whey.

Bertay (1977) discussed about the possibilities for saving energy by heat recovered from concentrated whey (66°C) and from the condensate of steam evaporated from the whey (70°C), is used to heat the incoming whey from 5 to 48°C. Kalteneckar (1980) reported that by installing a heat exchanger before whey cooler, the heat in the whey is transferred to water as whey is cooled to 21°C. The amount of heat extracted from whey is 2.32 million Kcal/day.

2.2.3.4. Heat Recovery from Exhaust Air:

Varshney (1978) investigated that heat from exhaust air may be recovered by using a heat pump or dehumidifier and condenser coil.

It has been observed that by expanding 1 KW of electrical energy 6 KW worth of primary fuel can be saved.

Dave et al (1979) extracted heat from exhaust air reducing its temperature from 80 - 100°C and recovered heat is transferred to air entering the dryer increasing its temperature from 10-20°C to 60-80°C. A 30% saving in primary energy is achieved.

2.2.3.5. Heat Recovery by Condensate Reutilization:

Rippen (1974) observed that returning steam condensate to the boiler is economical from water treatment stand point and the higher temperature is a fuel saver. He also observed that increasing feed water temperature about 11°F, by condensate return, often improves boiler efficiency by 1%.

According to I.D.F. Annual Bulletin (1977) - rising the temperature of boiler feed water, by condensate return, by 6°C results in a 1% reduction in fuel bill.

Rao and Goel (1977) have suggested recycling of condensate either back to boiler or to heat input water can reduce the direct energy use by as much as 12%.

2.2.3.6. Use of Low Pressure Steam:

Rippen (1974) investigated that if processes do not require steam temperatures in excess of 240°F low steam pressure should be considered. He also suggested that one of the main items favouring low pressure steam is cost reduction and fuel consumption reduction. The comparative costs for operating low pressure and high pressure steam generation has been observed to be 3.5 dollars/1000 lbs steam and 6.0 dollars/1000 lbs steam.

Rippen (1976) reported that a fluid milk plant in Michigan State curtailed energy use by more than 13% by reducing the steam pressure to about 55 psi.

2.2.3.7. Insulation of Steam Pipe:

Rippen (1974) reported that heat losses are generally reduced with 1 to 2 inch of insulation on a steam pipe. In terms of money value the about 75% economy can be achieved by only 1 inch insulation.

2.2.3.8. For Indigenous Dairy Products:

Sharma <u>et al.</u> (1978) designed one electrically heated direct contact heat exchanger and found that the energy required is lowered by about 71 Kcal/kg butter as compared to conventional method.

2.3. HEAT TRANSFER CHARACTERISTICS

The knowledge of thermal properties and heat transfer characteristics of dairy products is the basic necessity for design of dairy equipments. With the variation in working parameters viz. temperature and evaporation the thermal properties of dairy products vary. A very little information is available regarding the heat transfer characteristics of indigenous dairy products, like khoa, ghee and paneer. Wilson

(1977) worked on the heat transfer characteristics of a product on the design of equipment. To get an idea regarding heat transfer characteristics of khoa, ghee and paneer, it is necessary to have knowledge about heat transfer coefficients of dairy product as well as of the heating mediums.

2.3.1. Heat Transfer Coefficient of Condensing Steam

For almost all parts of geometry enough information is available on the heat transfer coefficient of condensing steam.

Nusselt (1916) has given the correlation for heat transfer coefficient of pure condensing steam.

For vertical tube: $$\frac{h.L}{K} = 0.943 \left[\frac{L^3 . \rho^2 . g . h_{fg}}{K . \mu \, (t_{sv} - t_s)}\right]^{1/4} \qquad \text{..........(2.5)}$$

For horizontal tube : $$\frac{h.D}{K} = 0.725 \left[\frac{D^3 . \rho^2 . g . h_{fg}}{K . \mu \, (t_{sv} - t_s)}\right]^{1/4} \qquad \text{.........(2.6)}$$

For inclined surface: $$\frac{h.L}{K} = 0.934 \left[\frac{L^3 . \rho^2 . g . h_{fg} . \sin \theta}{K . \mu \, (t_{sv} - t_s)}\right]^{1/4} \qquad \text{........(2.7)}$$

The equation of laminar film condensation on a vertical plate given by Nusselt (1916) was corrected by Roshenow (1956). The modified equation is given as:

$$Nu = 0.707 \left[\frac{g . \rho_f \, (\rho_f - \rho_v) . h'_{fg} . L^3}{K . \mu . \, (t_{sv} - t_s)}\right]^{1/4} \qquad \text{.........(2.8)}$$

Sparrow and Gregg (1959) has corrected the equation given by Nusselt (1916) for vapour condensation on a horizontal pipe:

$$Nu_D = C\left[\frac{.g\,\rho_f.\;(\rho_f - \rho_g).h'_{fg}.D^3}{K.\,\mu\,(t_{sv} - t_s)}\right]^{1/4} \qquad \text{..........(2.9)}$$

Where $C = 0.733.$

Chen (1961) has corrected Sparrow and Gregg's (1959) analysis for vapour drag on the interface and obtained the presently accepted value of

$$C = 0.728$$

Lienbard and Dhir (1971) has reported the heat transfer coefficients for condensing steam on sphere in laminar film condensation as

$$Nu = 0.785\left[\frac{g\,.\,(\rho_f - \rho_g).h'_{fg}.D^3}{K.\mu\,(t_{sv} - t_s)}\right]^{1/4} \qquad \text{.........(2.10)}$$

Where, $h'_{fg} = h_{fg} + 0.68\ C_p.T$

Yang (1973) has reported the heat transfer coefficient for laminar film condensation over spheres for Prandtl number between 0.03 to 100.

$$Nu = C\left[\frac{g.\,(\rho_f - \rho_g).h_{fg}.D^3}{K.\mu\,(t_{sv} - t_s)}\right]^{1/4} \qquad \text{.......(2.11)}$$

Where,

$C = 1.098$ - for upper stagnation point.

$C = 1.032$ - for average Nu. over upper hemisphere.

$C = 0.803$ - for average Nu. over the entire sphere.

2.3.2. Thermodynamic Expression for Heat Transfer in Free - Convection

In natural convection heat transfer, the flow of fluid is reduced by difference in fluid density influenced by temperature gradient and the development of a bucyant force. Under these conditions, the fluid motion is described in terms of the Grashof number (Gr.).

$$Gr. = \frac{B.g.L^3.\rho^2.\Delta t}{\mu^2} \qquad \ldots\ldots\ldots\ldots(2.12)$$

The free convection in the form of dimensionless quantities is given as one group as a function of other two dimensionless groups. Thus Nusselt number is a function of Grashof number and Prandtl number.

$$Nu = C\,(Gr.Pr.)^m \qquad \ldots\ldots\ldots\ldots(2.13)$$

Nusselt (1916) has verified this equation in his experiment on the natural cooling of horizontal cylinder in atmospheric air.

Based on measurements of the temperature of the air at various locations, Schmidt and Beckman (1930) derived the following equation for short plate less than 2 feet high.

$$Nu = 0.52\,(Gr.Pr.)^{1/4} \qquad \ldots\ldots\ldots\ldots(2.14)$$

King (1932) has recommended the following dimensionless equation for the heat transfer coefficient in the natural convection for a vertical plate or cylinder to a fluid.

$$\frac{h_c L}{K_f} = C \left[\frac{L^3 \cdot \rho_f^2 \cdot g \cdot \beta_f (t_w - t_a)}{\mu_f^2} \left(\frac{\mu C_p}{K_f} \right) \right]^n \quad \text{........(2.15)}$$

Or, $\frac{h_c L}{K_f} = C.X^n$

Where,

$X = 3.5 \times 10^7$ to 10^{12}, $C = 0.13$, $n = 0.333$,

$X = 3.5 \times 10^7$ to 10^4, $C = 0.55$, $n = 0.25$

For a block, the heat transfer coefficient is expressed by same equation but the characteristic length 'L' is taken as

$$\frac{1}{L} = \frac{1}{L_{vertical}} + \frac{1}{L_{horizontal}} \quad \text{.......(2.16)}$$

Eckert (1951) derived a theoretical relation for vertical planes

$$\frac{h_c L}{K_f} = 0.68 \left[\frac{Pr_f}{0.952 + Pr_f} \right]^{1/4} (Pr._f \, Gr._f)^{1/4} \quad \text{.......(2.17)}$$

This equation agrees with experimental results for gases and liquids.

For turbulent, free convection over a vertical plane, Eckert (1951) has derived the equation.

$$Nu = 0.024 \left[\frac{Pr.^{1.17}}{1 + 0.494 \, Pr^{2/3}} Gr \right]^{2/5} \quad \text{.......(2.18)}$$

This equation satisfies the experimental data at Grashof number more than 10^{10}.

McAdams (1954) obtained extensive data for free convection. The values for the constants recommended by him in the Nusselt's equation, $Nu = C\,(Pr.Gr.)^m$ are below for vertical plate and cylinder.

Gr.Pr.	C	m
10^4 to 10^9	0.59	1/4
10^9 to 10^{12}	0.12	1/3
More than 10^{12}	0.13	1/3

For horizontal cylinder at uniform temperature

Gr.Pr.	C	m
10^4 to 10^9	0.53	1/4
10^9 to 10^{12}	0.13	1/3

For horizontal plate at uniform temperature

Plate	Gr.Pr.	C	m
Upper surface heated,	10^5 to $2x10^7$	0.54	1/4
Upper surface heated,	$2x10^7$ to $3x10^{10}$	0.14	1/3
Lower surface heated,	$3x10^5$ to $3x10^{10}$	0.27	1/4

Van De Pol and Tierney (1973) reported the heat transfer coefficient in free convection over a vertical U shapped channel as

$$Nu_H = 0.595\ (Gr.Pr.)^{1/4} \qquad \text{............(2.19)}$$

Since the film coefficient for free convection to a vertical plate differs from that to a horizontal plate, it is easy to understand that the film coefficient for free convection to an inclined plate will vary with the angle of inclination.

Yung and Oetting (1969) studied heat transfer coefficient in case of inclined plate, hot side down, the average value of the laminar from convection heat transfer coefficient to air is given by equation.

$$Nu = 0.48\ \left(\frac{1 + \cos\alpha}{2}\right)\ (Gr_{L}.\alpha)^{1/4} \qquad \text{..........(2.20)}$$

Where,

$$Gr._L = g\ (T_s - T_\infty)\ \frac{L^3}{T_\infty . \nu^2}$$

α = angle of inclination.

Stewart, Jr. (1981) did experiments for heat transfer coefficient over inclined cylinder for angle α = 0 to 90°. The heat transfer coefficient can be obtained by the relation.

$$\frac{Nu_D}{(Ra_D.\cos\alpha)^{0.25}} = 0.53+0.555\left[\frac{D}{(D.\ \cos\alpha)^{0.25}} - \frac{D}{L}\right]^{0.25} \qquad \text{........(2.21)}$$

Al-Arabi and Salman (1980) has studied the heat transfer coefficient in laminar free convection over inclined cylinder. The general equation for average heat transfer for all angle between 0 to 90°, is given by equation.

$$Nu_L = 0.60 - 0.488(\sin\theta)^{1.03}(Gr_L\ Pr.)^{1/4+1/12(\sin\theta)^{0.75}} \qquad \text{.........(2.22)}$$

Al-Arabi and Khamis (1982) has determined the average and local heat transfer by natural convection from the outside surface of isothermal cylinders of different diameters and lengths at different inclination in both laminar and turbulent regions. The average Nusselt number in laminar natural convection is given by

$$Nu_L = \left[2.9 - 2.32(\sin\theta)^{0.8}\right](Gr._D)^{-1/12} \times (Gr_L\ Pr)^{1/4} + \frac{1}{12}(\sin\theta)^{1.2} \qquad \text{..........(2.23)}$$

for $1.08 \times 10^4 \leq Gr_D \leq 6.9 \times 10^5$

and $9.88 \times 10^7 \leq Gr_L Pr \leq (Gr_L.Pr)_{Cr}$

In turbulent region of $1.08 \times 10^4 \leq Gr_D \leq 6.9 \times 10^5$ and $(Gr_L\ Pr)_{Cr} \leq Gr_L\ Pr. \leq 2.95 \times 10^{10}$ for the range of angle 0 to 90°.

Where, $(Gr_L\ Pr)_{Cr} = 2.6 \times 10^9 + 1.1 \times 10^9$

Cr = Critical.

Geoola and Cornish (1982) has studied free convective heat transfer from a solid sphere to Newtonian fluid of Gr.No. between 0.05 to 12 500 and Pr.0.72, 10 and 100. The result obtained for average Nusselt number in above studies is given by equation

$$Nu = 2.0 + 0.39\,(Ra)^{0.42} \qquad \text{.............(2.24)}$$

for $0.05 \leq Gr. \leq 50$

$Pr. = 0.72$

and $$Nu = 2.0 + 0.75\,(Ra)^{0.25} \quad \text{for} \quad 36 \leq Ra \leq 125000$$

$$50 \leq Gr \leq 12500$$

$$0.70 \leq Pr \leq 100$$

Amato and Tien (1972) has developed an empirical relation for natural convection from an isothermal sphere to water as

$$Nu = 2.0 + 0.5\,(Ra_D)^{0.25} \qquad \ldots\ldots\ldots\ldots\ldots(2.25)$$

Yage (1960) has developed that the relation for natural convection heat transfer from sphere to atmosphere of infinite extent by equation.

$$Nu_D = 2.0 + 0.428\,(Ra_D)^{0.25} \qquad \ldots\ldots\ldots\ldots\ldots(2.26)$$

2.3.3. Heat Transfer Coefficient

Very little information is available on heat transfer characteristics in free convection for dairy products.

Peepless et al. (1962) investigated the forced convection heat transfer characteristics for few dairy products and has given separate equation in the form of Nusselt number, Reynold number and Prandtl number. He has also given a single equation for different types of dairy products.

$$K\,(Nu/Pr.^{0.4})^{Z} = 0.11\,Re^{0.395} \qquad \ldots\ldots\ldots\ldots(2.27)$$

Where,

$$K = \log \frac{(D+E-F)-0.853)}{0.467}$$

$$Z = \frac{P}{E.N.+B.O}$$

B = % fat

D = $(\% \text{ fat})^{0.364}$

E = % SNF

F = $0.8 (\%\text{SNF})^{4} (\% \text{ Fat})^{0.165}$

P = % total solids

N = 2.54 log (%SNF) - 1.04

O = 0.97 log (% fat) + 0.94

Vinogradov (1962) has studied heat transfer coefficient in cooling system of high butter fat cream thin layer and observed the same to be 150 - 275 Kcal/m^2-hr-°C. Modification in the system is done by providing jacketed channel with scraper rotar arrangement which gives the value of film coefficient more than 1000 Kcal/m^2-hr.°C. It shows considerable improvement in the cooling rate of high fat cream and other viscous dairy products.

Shillo and Zolotion Yu (1973) has studied the coefficient of heat transfer in plate evaporator using water as test liquid at boiling temperature of 50, 55, 60 and 65°C. The coefficient increases with increase in the pressure on the steam resulting from evaporation of the liquid and with an increase in the temperature difference between heating steam and boiling liquid.

Sayana and Verma (1975) studied forced convection heat transfer characteristics of butter during its conversion into ghee. The observed film co-efficient of butter vary with fat percentage. The Nusselt type equations developed are

84 - 86% fat - $Nu = 0.00975\ Re^{0.89}\ Pr.^{0.4}$ ....(2.28)

87 - 86% fat - $Nu = 0.0042\ Re^{1.01}\ Pr.^{0.4}$ ....(2.29)

95 - 97% fat - $Nu = 0.00106\ Re^{1.10}\ Pr.^{0.4}$ ....(2.30)

Agrawala and Ojha (1976) studied the heat transfer coefficient in single tube single effect falling film evaporator. The heat transfer coefficient increases with increase in preheating temperature and with decrease in temperature difference. Heat transfer coefficient for milk were just half of sucrose solution under similar conditions.

Konstantinov (1976) has observed the heat transfer coefficient during boiling of skim milk, whey, sugar solution in closed circuit channels with natural circulation. At various concentration of milk (10, 30, 50%) and various heights of the solution in circular channel, under atmospheric and vacuum condition. The heat transfer coefficient drops with increasing concentration of the liquid being evaporated.

Verma and Verma (1978) developed the equation given below to determine the free convection heat transfer coefficient of buffalo milk during agitation.

$Nu = 0.55\ (Gr.Pr.)^{0.29}$ ....(2.31)

Rajendra Kumar and Verma (1980) have studied film coefficient of heat transfer of milk during cooling. The equations developed for different types of milk are -

$$Nu = 0.104\ (Gr.Pr.)^{0.239} \text{ - for skim milk.} \qquad \ldots\ldots\ldots\ldots(2.32)$$

$$Nu = 0.545\ (Gr.Pr.)^{0.302} \text{ - for standard milk (3.5\% fat)} \qquad \ldots\ldots\ldots\ldots(2.33)$$

$$Nu = 0.486\ (Gr.Pr.)^{0.306} \text{ - for cow milk} \qquad \ldots\ldots\ldots\ldots(2.34)$$

$$Nu = 0.241\ (Gr.Pr.)^{0.246} \text{ - for buffalo milk.} \qquad \ldots\ldots\ldots\ldots(2.35)$$

*****

CHAPTER 3

OBJECTIVES AND SCOPE

3. OBJECTIVES AND SCOPE

3.1. OBJECTIVES

The objectives of the present work are to study the following:

1) To estimate energy consumption in processing of khoa, ghee and paneer.
2) To identify and estimate energy losses in processing operations of khoa, ghee and paneer.
3) To evaluate the gross thermal energy requirement from milk production to finished product, for khoa, ghee and paneer.
4) To study the feasibility of energy conservation techniques considering technological and economical aspects.
5) To study the heat transfer characteristics of milk during conversion into khoa.

6) To study the heat transfer characteristics of cream during conversion into ghee.

3.2. SCOPE

There is necessity to design and develop equipments for continuous manufacture of khoa, ghee and paneer. In most of the dairy plants in the country these products are manufactured as a batch process. For designing of suitable heat exchangers, to be used in continuous equipments, the information on energy requirement, heat losses, heat and flow characteristics of these products have to be studied thoroughly. There is very few documented information, on any of these aspects, available in the literature.

The present study is for collecting data on energy requirement, heat losses, heat transfer characteristics and feasibility studies on reutilization of the condensate leaving the processing vessel. The data is collected with variation in steam pressure to exactly understand the impact of same on overall energy consumption and losses etc. The information collected on heat transfer characteristics of khoa, ghee and paneer will prove to be very useful in optimising the design of heat exchangers to be used for these products. The effect of application of suitable insulation on the pipes and vessel etc. will be helpful in design and layout of these equipments. The information collected in the present study will prove beneficial in attempts to be made in the dairy industry for conservation of energy.

*****

CHAPTER 4

MATERIALS AND METHODS

4. MATERIALS AND METHODS

4.1. EXPERIMENTAL SET-UP

The experiments for studying the steam consumption, heat losses, condensate reutilisation, temperature distribution and heat transfer characteristics for khoa, ghee and paneer processing were carried out in a jacketed stainless steel vessle. The complete experimental set up has been shown in Figure 4.1. The flow of steam was regulated with the help of valve (1) provided in the steam line. Pressure gauges (2) and (3) were provided to measure the steam pressure accurately. Air vent valve (4) was provided for removing air and non-condensable gases from the system during initial stages of operation. A steam trap (5) and two-way valve (6) were provided in the condensate line from the vat to the condensate collection tank (7) on which one graduated water level indicator (8) and air-vent (9) were provided. The condensate from the storage tank was pumped with the help of pump (10) to the vaporiser (11). Valve (12) was provided in the line between the pump and vaporiser to regulate

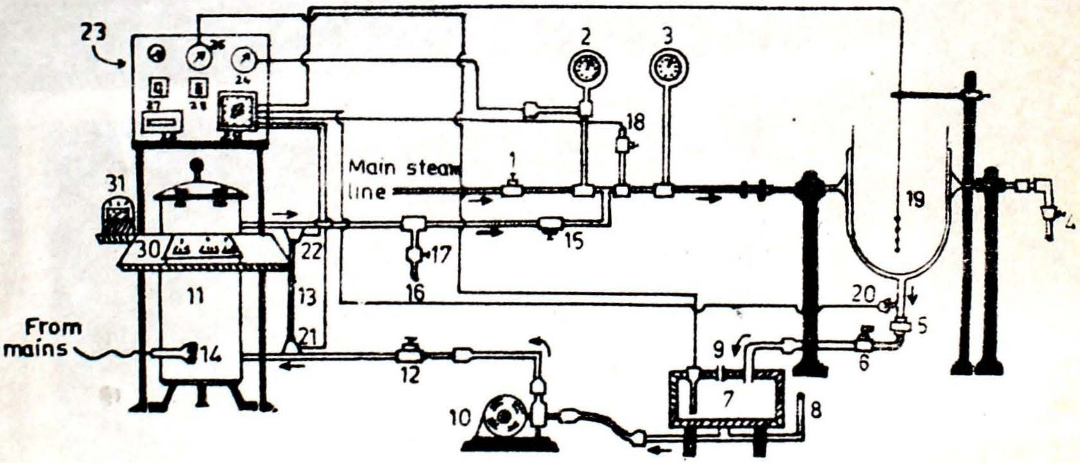
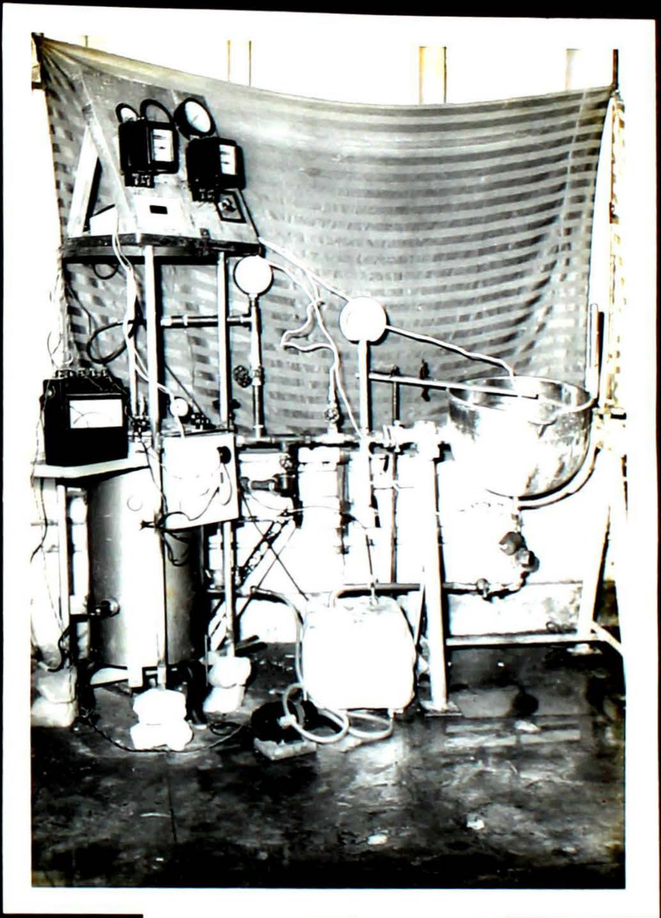


FIG. 4.1. SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SET-UP

1, 4, 12, 15, 17	- Valve	9, 16	- Air vent.	26	- Millivolt meter
2, 3	- Pressure gauge	10	- Pump	27, 28	- Energy meter
5	- Steam trap	11	- Vaporizer	29	- Selector switch
6	- Two way valve	14	- Electric heater	30	- Switch board
7	- Condensate collection tank (insulated)	18 to 22	- Thermocouple	31	- Wattmeter
		23	- Panel board		
8, 13	- Water level indicator	24, 25	- Dial thermometer		



EXPERIMENTAL SET-UP.

the flow of condensate. Water level indicator (13) was provided in the vaporizer to measure the level of condensate. An electrical heater (14) was provided to heat the condensate for converting into steam. The steam from vaporizer is taken to the main steam line and a valve (15) was provided in between for regulating the flow of steam from the vaporizer. Air-by-pass vent (16) alongwith valve (17) was provided in the steam line from vaporizer to the main steam line. Thermocouples (18),(19), (20), (21) and (22) were provided to measure the temperature of steam, product temperature at different layers during processing, temperature of steam and condensate leaving the vat, temperature of condensate during pumping and temperature of steam leaving the vaporizer. A panel board (23) with dial thermometer (24) and (25), digital milli-volt-meter (26), energy-meter (27) and (28) and selector switch (29) were provided for measurement of temperatures of steam in main pipe line and of condensate in condensate storage tank, for measurements of millivolts and KWH. Switch board (30) was used for controlling pump, heater, millivolt-meter etc. As the energy consumption by the pump was very less, hence for the sake of accuracy one wattmeter (31) was also provided in the system for comparison and accurate measurements.

4.2. SPECIFICATIONS OF INSTRUMENTS

The specifications of the instruments used for experiments and calibration are given below:-

i) Dial Thermometer

a) Make	-	JAPSIN
Type	-	Probe type
Range	-	50 to 200°C.
b) Make	-	ESKAY
Type	-	Probe type
Range	-	0 to 150°C.

ii) Digital Thermometer

Make	-	Vaiseshika Electron Devices.
Sr. No.	-	1017
Range	-	50 to 200°C
Supply	-	9 volts D.C.

iii) Digital Milli-volt Meter

Make	-	Aplab
Model	-	1007
Precision	-	0.01 mv.
Range	-	± 99.99 mv.
Mains	-	230 v/50 Hz.

iv) Energy Meter

Make	-	METERS & INSTRUMENTS LTD.
Type	-	TK2 (Single phase 2 wire)

Volts	-	240
Amps	-	5 (Max 10)
Frequency	-	50 Hz.
REVS/KWH	-	1200

v) Milli-volt Recorder

Make	-	KIPP and ZONEN
Type	-	BD41
Mains	-	115/220 v, -15% + 20%, 50/60 Hz.
Inaccuracy	-	0.3% fsd max.

vi) Pressure Gauge

a) Make	-	U.P.G.E.C.
Type	-	Bourdon Pattern
Range	-	0 to 3.5 kg/cm^2.
b) Make	-	FIEBIG
Type	-	Bourdon's Patent
Range	-	0 to 7.0 kg/cm^2.

vii) Selector Switch

Make	-	Toshniwal
Points	-	Twelve golden tipped.

viii) Tullu Pump

Make	-	U.P. National Mfrs.P.Ltd.
H.P.	-	0.05
Head	-	7.5 m.

Volts	-	230
L.H.P.	-	364

ix) Vaporizer

Make	-	INDIAN EQUIPMENT CORPORATION
Type	-	JEC - 232
Sr.No.	-	530
KW	-	2.
Phase	-	Single.

x) Variable Resistance Heater

Make	-	Precision Scientific Co.
Cat. No.	-	61561
Ser. No.	-	10-R-12
Mains	-	240 V, AC/DC
Power consumption	-	550 watts.

xi) Wattmeter

Make	-	Automatic Electric Pvt. Ltd.
Model	-	DVS/1005
Class	-	2.5
Range	-	0 to 150 watts.
Supply	-	AC/DC.

4.3. METHODS

4.3.1. Steam Consumption in Khoa, Ghee and Paneer Processing

The steam consumed in khoa, ghee and paneer processing was measured by collecting condensate leaving the jacketed vat during processing. The condensate was collected in the insulated storage tank, to which condensate flows under gravity and the flow was regulated by observing the water level indicator at regular intervals. The steam pressure, steam temperature, and condensate temperature leaving the vessel were also observed. During each trial the steam pressure was kept constant.

4.3.2. Condensate Recovery and Reutilization

When sufficient amount of condensate was accumulated in the collection tank, after measuring the condensate temperature, it was pumped to the vaporizer. The condensate was heated in the vaporizer. When the steam pressure in the vaporizer attains the desired pressure, the main steam supply was stopped and steam from vaporizer is supplied to the vat. The remaining heating for processing of khoa and ghee was carried out by supply of steam from vaporizer.

4.4. MEASUREMENT OF TEMPERATURE

The measurement of temperatures at different layers of the product was done by calibrated thermocouples, which has advantages of accurate and instantaneous measurement. It is easy to use thermocouple even at inaccessible position. Copper-constantan (22 gauge) wire was used for the thermocouples.

4.5. CALIBRATION OF THERMOCOUPLE

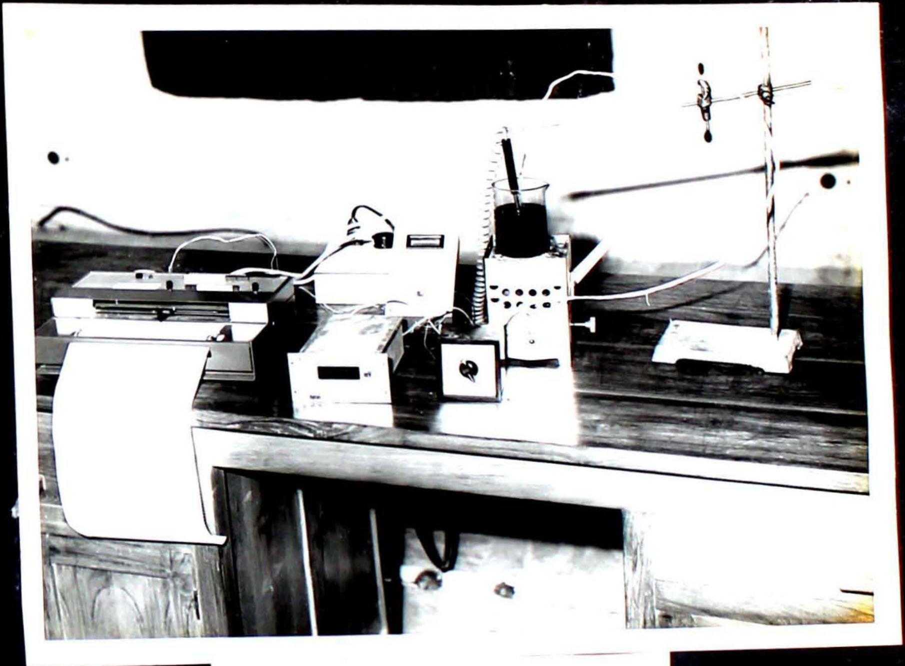
Paraffin oil was used for calibration of thermocouples. The fused junctions of the thermocouples, bulbs of mercury-in-glass-thermometer and probe of digital thermometer were clamped together at the same height and immersed in the oil. The terminals of the thermocouples were led to the digital milli-voltmeter through the selector switch. The millivolt recorder was also connected to the millivolt meter. The oil is heated gradually by variable heater provided for this purpose. Observations were taken during heating as well as during cooling. The calibration curves were drawn with mean value. All the thermocouples used, for measuring steam temperature, product temperature, condensate temperature; during the study were calibrated and calibration curves were drawn and one of those curves is shown in Figure 4.2.

4.6. LOCATION OF THERMOCOUPLES

To study the temperature distribution during heating, four thermocouples were arranged at 0.5 cm, 2.5 cm, 4.5 cm and 6.5 cm, respectively from the bottom with the help of a wooden support. The arrangement of thermocouples was made in such a way that they can be put at proper places when required. This facilitated required amount of agitation necessary during khoa, ghee and paneer processing.

4.7. GROSS ENERGY CONSUMPTION AND HEAT LOSSES DURING KHOA, GHEE AND PANEER PROCESSING

The gross energy consumption for khoa, ghee and paneer processing has been divided into two parts as given below:



CALIBRATION OF THERMOCOUPLE

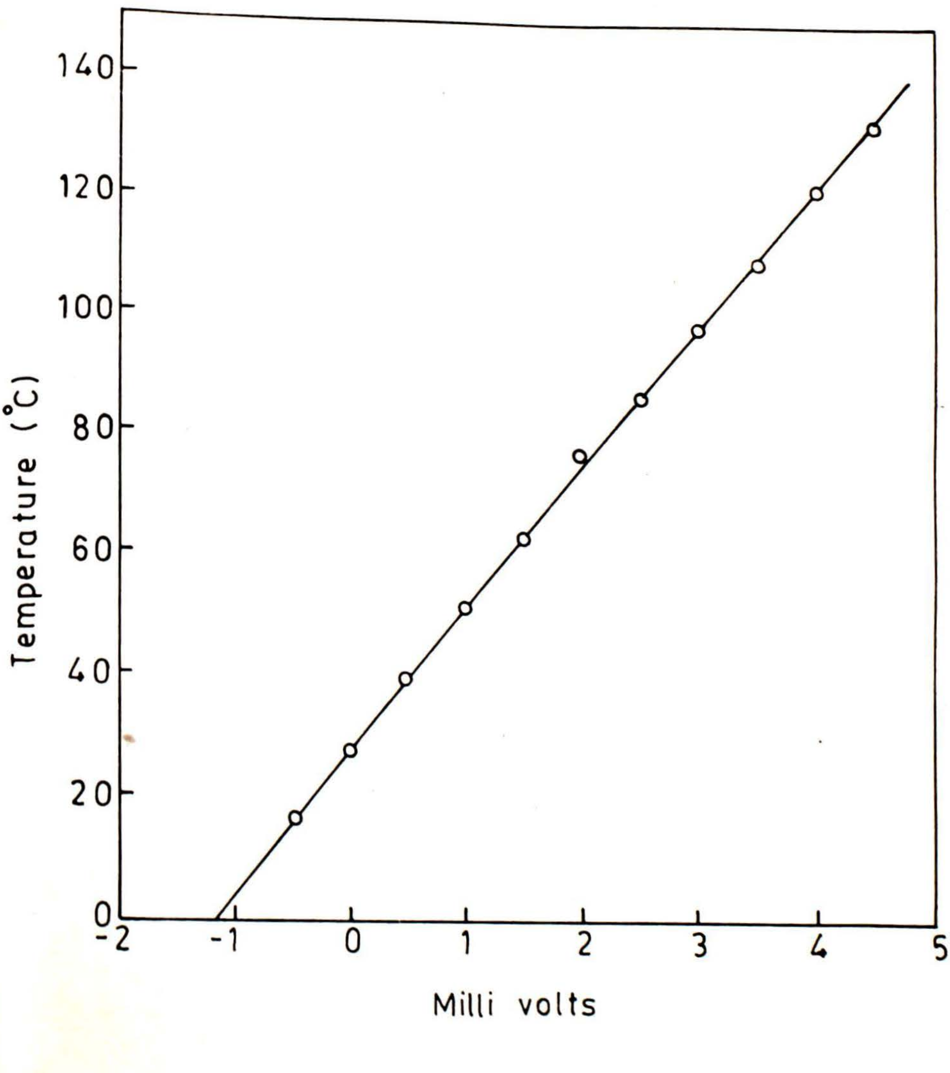


FIG.4.2. CALIBRATION CURVE OF THERMOCOUPLE

Gross Energy = Indirect Energy (required for milk production)

+

Direct Energy (required for processing)

4.7.1. Indirect Energy

4.7.1.1. Heat from Animals: The energy content of milk, just after milking, was measured by measuring the body temperature of animals and the temperature of milk.

4.7.1.2. Transportation Energy: The energy required for transportation of milk from farm to processing plant was estimated.

4.7.2. Direct Energy

The heat energy required for khoa, ghee and paneer processing were estimated with the help of the observed data. The amount of steam required was calculated in terms of per kg milk, per kg khoa, per kg ghee, per kg paneer and per kg water evaporated. The similar values have been estimated in terms of heat units also. The heat losses during khoa, ghee and paneer making, due to convection and radiation, from product surface and with condensate were calculated separately and thus the total percentage loss of heat energy was also estimated. The steam consumption and losses were calculated as shown in Appendix-A.

4.8. SAVING IN STEAM CONSUMPTION

The saving in steam consumption during processing was calculated by collecting the condensate and recirculating it in the form of steam through vaporizer. In due course of time, the whole system was turned into a loop of direct reutilization of condensate in the form of steam. The percentage saving in energy requirement for steam generation in vaporizer over the boiler was calculated. These trials were repeated by insulating the steam line with asbestos rope.

4.9. CALCULATION OF HEAT TRANSFER COEFFICIENT

The heat transfer coefficient during conversion of milk into khoa and cream into ghee were determined as shown in Appendix-B. The amount of heat transferred and temperature of products were recorded. The values of viscosity, density, thermal conductivity, specific heat and coefficient of thermal expansion were taken from available literature.

4.10. PRODUCT ANALYSIS

The following analysis of products were carried out during the study:-

4.10.1. Fat Content of Milk and Cream

The fat content of milk and cream were estimated by Gerber method as described in IS:1224 (Part - II) 1977.

4.10.2. Moisture Content of Milk, Khoa and Paneer

The moisture content of milk, khoa and paneer were determined by gravimetric method. The weight of moisture disc was taken after cleaning, drying and cooling properly. Then 5 grams of sample was taken in the disc and after taking weight, it was kept in hot air oven, maintained at $100 \pm 1^{o}C$ for 2 - 3 hours. After drying, the weight was taken again. Then from the observations percentage moisture in milk, khoa and paneer was calculated as :

$$\% \text{ moisture} = \frac{m_1 - m_2}{m_1 - m} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

Where,

m = weight of empty disc.

m_1 = weight of disc plus sample

m_2 = weight of disc plus sample after drying.

4.10.3. Moisture Content of Cream and Ghee

The moisture determination of cream was carried out by gravimetric method using hot air oven and procedure as described in IS:769-1961 was followed.

The moisture content of ghee was determined as described in IS:3508-1966.

4.11. OBSERVATION

The observations taken for energy consumption, heat losses, condensate recovery, condensate reutilization and for time temperature distribution used for conversion of milk into khoa have been tabulated in Tables 4.1, 4.2 and 4.3.

The similar types of observations taken for steam consumption and temperature distribution during conversion of cream into ghee have been tabulated in Tables 4.4, 4.5 and 4.6.

The observations taken for steam consumption and temperature distribution during conversion of milk into paneer have been tabulated in Table 4.7.

The observations for condensate recovery and reutilization for khoa and ghee have been tabulated in Table 4.8.

*****

Table - 4.1

Observations:- Khoa Processing

Milk - 5 kg.

Fat % - 6.6

Moisture % - 83.324

Khoa - 1.080 kg.

Moisture % - 29.6248

Sr.No.	Time (min)	Steam pressure (kg/cm^2)	Steam temp. (°C)	Condensate (kg)	Condensate (°C)	Temperature of product during heating at different layers(°C) T_1	T_2	T_3	T_4	Bulk temp. (°C)	Surface temp.of vat(°C)
1.	0	-	-	-	-	30.25	30.25	30.25	30.00	30.12	-
2.	5	0.50	119.50	0.67	116.50	81.25	81.00	80.96	80.73	80.98	85.75
3.	10	0.50	119.50	0.67	116.50	89.72	89.70	89.25	89.05	89.43	95.74
4.	15	0.50	119.50	0.67	116.50	99.73	99.55	99.25	98.99	99.39	107.73
5.	20	0.50	119.50	0.67	116.50	108.36	108.21	108.00	107.95	108.13	114.95
6.	25	0.50	119.50	0.67	116.50	115.75	115.75	115.36	115.21	115.46	116.75
7.	30	0.50	119.50	0.67	116.50	115.79	115.63	115.45	115.35	115.55	116.80
8.	35	0.50	119.50	0.67	116.50	115.95	115.75	115.62	115.49	115.70	116.95
9.	40	0.50	119.50	0.67	116.50	115.99	115.83	115.80	115.75	115.84	116.98
10.	45	0.50	119.50	0.67	116.50	116.05	115.96	115.83	115.79	115.90	117.00

T_1, T_2, T_3 and T_4 are temperatures at 0.5, 2.5, 4.5 and 6.5 cm from the bottom, respectively.

Table - 4.2

Observations:
Khoa Processing

Milk - 5 kg. Khoa - 1.280 kg.

Fat % - 6.6 Moisture % - 30.2695

Moisture % - 83.084

Sr.No.	Time (min)	Steam pressure (kg/cm^2)	Steam temp. (°C)	Condensate Amount (kg)	Condensate Temp. (°C)	Temperature of product during heating at different layers (°C) T_1	T_2	T_3	T_4	Bulk temp. (°C)	Surface temp. of vat (°C)
1.	o	-	-	-	-	30.50	30.40	30.36	30.35	30.40	-
2.	5	0.75	121.35	0.82	118.95	83.52	83.23	83.00	82.92	83.16	87.35
3.	10	0.75	121.35	0.82	118.95	92.56	92.35	92.00	91.95	92.21	98.46
4.	15	0.75	121.35	0.82	118.95	102.35	102.12	102.00	101.98	102.11	109.37
5.	20	0.75	121.35	0.82	118.95	110.95	110.30	110.73	110.56	110.78	116.35
6.	25	0.75	121.35	0.82	118.95	118.53	118.25	118.20	118.05	118.25	120.20
7.	30	0.75	121.35	0.82	118.95	118.63	118.54	118.36	118.24	118.44	120.25
8.	35	0.75	121.35	0.82	118.95	118.74	118.62	118.46	118.39	118.54	120.39
9.	40	0.75	121.35	0.82	118.95	118.79	118.75	118.60	118.45	118.64	120.39

T_1, T_2, T_3 and T_4 are temperatures at 0.5, 2.5, 4.5 and 6.5 cm from the bottom, respectively.

Observations:

Khoa Processing

Table - 4.3

Milk	- 5 kg.	Khoa	- 1.180 kg.
Fat %	- 6.8	Moisture %	- 29.6341
Moisture %	- 82.3214		

Sr.No.	Time (min)	Steam pressure (kg/cm^2)	Steam temp. (^oC)	Condensate		Temperature of product during heating at different layers (^oC)				Bulk temp. (^oC)	Surface temp. of vat (^oC)
				Amount (kg)	Temp. (^oC)	T_1	T_2	T_3	T_4		
1.	0	-	-	-	-	32.50	32.50	32.05	32.00	32.15	-
2.	5	1.00	125.00	1.12	120.15	86.65	86.45	86.23	86.05	86.34	89.70
3.	10	1.00	125.00	1.12	120.15	95.36	95.21	95.00	94.95	95.13	99.60
4.	15	1.00	125.00	1.12	120.15	108.74	108.68	108.45	108.21	108.43	112.46
5.	20	1.00	125.00	1.12	120.15	116.36	116.20	116.05	116.00	116.15	119.31
6.	25	1.00	125.00	1.12	120.15	119.95	119.83	119.74	119.64	119.79	119.89
7.	30	1.00	125.00	1.12	120.15	119.99	119.95	119.86	119.73	119.88	119.95

T_1, T_2, T_3 and T_4 are temperatures at 0.5, 2.5, 4.5 and 6.5 cm from the bottom, respectively.

Observations:
Ghee Processing

Table - 4.4

Cream	-	5 kg.	Ghee	-	2.280 kg
Fat %	-	40	Moisture %	-	0.0943
Moisture %	-	52.8371			

Sr.No.	Time (min)	Steam pressure (kg/cm²)	Steam temp. (°C)	Condensate		Temperature of product during heating at different layers(°C)				Bulk temp. (°C)	Surface temp. of vat (°C)
				Amount (kg)	Temp. (°C)	T_1	T_2	T_3	T_4		
1.	0	-	-	-	-	37.50	37.50	37.25	37.00	37.35	38.50
2.	10	1.00	125.00	1.12	120.15	89.50	88.75	88.25	88.00	88.50	98.50
3.	20	1.00	125.00	1.12	120.15	96.00	95.95	99.43	95.25	95.65	109.36
4.	30	1.00	125.00	1.12	120.15	110.75	110.35	109.79	109.70	110.14	115.45
5.	40	1.00	125.00	1.12	120.15	119.94	113.76	113.10	112.75	113.39	120.35
6.	50	1.00	125.00	1.12	120.15	120.00	119.81	119.63	118.23	119.65	120.40
7.	60	1.00	125.00	1.12	120.15	120.02	120.00	119.95	119.74	119.93	120.99
8.	70	1.00	125.00	1.12	120.15	120.03	120.01	119.99	119.79	119.95	121.73
9.	80	1.00	125.00	1.12	120.15	120.04	120.03	120.00	119.99	120.01	121.93
10.	90	1.00	125.00	1.12	120.15	120.09	120.05	120.02	120.01	120.02	121.95
11.	100	1.00	125.00	1.12	120.15	120.09	120.06	120.05	120.01	120.04	122.00
12	110	1.00	125.00	1.12	120.15	120.10	120.07	120.06	120.02	120.05	122.95
13	120	1.00	125.00	1.12	120.15	120.12	120.08	120.06	120.04	120.07	122.99
14.	130	1.00	125.00	1.12	120.15	120.13	120.08	120.07	120.07	120.08	123.00

T_1, T_2, T_3 and T_4 are temperatures at 0.5, 2.5, 4.5 and 6.5 cm from the bottom, respectively.

Table - 4.5

Observations:

Ghee Processing

Cream	- 5 kg.	Ghee	- 2.400 kg.
Fat %	- 42	Moisture %	- 0.129
Moisture %	- 50.3728		

Sr.No.	Time (min)	Steam pressure (kg/cm^2)	Steam temp. (^oC)	Condensate Amount (kg)	Condensate Temp. (^oC)	Temperature of product during heating at different layers (^oC) T_1	T_2	T_3	T_4	Bulk temp. (^oC)	Surface temp. of vat (^oC)
1.	0	-	-	-	-	37.25	37.00	36.50	36.50	36.80	38.45
2.	10	1.50	128.50	1.34	122.50	90.15	90.00	89.85	89.50	89.87	100.53
3.	20	1.50	128.50	1.34	122.50	98.75	98.45	98.23	98.01	98.360	111.50
4.	30	1.50	128.50	1.34	122.50	113.65	113.53	113.00	112.95	113.28	118.75
5.	40	1.50	128.50	1.34	122.50	120.57	120.25	120.00	120.00	120.20	120.85
6.	50	1.50	128.50	1.34	122.50	120.62	120.50	120.35	120.25	120.43	126.00
7.	60	1.50	128.50	1.34	122.50	120.71	120.65	120.55	120.45	120.59	126.05
8.	70	1.50	128.50	1.34	122.50	120.80	120.76	120.73	120.62	120.72	126.08
9.	80	1.50	128.50	1.34	122.50	120.81	120.80	120.79	120.75	120.78	126.15
10.	90	1.50	128.50	1.34	122.50	120.85	120.82	120.80	120.80	120.81	126.23
11.	100	1.50	128.50	1.34	122.50	120.91	120.85	120.83	120.82	120.85	126.31
12.	110	1.50	128.50	1.34	122.50	120.95	120.93	120.89	120.87	120.91	126.40

T_1, T_2, T_3 and T_4 are temperatures at 0.5, 2.5, 4.5 and 6.5 cm from the bottom, respectively.

Table - 4.6

Observations:
Ghee Processing

Cream	- 5 kg.	Ghee	- 2.150 kg.
Fat %	- 40	Moisture	- 0.0995
Moisture	- 51.3928		

Sr.No.	Time (min)	Steam pressure (kg/cm^2)	Steam temp. (^oC)	Condensate		Temperature of product during heating at different layers (^oC)				Bulk temp. (^oC)	Surface temp. of vat (^oC)
				Amount (kg)	Temp. (^oC)	T_1	T_2	T_3	T_4		
1.	0	-	-	-	-	35.25	35.20	35.00	35.00	35.12	38.65
2.	10	2.00	130.05	1.876	126.75	93.73	93.43	93.20	93.05	93.35	102.72
3.	20	2.00	130.05	1.876	126.75	99.99	99.85	99.73	99.54	99.77	113.53
4.	30	2.00	130.05	1.876	126.75	115.34	115.25	115.00	114.95	115.13	120.75
5.	40	2.00	130.05	1.876	126.75	120.05	120.01	120.00	119.95	120.00	126.67
6.	50	2.00	130.05	1.876	126.75	120.07	120.03	120.00	119.99	120.02	126.95
7.	60	2.00	130.05	1.876	126.75	120.15	120.09	120.05	120.02	120.07	127.00
8.	70	2.00	130.05	1.876	126.75	120.23	120.18	120.14	120.09	120.16	127.05
9.	80	2.00	130.05	1.876	126.75	120.36	120.21	120.19	120.13	120.22	127.65

T_1, T_2, T_3 and T_4 are temperature at 0.5, 2.5, 4.5 and 6.5 cm from the bottom, respectively.

Table - 4.7

Observations:

Paneer Processing

Milk - 5 kg.		Paneer - 0.850 kg.	
Fat % - 6.8		Moisture % - 54.3725	
Moisture % - 82.5213			

Sr.No.	Time (min)	Steam pressure (kg/cm^2)	Steam temp. (^oC)	Condensate		Temperature of product during heating at different layers(^oC)				Bulk temp.
				Amount (kg)	Temp. (^oC)	T_1	T_2	T_3	T_4	
1.	0	-	-	-	-	30.50	30.49	30.45	30.40	30.46
2.	1	0.50	119.50	0.134	116.50	40.55	40.25	40.25	40.00	40.23
3.	2	0.50	119.50	0.134	116.50	49.37	49.23	49.00	48.95	49.13
4.	3	0.50	119.50	0.134	116.50	62.90	62.65	62.47	62.36	62.59
5.	4	0.50	119.50	0.134	116.50	79.95	79.83	79.80	79.75	79.80
6.	5	0.50	119.50	0.134	116.50	81.55	81.47	81.35	81.23	81.40

T_1, T_2, T_3 and T_4 are temperatures at 0.5, 2.5, 4.5 and 6.5 cm from the bottom, respectively.

Observations:

Table - 4.8

Condensate Recovery and Reutilization.

Sr. No.	Product	Steam pressure (kg/cm^2)	Steam condensate leaving of vat: Without insulation (kg)	Without insulation (°C)	With insulation (kg)	With insulation (°C)	Condensate temp. in storage tank: Without insulation (°C)	With insulation (°C)	Steam from vaporizer (kg)	Pumping energy: Without insulation (KWH/kg x10^{-4})	With insulation (KWH/kg) x 10^{-4}	Electrical energy: Without insulation (KWH/kg)	With insulation (KWH/kg)
1.	Khoa	0.50	6.03	116.50 (96.0)	5.86	117.75 (96.50)	89.35	90.55	1.34	8.855	8.280	0.588	0.585
2.	Khoa	0.75	6.56	118.95 (96.75)	6.39	119.89 (97.35)	91.75	92.83	1.64	9.224	8.643	0.584	0.580
3.	Khoa	1.00	6.72	120.15 (97.30)	6.59	120.95 (97.95)	94.25	95.50	2.24	9.016	8.807	0.575	0.573
4.	Ghee	1.00	14.56	120.15 (97.30)	14.05	120.95 (97.95)	94.25	95.50	4.48	9.073	8.755	0.593	0.590
5.	Ghee	1.50	14.74	120.50 (98.50)	14.35	124.02 (99.35)	97.30	98.25	5.36	8.995	8.757	0.590	0.587
6.	Ghee	2.00	15.01	126.75 (99.25)	14.65	127.65 (99.97)	98.95	99.65	5.625	9.064	8.846	0.589	0.585
7.	Paneer	0.50	0.67	116.50 (96.0)	-	-	-	-	-	-	-	-	-

* (Values in parentheses are for condensate)

CHAPTER 5

RESULTS AND DISCUSSION

5. RESULTS AND DISCUSSION

5.1. ENERGY CONSUMPTION, HEAT LOSSES, CONDENSATE RECOVERY AND REUTILIZATION IN KHOA PROCESSING

5.1.1. Energy Consumption and Heat Losses

The trials of khoa making have been taken with 5 kg milk per batch. The steam pressure during the experiments have been varied between 0.5 to 1.0 kg/cm^2. The observed values of condensate collected and the temperature measured have been used to calculate the energy consumption, steam requirement and heat losses by convection and radiation, heat loss from product surface and with the condensate. The amount of steam consumed for processing milk into khoa varies from 1.206 to 1.344 kg/kg milk, 5.5833 to 5.6949 kg/ka khoa, and 1.56778 to 1.78423 kg/kg water evaporated. The heat supplied varies from 778.352 to 869.829 Kcal/kg milk, 3603.483 to 3685.717 Kcal/kg khoa and 1011.827 to 1154.747 Kcal/kg water evaporated. The total heat losses vary from 39.494% to 46.611%. The losses due to convection and radiation vary from 4.3134% to 5.5839%,

Table - 5.1

Energy Consumption and Heat Losses in Khoa Processing.

Sr. No.	Particulars	Steam pressure (kg/cm^2)			% of steam heat: Steam pressure (kg/cm^2)		
		0.5	0.75	1.00	0.5	0.75	1.00
1.	Heat supplied by steam (Kcal)	3891.762	4238.081	4349.147			
2.	Kg steam / kg milk	1.206	1.312	1.344			
3.	Kg steam / kg khoa	5.583	5.125	5.694			
4.	Kg steam/kg water evaporated	1.567	1.741	1.784			
5.	Kcal / kg milk	778.352	847.616	869.829			
6.	Kcal/ kg khoa	3603.483	3311.000	3685.717			
7.	Kcal/ kg water evaporated	1011.827	1125.129	1154.747			
8.	Heat utilised for processing (Kcal)	2354.673	2319.829	2308.892	60.504	54.737	53.088
9.	Heat loss by convection and radiation (Kcal)	167.869	153.404	112.379	4.313	3.619	2.583
10.	Heat loss from product surface (Kcal)	189.9026	475.0097	602.262	4.879	11.208	13.847
11.	Heat loss with condensate (Kcal)	1179.317	1289.837	1325.613	30.302	30.434	30.479
12.	Total heat loss (Kcal)	1537.088	1918.250	2040.254	39.494	45.262	46.611

from product surface 4.879% to 13.847% and with condensate 30.302% to 30.479%. All these values regarding steam consumption and heat losses at different steam pressures have been shown in Table 5.1.

The total amount of steam consumed for processing 5 kg milk to khoa varies from 6.03 to 6.72 kg and 5.86 to 6.59 kg with insulated steam pipe, when the steam pressure varies from 0.5 to 1.0 kg/cm^2. It has been observed that with insulated steam pipe 2.819 to 1.934% less steam is required over uninsulated pipe. The steam consumption increases with the increase in pressure. This has been represented in Figure 5.1. The percentage steam saving with insulated pipe has been shown in Figure 5.2. The various percentage heat losses increase with the increase in steam pressure, except heat loss due to convection and radiation. However, the percentage heat utilization decreases with the increase in steam pressure. The percentage heat utilization varies from 60.504% to 53.088%. All these results have been plotted in Figure 5.3.

5.1.2. <u>Condensate Recovery and Reutilization</u>

The condensate have been collected and heated in the vaporizer for generating steam at desired pressures. The heat losses with the condensate have been reduced from 45.685% to 47.778% of the total heat available in the condensate. Percentage energy saving by reutilising condensate for generating steam varies from 17.647% to 19.737%. All these results have been plotted in Figure 5.4. The percentage steam saving with vaporizer varies from 22.222% to 33.333%. The pumping energy requirement varies from 0.7645 to 0.7932 Kcal/kg condensate and the electrical

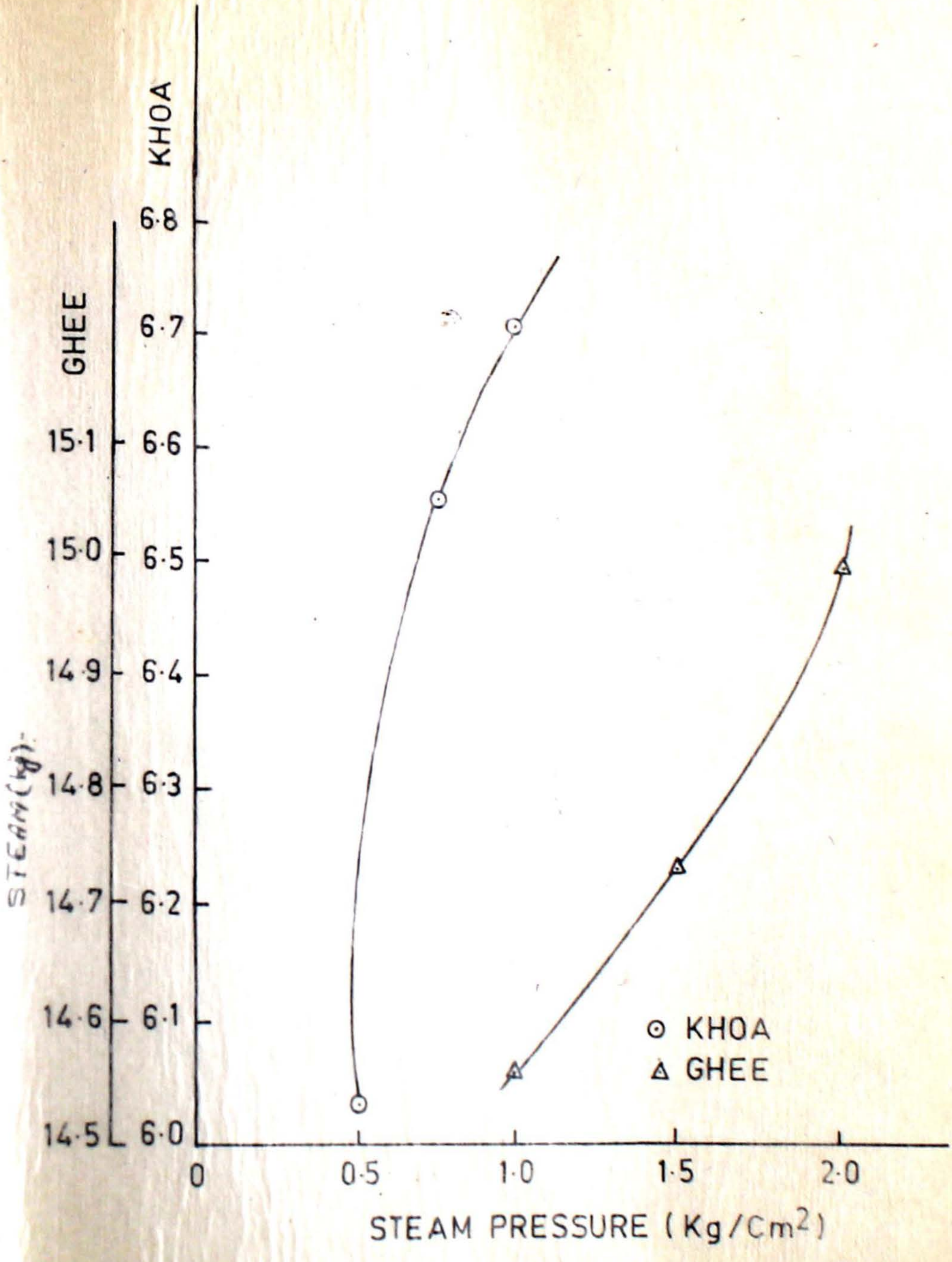


FIGURE 5.1 STEAM CONSUMPTION AT DIFFERENT PRESSURES

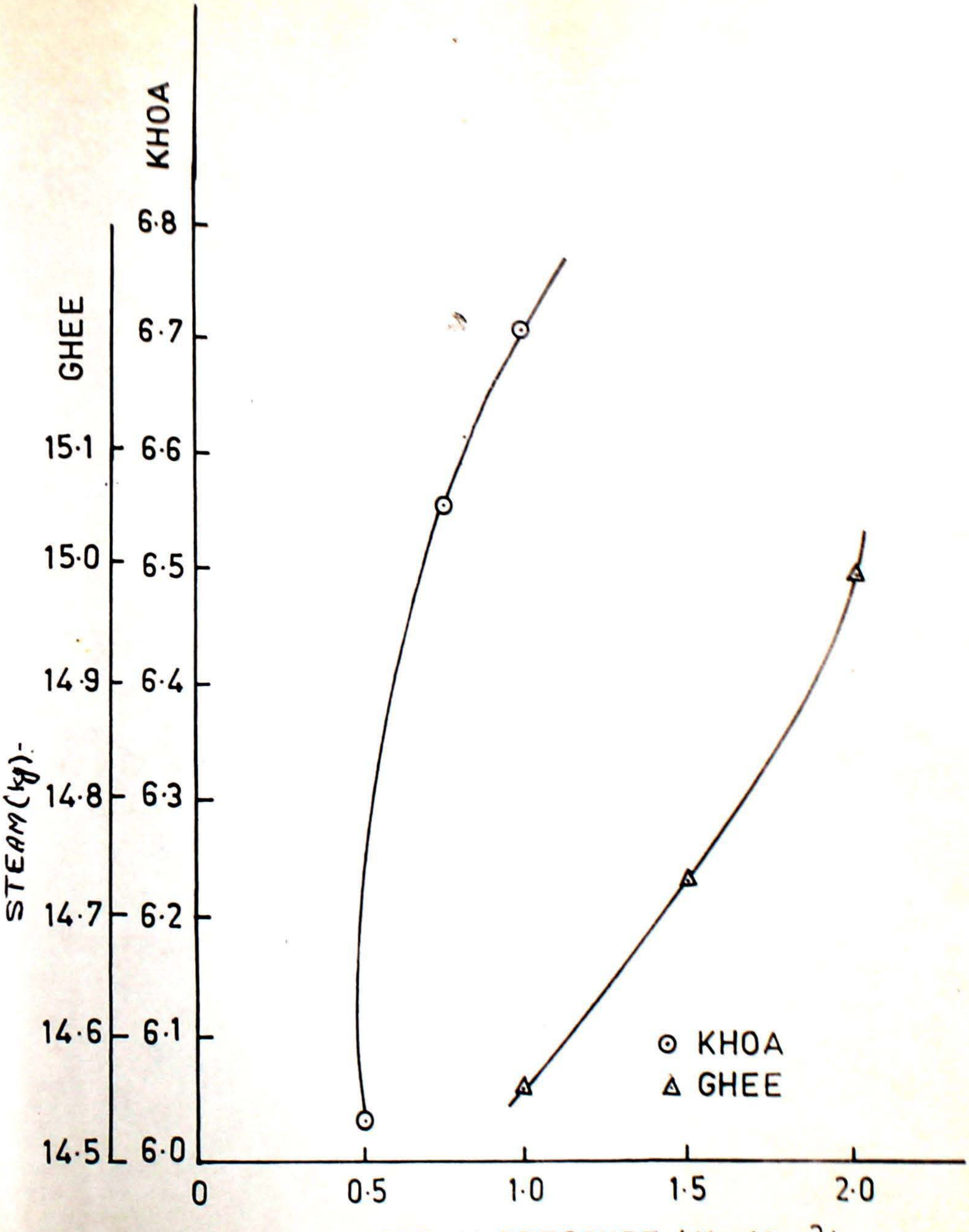


FIGURE 5.1 STEAM CONSUMPTION AT DIFFERENT PRESSURES

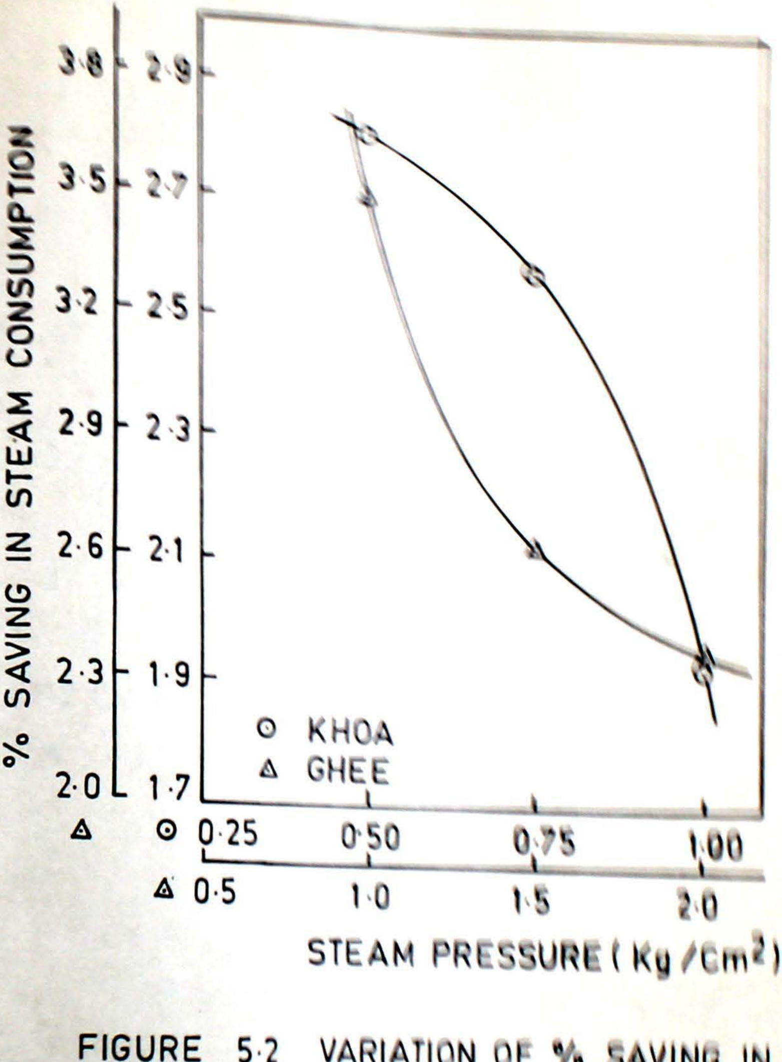
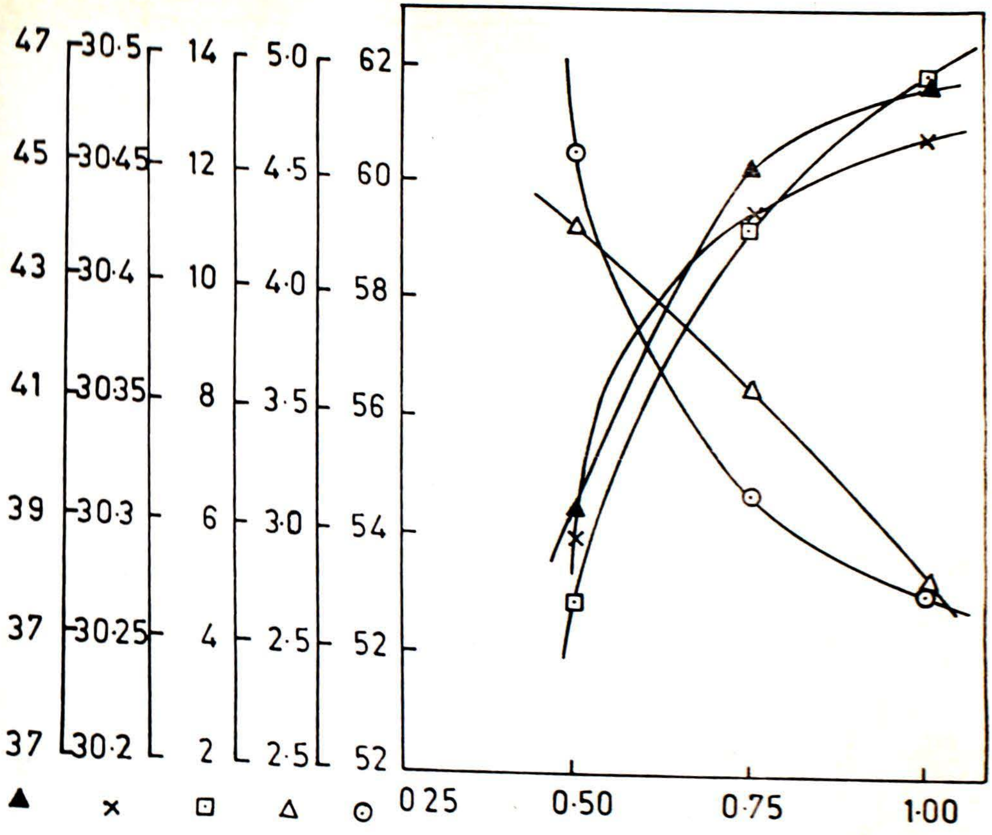


FIGURE 5·2 VARIATION OF % SAVING IN STEAM CONSUMPTION WITH INSULATED STEAM PIPE VS STEAM PRESSURE



⊙ → % Heat utilized for processing

△ → % Heat loss by convection & radiation

⊡ → % Heat loss from product surface

× → % Heat loss with condensate

▲ → % Total heat loss

FIGURE 5.3 % HEAT LOSS AND % HEAT UTILIZATION VS STEAM PRESSURE (FOR KHOA)

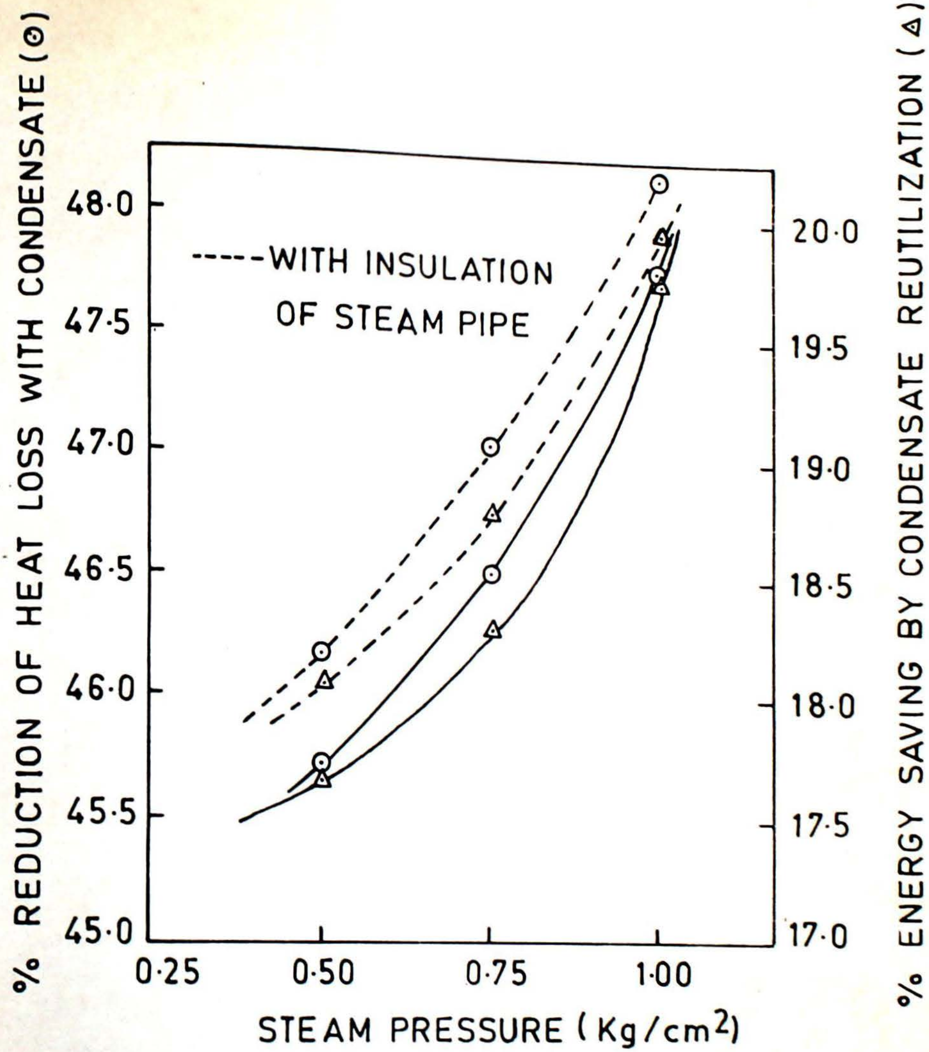


FIGURE 5·4 VARIATION OF % ENERGY SAVING AND HEAT LOSS VS STEAM PRESSURE

(FOR KHOA)

Table - 5.2

Energy Conservation with Condensate Reutilization with Vaporizer and with Insulated Steam Pipe in Khoa Processing.

Sr.No.	Particulars	Steam pressure (kg/cm^2)		
		0.50	0.75	1.00
1.	Steam temperature (°C)	119.50	121.35	125.00
2.	Steam/Condensate for processing(kg)	6.03 (5.86)	6.56 (6.39)	6.72 (6.59)
3.	% saving in total steam consumption with insulated steam pipe	2.819	2.591	1.934
4.	Steam from boiler (kg)	4.69	4.92	4.48
5.	Steam from vaporizer (kg)	1.34	1.64	2.24
6.	% steam saving	22.222	25.000	33.333
7.	Temp. of steam & condensate just coming out of kettle (°C)	116.5 & 96.0 (117.75 & 96.5)	118.95 & 96.75 (119.89 & 97.95)	120.15 & 97.30 (120.95 & 97.95)
8.	Heat energy with steam and condensate (Kcal)	1179.317 (1149.845)	1289.837 (1260.564)	1325.613 (1303.965)
9.	Condensate temp. in storage tank (°C)	89.35 (90.55)	91.75 (92.83)	94.25 (95.50)
10.	Heat with condensate (Kcal)	538.780 (530.713)	601.880 (593.183)	633.36 (629.345)
11.	% saving of heat loss with condensate reutilization	45.685 (46.155)	46.663 (47.056)	47.778 (48.263)
12.	Pumping energy requirement (Kcal/kg)	0.7614 (0.7120)	0.7932 (0.7432)	0.7753 (0.7573)
13.	Electrical energy requirement in vaporizer (Kcal/kg)	506.120 (503.690)	502.561 (499.466)	495.043 (493.467)
14.	Total energy requirement for steam generation in vaporizer (Kcal/kg)	506.882 (504.402)	503.355 (500.521)	495.819 (494.225)
15.	Energy required in boiler for steam generation (Kcal/kg)	615.5	616.049	617.743
16.	% saving (Energy) with vaporizer	17.647 (18.050)	18.293 (18.753)	19.737 (19.995)

* Values insides the parentheses are of insulated steam pipes.

energy requirement in vaporiser varies between [illegible] to [illegible] Kcal/kg condensate. By using asbestos rope insulation on the steam pipe, the percentage energy saving with vaporiser vary from [illegible] to [illegible]. The energy input for pumping the condensate to the vaporiser, heating the condensate for steam generation and the comparative values for generating steam by feed water have been shown in Table [illegible]. It is observed that there is definite increase in percentage energy saving and energy inputs in reutilising the condensate by providing proper insulation on the steam pipe. Hence, 0.258% to 0.48% more energy can be saved in vaporiser, provided the steam pipe is insulated.

5.2. ENERGY CONSUMPTION, HEAT LOSSES, CONDENSATE RECOVERY AND REUTILIZATION IN GHEE PROCESSING

5.2.1. <u>Energy Consumption and Heat Losses</u>

The trials of ghee making have been taken with 5 kg cream per batch. The steam pressure during the experiments have been varied between 1.00 to 2.00 kg/cm^2. The observed values of condensate collected and the temperatures measured have been used to calculate the energy consumption, steam requirement and heat losses by convection and radiation, heat losses from product surface and with the condensate. The amount of steam consumed for processing cream into ghee varies from [illegible] to [illegible] kg/kg cream, 6.3859 to 6.9813 kg/kg ghee and 5.5361 to 5.8960 kg/kg water evaporated. The heat supplied varies from 1885.236 to 1917.836 Kcal/kg cream, 4132.961 to 4628.440 Kcal/kg ghee, and 3560.786 to 3791.886 Kcal/kg water evaporated. The total heat losses vary from [illegible] to 82.652%. The losses due to convection and radiation vary from [illegible] to

Table - 5.3

Energy Consumption and Heat Losses in Ghee Processing.

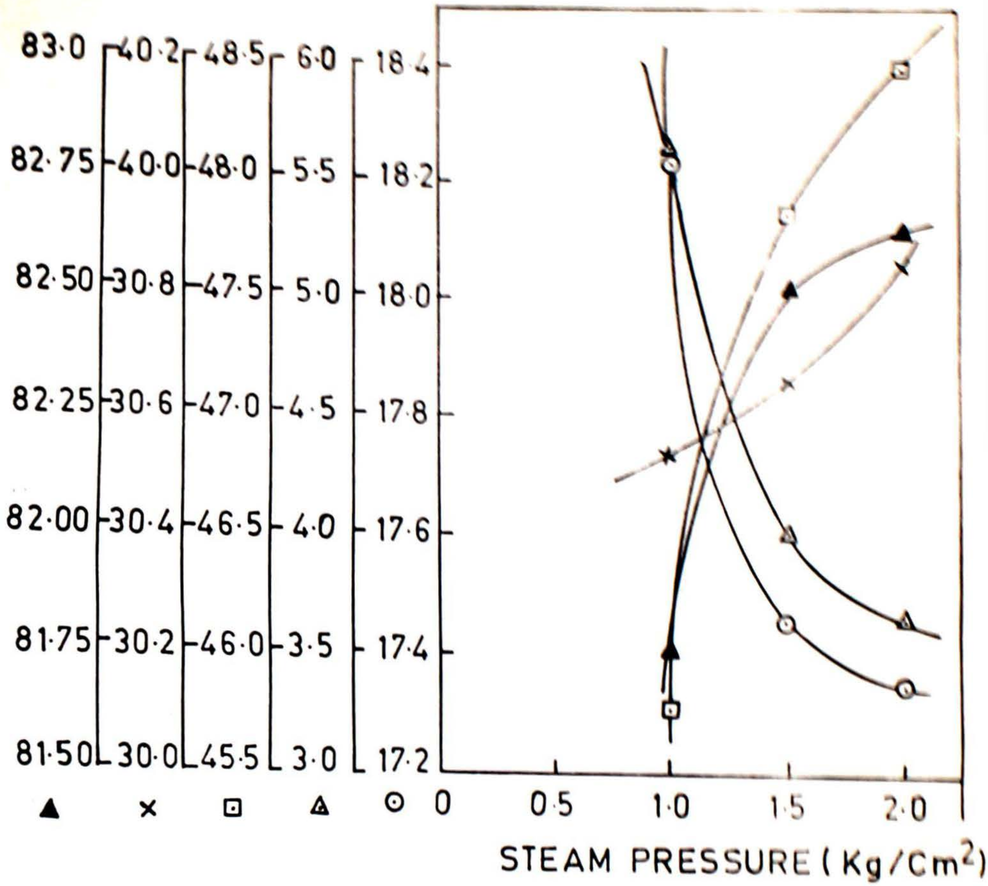
Sr.No.	Particulars	Steam pressure (kg/cm^2)			% of steam heat – Steam pressure (kg/cm^2)		
		1.00	1.50	2.00	1.00	1.50	2.00
1.	Heat supplied by steam (Kcal)	9423.151	9555.820	9738.157			
2.	Kg steam / kg cream	2.912	2.948	3.062			
3.	Kg steam/ kg ghee	6.385	6.541	6.981			
4.	Kg steam/kg water evaporated	5.536	5.859	5.896			
5.	Kcal/ kg cream	1885.230	1911.160	1947.230			
6.	Kcal/ kg ghee	4132.961	4381.590	4528.440			
7.	Kcal/kg water evaporated	3569.780	3778.715	3792.220			
8.	Heat utilised for processing (Kcal)	1717.847	1668.436	1689.769	18.230	17.459	17.352
9.	Heat loss by convection and radiation (Kcal)	521.922	383.778	327.760	5.538	4.016	3.657
10.	Heat loss from product surface (Kcal)	4311.990	4574.474	4718.274	45.759	47.871	48.451
11.	Heat loss with condensate (Kcal)	2871.392	2927.1318	3002.750	30.471	30.631	30.834
12.	Total heat loss (Kcal)	7705.304	7885.383	8048.784	81.769	82.519	82.652

3.3657%, from product surface 45.759% to 48.451%, and with condensate 30.471% to 30.834%. All these values regarding steam consumption and heat losses at different pressures have been shown in Table 5.3.

The total amount of steam consumed for processing 5 kg cream into ghee varies from 14.56 kg to 15.01 kg and 14.05 to 14.65 kg with insulated steam pipe, when the pressure varies from 1.00 to 2.00 kg/cm^2. It has been observed that 3.5027% to 2.3984% less steam is required with insulated steam pipe over uninsulated steam pipe. The steam consumption increases with the increase in pressure. This has been represented in Figure 5.1. The percentage steam saving with insulated pipe has been shown in Figure 5.2. The various percentage heat losses increase with the increase in steam pressure, except heat loss due to convection and radiation. However, the percentage heat utilization decreases with the increase in pressure. The percentage heat utilization varies from 18.230% to 17.352%. All these results have been plotted in Figure 5.5.

5.2.2. Condensate Recovery and Reutilization

The condensate have been collected and heated in the vaporizer for generating steam at desired pressures. The heat losses with condensate have been reduced from 47.791% to 49.462% of the total heat available in the condensate. Percentage energy saving by re-utilizing condensate for generating steam varies from 17.2002% to 18.003%. All these results have been plotted in Figure 5.6. The percentage steam saving varies from 30.896% to 37.475%. The pumping energy requirement varies from 0.773 to 0.779 Kcal/kg condensate and the electrical energy requirement in vaporizer



⊙ → % Heat utilised for processing

△ → % Heat loss by convection & radiation

⊡ → % Heat loss from product surface

× → % Heat loss with condensate

▲ → % Total heat loss

FIGURE 5.5 % HEAT LOSS AND % HEAT UTILIZATION VS STEAM PRESSURE (FOR GHEE)

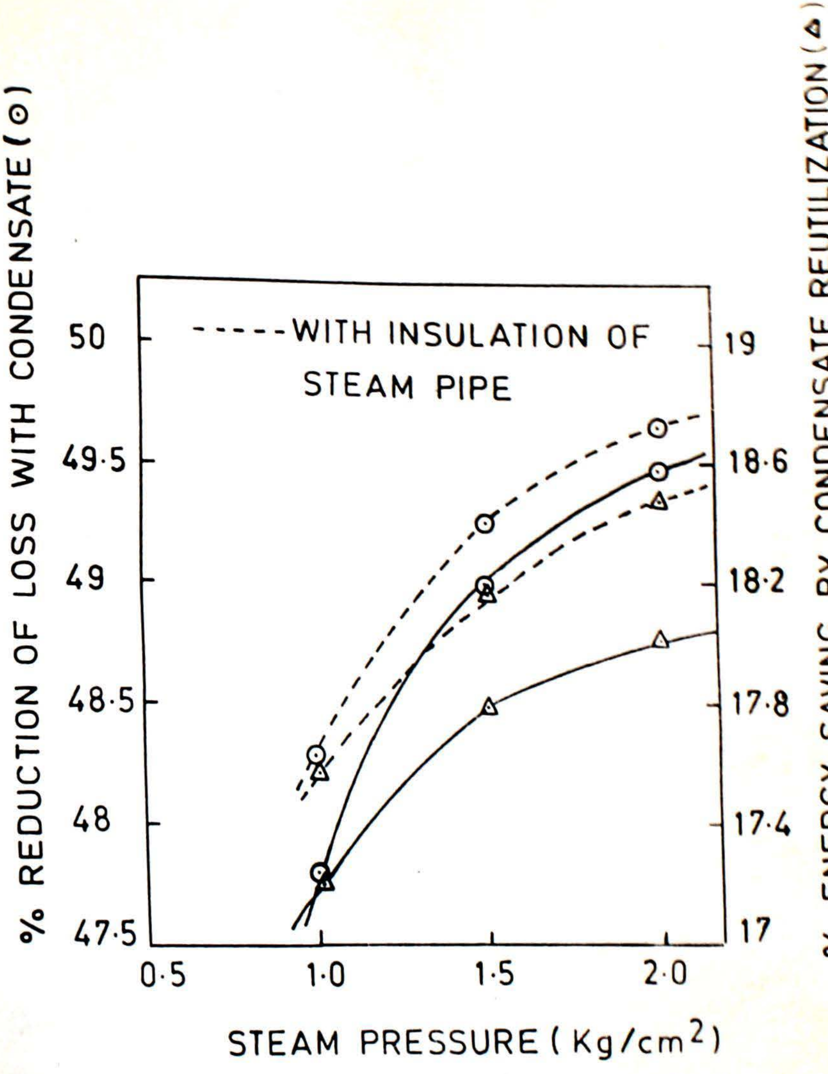


FIGURE 5.6 VARIATION OF % ENERGY SAVING AND HEAT LOSS VS STEAM PRESSURE (FOR GHEE)

Table - 5.4

Energy Conservation with Condensate Reutilization with Vaporizer and with Insulated Steam Pipe in Ghee Making.

Sr.No.	Particulars	Steam pressure (kg/cm^2)		
		1.00	1.50	2.00
1.	Steam temperature (°C)	125.00	128.50	130.05
2.	Steam/condensate for processing(kg)	14.56 (14.05)	14.74 (14.35)	15.01 (14.65)
3.	% saving in total steam consumption with insulated steam pipe	3.502	2.645	2.398
4.	Steam from boiler (kg)	10.08	9.38	9.385
5.	Steam from vaporizer (kg)	4.48	5.36	5.625
6.	% steam saving	30.896	36.3636	37.4750
7.	Temp. of steam & condensate just coming out of kettle (°C)	120.15 & 97.30 (120.95 & 97.95)	122.50 & 98.50 (124.02 & 99.35)	126.75 & 99.25 (127.65 & 99.97)
8.	Heat energy with steam and condensate (Kcal)	2871.392 (2780.077)	2927.131 (2862.627)	3002.750 (2940.565)
9.	Condensate temp. in storage tank (°C)	94.25 (95.50)	97.30 (98.25)	98.95 (99.65)
10.	Heat with condensate (Kcal) in storage tank	1372.28 (1341.775)	1434.202 (1409.887)	1485.2395 (1459.872)
11.	% saving of heat loss with condensate reutilization	47.791 (48.263)	48.996 (49.251)	49.462 (49.645)
12.	Pumping energy requirement (Kcal/kg)	0.7802 (0.7528)	0.7735 (0.7530)	0.7794 (0.7607)
13.	Electrical energy requirement in vaporizer (Kcal/kg)	510.254 (507.993)	507.554 (505.238)	506.599 (503.734)
14.	Total energy requirement for steam generation in vaporizer (Kcal/kg)	511.035 (508.746)	508.328 (505.991)	507.379 (504.495)
15.	Energy required in boiler for steam generation (Kcal/kg)	617.194	618.292	618.778
16.	% Energy saving with vaporizer	17.2002 (17.571)	17.785 (18.163)	18.003 (18.469)

* Values insides the parentheses are of insulated steam pipes.

varies from 506.599 to 510.254 Kcal/kg. By using asbestos rope insulation on the steam pipe, the percentage energy saving with vaporizer varies from 17.571% to 18.469%. Hence, 0.370% to 0.439% more energy can be saved in vaporizer, provided the steam pipe is insulated. The energy input for pumping the condensate to vaporizer, heating the condensate for steam generation and the comparative values for generating steam by feed water have been shown in Table 5.4. It is observed that there is definite increase in percentage energy saving and energy inputs in reutilizing the condensate by providing proper insulation on the steam pipe.

5.3. ENERGY CONSUMPTION AND HEAT LOSSES IN PANEER PROCESSING

The trials of paneer making have been taken with 5 kg milk per batch. The steam pressure during the experiments has been 0.5 kg/cm^2. The observed values of condensate collected have been used to calculate the energy consumption, steam requirement and heat losses by convection and radiation, heat loss from product surface and with condensate. The average amount of steam consumed for processing milk into paneer is 0.134 kg/kg milk and 0.788 kg/kg paneer. The average heat supplied is 86.483 Kcal/kg milk and 508.727 Kcal/kg paneer. The average amount of total heat loss is 45.221%. The losses due to convection and radiation is 2.751%, from product surface is 12.166% and with condensate is 30.302%. All these values regarding steam consumption and heat losses during paneer processing have been shown in Table 5.5.

5.4. GROSS ENERGY CONSUMPTION

The average value of gross thermal energy input for khoa is 1021.23 Kcal/kg milk considering inputs in milk production and processing.

Table : 5.5 : Energy Consumption and Heat Losses in Paneer Processing

Sr.No.	Particulars	Steam pressure 0.50 kg/cm^2	
1.	Heat supplied by steam (Kcal)	432.418	
2.	Kg steam / kg milk	0.194	
3.	Kg steam / kg paneer	0.788	
4.	Kcal / kg milk	86.483	
5.	Kcal / kg paneer	508.727	% of steam heat
6.	Heat utilized for processing (Kcal)	279.191	64.565
7.	Heat loss by convection and radiation (Kcal)	11.899	2.751
8.	Heat loss from product surface (Kcal)	52.612	12.166
9.	Heat loss with condensate (Kcal)	131.035	30.302
10.	Total heat loss (Kcal)	195.546	45.221

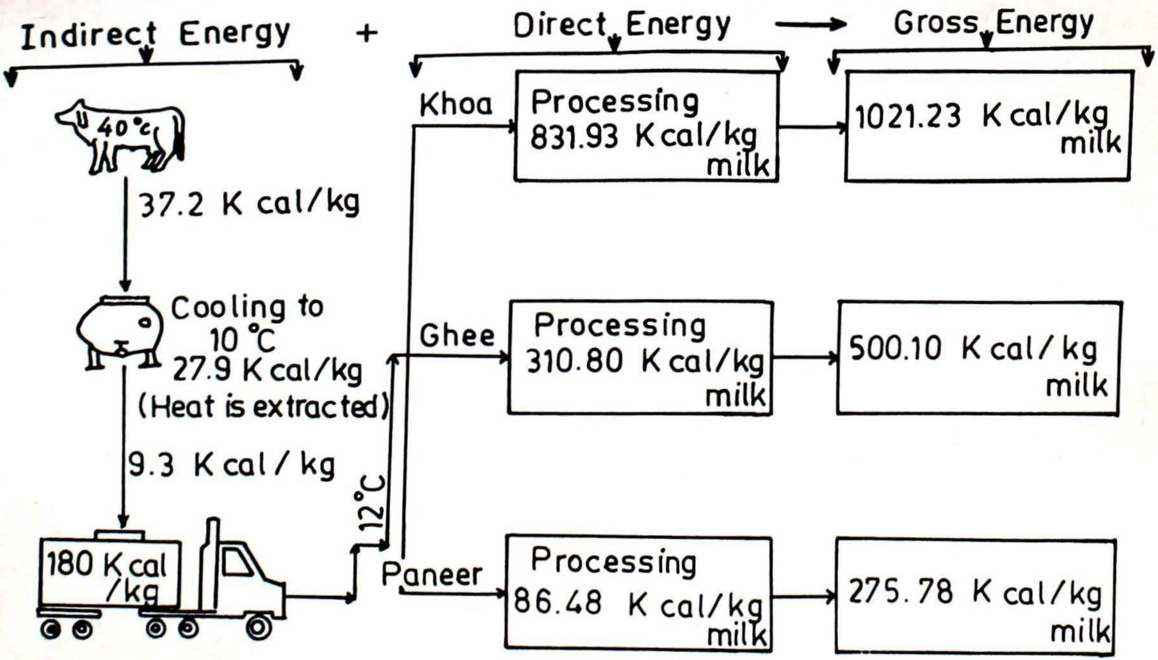


FIG. 5.7. GROSS ENERGY CONSUMPTION

Similar average value of gross thermal energy input for ghee and paneer are 500.1001 Kcal/kg milk and 275.787 Kcal/kg milk, respectively.

All these results have been shown in Figure 5.7.

5.5. TEMPERATURE DISTRIBUTION CURVES FOR KHOA, GHEE AND PANEER

5.5.1. Khoa

The time temperature distribution curves at different layers of product during khoa processing have been shown in Figure 5.8. As the quantity of milk taken during trials have been only 5 kg per batch, therefore the layers at which temperatures have been measured were very close. The variation in temperature between the top and bottom layer is between 0.28 to 0.67°C. The small difference at different layers indicates proper heating and agitation of the product during khoa making.

5.5.2. Ghee

The time temperature distribution curves at different layers of product during ghee processing have shown in Figure 5.9. As the quantity of cream taken during trials have been only 5 kg per batch, therefore the layers at which temperatures have been measured were very close. The variation in temperature between the top and bottom layer is between 0.06 to 1.50°C. The small difference at different layers indicates proper heating and agitation of the product during ghee making.

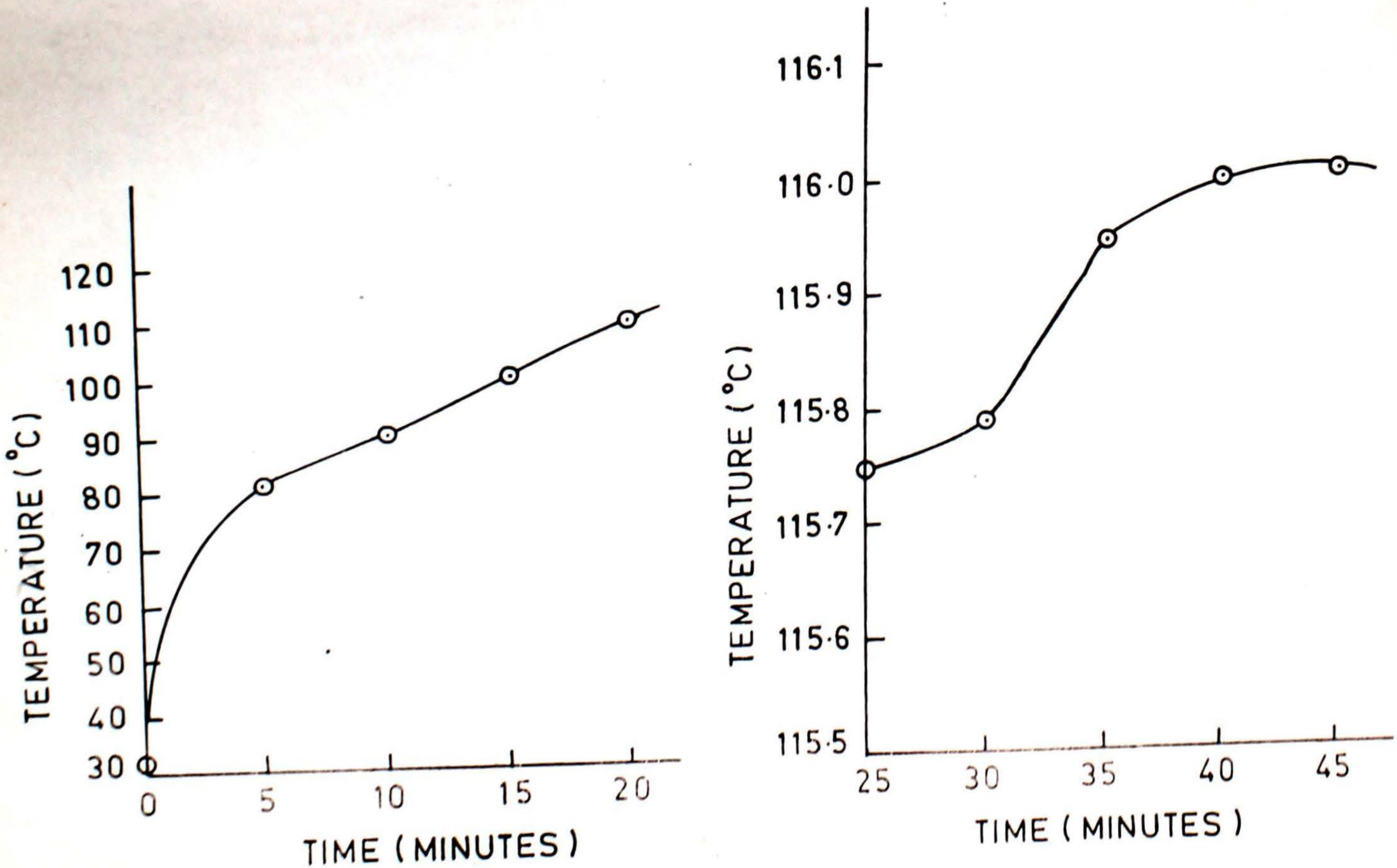


FIGURE 5·8 TIME TEMPERATURE DISTRIBUTION DURING KHOA PROCESSING

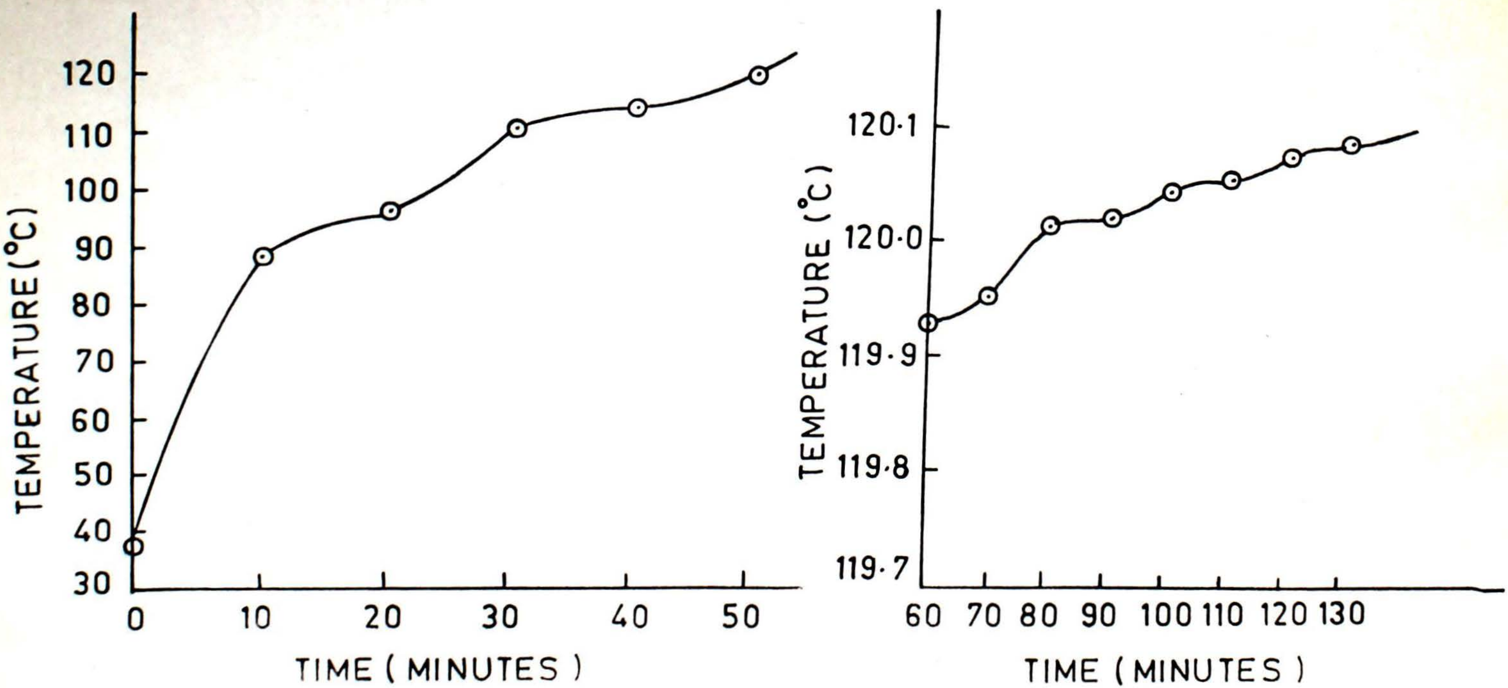


FIGURE 5·9 TIME TEMPERATURE DISTRIBUTION DURING GHEE PROCESSING.

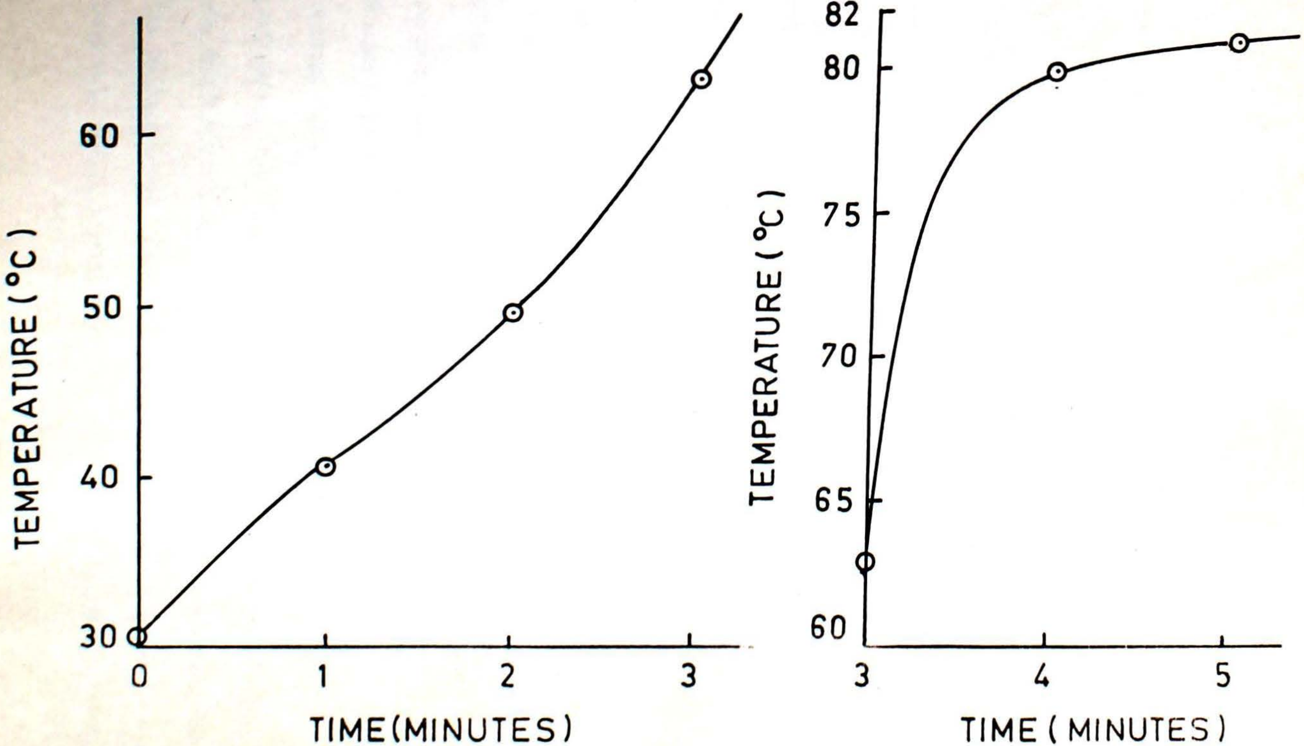


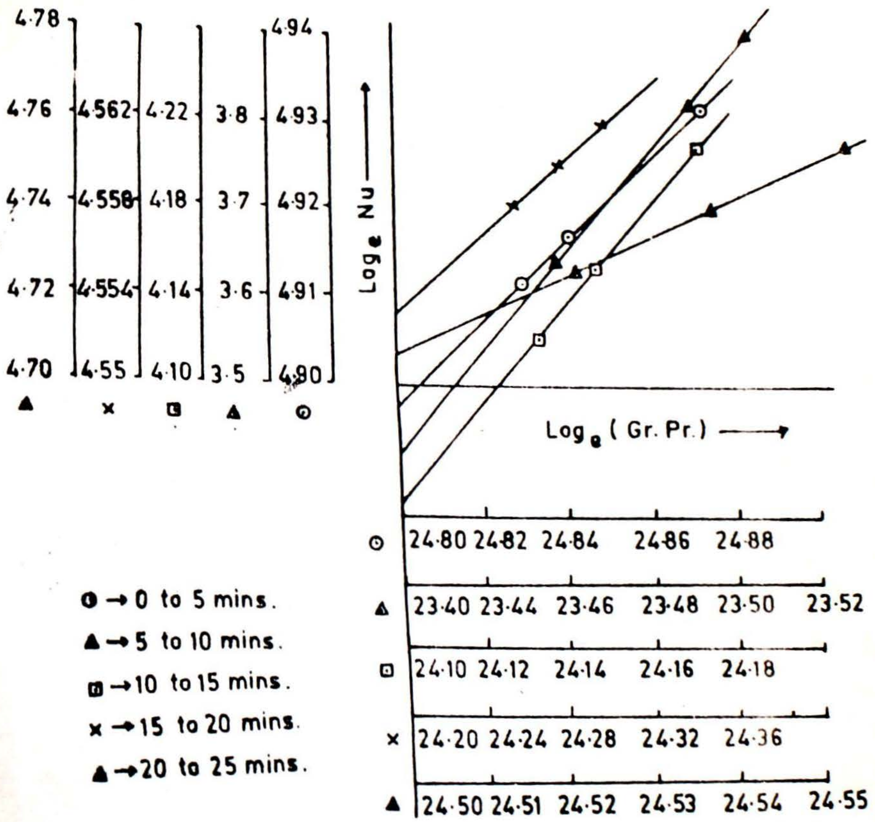
FIGURE 5·10 TIME TEMPERATURE DISTRIBUTION DURING PANEER PROCESSING

5.5.3. Paneer

The time temperature distribution curves at different layers of product during paneer processing have shown in Figure 5.10. As the quantity of milk taken during trials have been only 5 kg per batch, therefore the layers at which temperatures have been measured were very close. The variation in temperature between the top and bottom layer is between 0.15 to 0.55°C. The small difference at different layers, indicates proper heating and agitation of the product during paneer making.

5.6. HEAT TRANSFER CHARACTERISTICS DURING KHOA PROCESSING

The time temperature data collected during processing of milk into khoa have been analysed to determine the film-coefficients of heat transfer of different stages during conversion of milk into khoa. The time taken for processing milk to khoa varies between 30 minutes to 45 minutes when the steam pressue is varied from 1 to 0.5 kg/cm^2. The concentration of milk is varying with time during khoa processing. Therefore, for determination of heat transfer coefficients, the thermal properties have to be taken for each stage separately. The viscosity, specific heat, thermal conductivity and coefficient of thermal expansion values have been taken from available literature for calculations. The average value of film coefficient for convection heat transfer during processing have been found to be 181.07475, 51.5598, 90.0406, 132.08051 and 164.9092 Kcal/m^2-hr-°C at an interval of five minutes, respectively. The average value of Nusselt number have been determined for all these intervals and have been found to be 138.0272, 37.2902, 64.1770, 93.5301,



⊙ $Nu = 1{\cdot}0025\,(Gr.Pr.)^{0{\cdot}53}$

▲ $Nu = 1{\cdot}0356\,(Gr.Pr.)^{2{\cdot}2362}$

⊡ $Nu = 1{\cdot}0512\,(Gr.Pr.)^{2{\cdot}2}$

× $Nu = 1{\cdot}0035\,(Gr.Pr.)^{0{\cdot}0995}$

▲ $Nu = 1{\cdot}0151\,(Gr.Pr.)^{2{\cdot}53}$

FIGURE :- 5·11 HEAT TRANSFER CHARACTERISTICS FOR KHOA PROCESSING.

120.0427, respectively. The variation of Nusselt number with (Gr.Pr.) have been shown in Figure 5.11. The Nusselt type equation in the form of

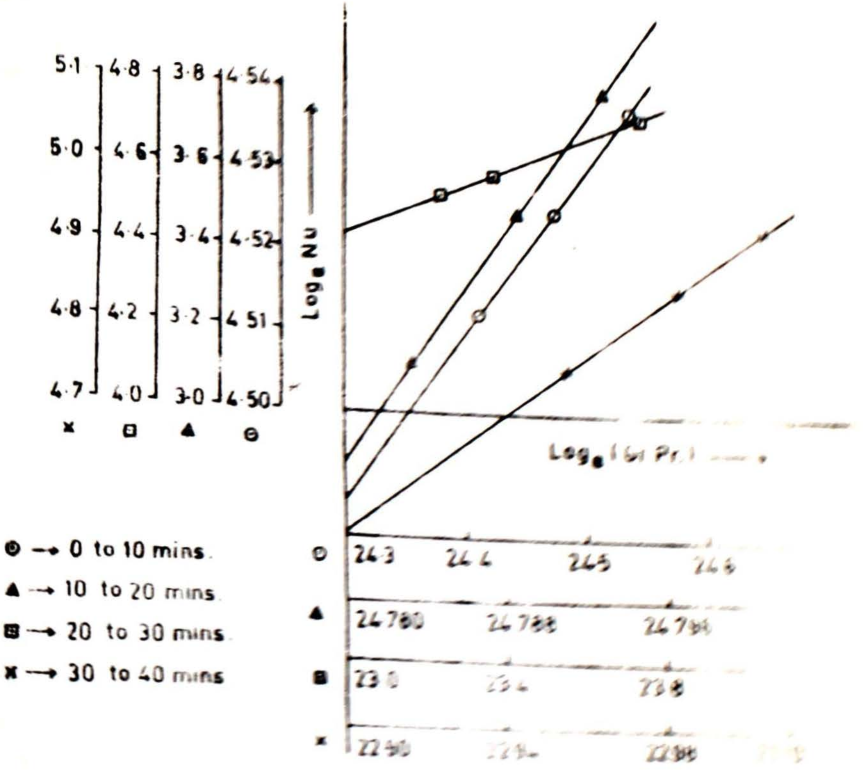
$$Nu = C\ (Gr.Pr.)^{m} \qquad \ldots\ldots\ldots\ldots\ldots(5.1)$$

have been developed for different stages in khoa processing, are as below:

Time interval		Developed equations	
0 to 5 minutes	-	$Nu = 1.0025\ (Gr.Pr.)^{0.53}$	...........(5.2)
5 to 10 minutes	-	$Nu = 1.0356\ (Gr.Pr.)^{2.236}$	...........(5.3)
10 to 15 minutes	-	$Nu = 1.0512\ (Gr.Pr.)^{2.2}$	...........(5.4)
15 to 20 minutes	-	$Nu = 1.0035\ (Gr.Pr.)^{0.0995}$	...........(5.5)
20 to 25 minutes	-	$Nu = 1.0151\ (Gr.Pr.)^{2.53}$	...........(5.6)

5.7. HEAT TRANSFER CHARACTERISTICS DURING GHEE PROCESSING

The time temperature data collected during processing of cream into ghee have been analysed to determine the film coefficients of heat transfer at different stages during conversion of cream into ghee. The time taken for conversion of cream into ghee varies between 80 minutes to 130 minutes when the steam pressure varied from 2.00 to 1.00 kg/cm^2. The concentration of cream is varying with time during ghee making. Therefore, for determination of heat transfer coefficients, the thermal properties have to be taken for each stage, separately. The viscosity, specific heat, thermal conductivity and coefficient of thermal expansion values have been taken from available literature for calculations. The average



⊖ $Nu = 1.01005\,(Gr.Pr.)^{0.19804}$ ▲ [illegible]

⊟ $Nu = 1.53720\,(Gr.Pr.)^{0.39990}$ ✖ [illegible]

FIGURE :- 5.12 HEAT TRANSFER CHARACTERISTICS FOR GHEE PROCESSING

value of film coefficient for convection heat transfer during ghee making have been found to be 73.042, 19.755, 67.394 and 72.7704 $Kcal/m^2$-hr-^oC at an interval of ten minutes, respectively. The average value of Nusselt number have been determined for all these intervals and have been found to be 91.7906, 31.434, 114.599 and 125.115, respectively. The variation of Nusselt number with (Gr.Pr.) have been shown in Figure 5.12. The Nusselt type equation in the form of

$$Nu = C\ (Gr.Pr.)^m \qquad \text{............(5.7)}$$

have been developed for different stages during conversion of cream to ghee are given below:

Time interval	Developed equations
0 to 10 minutes	$Nu = 1.01005\ (Gr.Pr.)^{0.19804}$ ....(5.8)
10 to 20 minutes	$Nu = 1.12749(\ Gr.Pr.)^{0.795}$ ....(5.9)
20 to 30 minutes	$Nu = 1.53720\ (Gr.Pr.)^{0.39990}$ ....(5.10)
30 to 40 minutes	$Nu = 1.15027\ (Gr.Pr.)^{0.14047}$ ....(5.11)

*****

CHAPTER 6

SUMMARY AND CONCLUSIONS

6. SUMMARY AND CONCLUSIONS

6.1. SUMMARY

6.1.1. The cost and demand of various energy sources such as oil, coal, hydel/thermal electrical power are increasing. Thus the industry has to become energy conscious and adopt energy conservation techniques to provide some relief on the energy requirement. The dairy industry, which consumed a lot of thermal energy for heating and cooling the product during processing, has to think very seriously on energy requirements for manufacture of different products and adopt suitable measures to conserve the same to the maximum possible extent. The equipments required for continuous processing of indigenous milk products have to be designed to make processing more efficient, hygienic and economical. To optimise the dimensions of the heat exchangers to be used, for such equipments, the information on energy requirements, various losses and heat and flow characteristics of these products have to be collected.

6.1.2. There is a very limited information available on energy consumption, heat losses and heat recovery from condensate in processing of indigenous milk products, such as khoa, ghee and paneer. Mrigendra

Kumar and Verma (1983) observed that the steam requirement for khoa and ghee making were 1.18 kg/kg milk and 0.635 kg/kg butter. Pandya (1978) mentioned that steam required in ghee processing was 0.36 kg/kg butter and 0.42 kg/kg ghee. Rao et al. (1976) studied various heat losses from cooker's surface by convection and radiation and losses with the condensate which were observed to be 2.0 to 2.8% and 13.62 to 21.61%, respectively. Rao and Goel (1977) suggested that recycling of the condensate to the boiler can reduce direct energy by 12%. Rippen (1974) reported that 13% energy can be saved by low pressure steam in dairy processing.

6.1.3. The present study was undertaken to estimate energy requirement, estimation of heat losses by convection and radiation, losses from product surface, loss with the condensate, recovery of heat from the condensate for energy conservation and to study the heat transfer characteristics during processing of khoa, ghee and paneer.

6.1.4. The methodology adopted for energy conservation was direct reutilization of condensate by heating the same in a vaporizer. The heat transfer characteristics studied have been used in formulating empirical relation similar to those developed by Nusselt (1916) and Yang (1973) for other products.

6.1.5. The following results were obtained during the study.

6.1.5.1. The average steam consumption has been found to be 1.275 kg/kg milk, 2.987 kg/kg cream and 0.134 kg/kg milk for khoa, ghee and paneer, respectively.

6.1.5.2. The average amount of total heat losses during processing have been found to be 43.052%, 82.210% and 45.221% of total heat supplied during khoa, ghee and paneer processing, respectively.

6.1.5.3. It has been observed that by direct reutilization of condensate, through a vaporizer, saved an average of 25.25% and 34.185% of total steam requirement during processing of khoa and ghee, respectively.

6.1.5.4. It has also been observed that by reutilising condensate an average of 18.692% and 17.601% energy can be saved for steam generation for khoa and ghee, respectively, in comparison to the energy used in boiler.

6.1.5.5. By insulating the steam pipe with asbestos rope the saving in steam requirements and energy requirement in vaporizer for steam generation from condensate have been found to be 2.376% and 0.369% less for khoa and 2.950% and 0.404% less for ghee, over uninsulated steam pipe, respectively.

6.1.5.6. It has been observed from the temperature distribution curves that the variation of temperature of the products and different layers during processing is not significant.

6.1.5.7. The heat transfer coefficients of milk and cream during conversion of khoa and ghee, respectively, have been found and Nusselt type equations have been developed for each stage of processing.

6.2. CONCLUSION

The following conclusions have been drawn from the present investigation:-

1) It is recommended that low pressure steam should be used to minimize the steam requirement and heat losses.

2) It has been established that the vaporizer can be effectively used for reutilization of condensate. The energy saving increases by converting condensate to steam in vaporizer.

3) The empirical relations developed can be used for designing the heat exchangers for processing of khoa and ghee.

*****

CHAPTER 7

SUGGESTIONS FOR FUTURE WORK

7. SUGGESTIONS FOR FUTURE WORK

1. The flow and heat transfer characteristics of indigenous milk products should be studied extensively.

2. Study should be carried out to collect data on energy requirement and losses during manufacture of indigenous milk products with variation in operation parameters such as quantity of products, size of vat and vat with and without insulation.

3. Studies on various techniques for condensate reutilization should be carried out.

4. The studies on energy conservation in service equipments, such as refrigeration plant and boiler should be carried out.

5. Studies should be carried out on changes in process techniques necessary for energy conservation.

*****

CHAPTER 8

BIBLIOGRAPHY

BIBLIOGRAPHY

Abichandani, H. (1978). Process feasibility of ghee making by direct contact heat exchange. J. of Food Sci. & Technol. (India), 15(6): 177-81.

Abichandani, H.; Agrawala, S.P.; Verma, R.D. ; Bector, B.S. (1978). Advances in continuous ghee making technique. Indian Dairyman, 30(11): 769-71.

Agrawala, S.P.; Ojha, T.P. (1976). Heat transfer studies in single tube single effect falling film milk evaporator. Int. J. Heat & Mass Transfer, 23(1): 45-51.

Al-Arabi, M.; Khamis, M. (1982). Natural convection heat transfer from inclined cylinders. Int. J. Heat & Mass Transfer, 25(1): 3-10.

Al-arabi, M.; Salman, Y.K. (1980). Laminar natural convection heat transfer from an inclined cylinder. Int. J. Heat & Mass Transfer, 23(1): 45-51.

Amato, W.S.; Tien, C. (1972). Free convection heat transfer from isothermal spheres in water. Int. J. Heat & Mass Transfer, 15, 327-39.

Andres, A. (1974). Pasteuriser for yoghurt milk with a maximum coefficient of regeneration.
(Cited in Dairy Sci. Abstr. 36; 4426, 1974).

Anon. (1979). Low energy milk drying plants. Dairy Ind. Int. 44(1): 18-20.

Bertay, A. (1977). Use of electricity in agriculture and the food industry: The example of whey concentration by evaporator, with mechanical recompression of steam. Industries Alimentaries et Agricoles. 94(9/10)
(Cited in FSTA : 10(05) E143, 1978).

Chen, M.M. (1961). An analytical study of laminar film condensation. J. of Heat Transfer. ASME, 83(1): 48-54.

Cheristerser, A. (1982). Vacuum evaporators with heat pumps. Meieriposten 71(25): 682-83.

Dave, A.R.; Bhadanbia, A.G.; Shah, U.S. (1979). Some aspects of conservation of energy in spray drying. Indian Dairyman. XXXII(12): 67.

Davis, D.C. (1980). Waste heat from food processing plants in the pacific northwest. Transection of the ASAE, 23(2): 498-502.

Eckert, E.R.G. (1951). Introduction to the transfer of heat and mass. McGraw-Hill Book Co., New York.

Elsy, B. (1980). Survey of energy and water usage in liquid milk processing. Milk Industry, 81(10): 18-20, 22-23.

Flink, J.M. (1977). Energy analysis in dehydration processes. Food Technology, 31(3): 77-84.

Geoola, F.; Cornish, A.R.H. (1982). Numerical simulation of free convective heat transfer from a sphere. Int. J. Heat & Mass Transfer, 25(11): 1677-87.

Goel, V.K. (1978). Thesis - Energy use and conservation in the food industry: USA and India. Cornell University (USA).

Heckenbury, R.W. (1975). Energy conservation and management. Activities Report, 27(1): 76-91.

Helamma, D. (1975). Energy conservation and the consumer. Science, 184: 134.

Hills, B.; Paul, H. (1977). The new 10,000 lit./hr milk processing line.
(Cited in Dairy Sci. Abstr. 99: 7046, 1977).

I.D.F. Group. Energy conservation in the dairy industry. I.D.F. Annual Bulletin (1977), 102: 1-9.

Indian Standard, (1961). Specification for determination of moisture in milk products. IS: 769. Indian Standard Institution.

Indian Standard (1966). Methods of sampling and tests for ghee (Butter fat). IS: 3508. Indian Standards Institution.

Indian Standard (1977). Determination of fat by Gerber method. Part I. Milk. IS: 1224. Indian Standards Institution.

Indian Standard (1977). Determination of fat by Gerber method. Part II. Milk Products. IS: 1224. Indian Standards Institution.

Jebson, R.S.; Lascelles, D.R. (1975). Energy recovery by the use of heat pumps on milk evaporators. N.Z.J. of Dairy Scil and Technol. 10(4): 174.

John, M.K. (1977). Solar energy cooling and freezing of food: A computer analysis. Food Technology, 31(3): 61-66.

Kessler, H.G. (1978). Saving energy in dairies. Milchwissenschaft. 33(7): 413-17.

King, J.H. (1932). Free convection. (Cited by Charm, S.E. Fundamentals of Food Engineering, 3rd ed. AVI Publishing Co.).

Kalteneckar (1980). Use of heat from whey in Emmental cheese factories. Molkerei-Zeitung welt der Milch, 34(14). (Cited in FSTA, 12 (12) P2187, 1980).

Konstantinov, S.M. (1976). Heat transfer during boiling of skim milk, whey and sugar solution in circular channels. (Cited in Dairy Sci. Abstr. 39: 2938, 1977).

Leistra, I. (1975a). Energy saving in cheese production. Zuivelzicht. 67(1). (Cited in FSTA, 7(06), D150, 1975).

Leistra, I. (1975b). Energy savings in cheese making. Voedingsmidel elentechnologie. 8(7). (Cited in FSTA, 7(11), P 2580, 1975).

Lienhard, J.H.; Dhir, V.K. (1971). Laminar film condensation on plane and axisymetric bodies in non-uniform gravity. J. of Heat Transfer, Trans. ASME, 93(1): 97-100.

McAdams, W.H. (1954). Heat transmission. 3rd ed. McGraw-Hill Book Co.

Morlok, J. (1978). Possibilities of reducing water and energy requirements in dairy industry. Deutsche Molkerei-Zeitung, 99(24). (Cited in FSTA, 10(12) P 2546, 1978).

Mrigendra Kumar; Verma, R.D. (1983). Heat transfer characteristics and energy conservation in dairy processing. M.Sc. Dissertation. Kurukshetra University, Kurukshetra.

Nusselt, W. (1916). Die oberflachenkonsation des wasserdampfes. (Cited by Frank Kreith in"Principals of Heat Transfer". 2nd ed. Int. Text Book Company).

Pandya, A.J. (1978). Energy economics in ghee making. M.Sc. Thesis, Kurukshetra University, Kurukshetra.

Peepless, M.L.; Could, I.A.; Jones, C.D.; Harper, W.J. (1962). Forced convection heat transfer characteristics of fluid milk products. J. of Dairy Sci., 45: 303-10.

Rajendra Kumar; Verma, R.D. (1980). Studies on temperature distribution of milk during cooling and freezing. J. of Institution of Engineers (India), 61 Pt. FD.I, 10-12.

Rao, M.A.; Katz, J. (1976). Computer estimation of heat losses in food processing plants. Food Technology, 30(3): 36-42.

Rao, M.A.; Katz, J.; Kenny, J.F.; Downing, D.L. (1976b). Thermal energy losses in vegetable canning plants. Food Technology, 30(12): 44.

Rippen, A.L. (1974). Fuel-saving with care. American Dairy Review May, 16-17, 43-44.

Rippen, A.L. (1975). Energy conservation in the food processing industry. J. of Milk and Food Technol., 38(11): 715-20.

Rippen, A.L. (1976). The energy situation and utilization by the dairy industry.
(Cited in Thesis: The energy use and conservation in food industry, Goel, V.K., 1978, Cornell University, USA).

Rippen, A.L. (1977). The mounting importance of energy conservation. Dairy & Ice-cream Field, 160(11): 36-38, 40.

.....
Sayanna, V.; Verma, R.D. (1975). Forced convection heat transfer characteristics of butter during manufacturing of ghee. J. of Institution of Engineers (India), 56: ME-6, 253-56.

Sampson, D.F. (1953). Some aspects of the technology of processing sterilization of canned foods. American Can Co., New York.

.....
Roshenow, W.M. (1956). Effect of vapour velocity on laminar and turbulent film condensation" (Cited by Frank Kreith in "Principles of Heat Transfer, 2nd ed." Int. Text Book Co.)

Schmidt, E.; Beckman, W. (1930). Das temperature und Geschwindigkeitsfeld vor einer Warmeabgebenden Senkrechten Platte bei naturlicher Konvection.
(Cited by Frank Kreith, "Principals of Heat Transfer", 2nd ed. Int. Text Book Co.).

Schwartzberg, H.G. (1977). Energy requirements for liquid food concentration. Food Technology, 31(3): 67-76.

Sharma, S.C.; Agarwala, S.P. (1978). Process feasibility of ghee making by direct contact heat exchange. J. of Food Sci. & Technol., 15(5): 177-183.

Shillo, L.F.; Zolotin, Yu.F. (1973). Determination of the coefficient of heat transfer in plate evaporator.
(Cited in Dairy Sci. Abstr., 36, 897, 1974).

Singh, R.P. (1977). Energy consumption and conservation in food sterilization. Food Technol. (3): 57-60.

Singh, R.P. (1978). Energy accounting in food process operations. Food Technol., 30(4): 40-46.

Sparrow, E.M.; Gregg, J.L. (1959). Laminar condensation heat transfer on a horizontal cylinder. J. of Heat Transfer, Trans. ASME, 81(4): 291-96.

Stewart, Jr. W.E. (1981). Experimental free convection from an inclined cylinder. J. of Heat Transfer, Trans. ASME, 103(4): 817-19.

Van De Pol, D.W.; Tierney, J.K. (1973). Free convection Nusselt number for vertical U-shaped channels. J. of Heat Transfer, Trans. ASME, 95(4): 542-43.

Varshney, N.N. (1978). Energy conservation in dairy plants. Indian Dairyman. XXX (6) : 389-326.

Varshney, N.N.; Narkhede, D.D.; Ojha, J.P. (1979). Modified high temperature short time cream pasteuriser for low energy consumption. J. of Food Sci. & Technol. (India), 16(2): 54-57.

Vautrin, P. (1979). Energy conservation in dairy industry.
(Cited in FSTA, 12(04): P 670, 1980).

Verma, S.K.; Verma, R.D. (1978). Studies on temperature distribution and heat transfer characteristics of milk during agitation. J. of Institution of Engineers (India), 58(12): 51-54.

Vinogradova, [illegible] (19[illegible]). Cooling high butter fat cream [illegible]. (Cited in Dairy Sci. Abstr., [illegible]).

Walzholz, [illegible] (19[illegible]). The production and utilization of [illegible] in German dairies. Dairy Engineering. [illegible].

Wilson, E.E. (1915). A basis for rational design of heat transfer apparatus. Trans. ASME, 37. (Cited by Bennett and Myers, "Momentum, Heat and Mass Transfer", McGraw-Hill Book Co., New York).

Yuge, T. (1960). Experiments on heat transfer from spheres including natural and forced convection. J. of Heat Transfer, Trans. ASME, 82: 214-20.

Yang, J.W. (1973). Laminar film condensation on a sphere. J. of Heat Transfer, Trans. ASME, 95(2), 174-78.

Yung, S.C.; Cotting, [illegible] (19[illegible]). Free convection heat transfer from an inclined heated flat plate in air. J. of Heat Transfer, Trans. ASME, 91(1), [illegible].

APPENDIX - A

ENERGY CONSUMPTION AND HEAT LOSSES IN KHOA MAKING

Type of milk	= Buffalo milk		
Milk	= 5.0 kg	Khoa	= 1.080 kg
Fat %	= 6.6	Moisture %	= 29.6248
Moisture %	= 83.324		

Initial temperature (t_i) = 30.12°C

Final temperature (t_o) = 80.98°C

Surface temperature of vat (t_w) = 109.85°C

Time of operation = 45 minutes

Water evaporated (m_w) = 3.84627 kg

Temperature of steam (t_s) = 119.50°C

Steam pressure = 0.50 kg/cm^2

Temperature of steam leaving vat = 116.50°C

Temperature of condensate leaving vat = 96°C

The analysis of energy was carried out by heat and mass balance.

Heat of steam (Q_s) + Heat of initial product (Q_p) = Heat utilized in processing (Q_v) + Heat losses due to convection & radiation (Q_{c+r}) + Heat losses from product surface (Q_{ps}) + Heat losses with steam and condensate leaving the vat (Q_{s+c}) ....(A-1)

(1) Heat energy entering with steam:

Amount of steam = 6.03 kg

Heat energy (Q_s) = 6.03 x 1 x (119.504525.9) Kcal.

= 3891.762 Kcal

(2) Initial Heat of Product:

Q_p = m.s.Δt. = 5 x 0.7 x(30.12-0)

= 140.058 Kcal.

(3) Heat utilized in Processing:

$$Q_v = m.s.(\Delta t_1) + m_{k.} s_{k.} (\Delta t_2) + m_w . h_{fg}$$

= 5 x 0.74 x(108.13-0) + 3.258 x 0.591 x(115.9 - 108.13)

+ 3.84 627 x 540 Kcal.

= 2494.731 Kcal.

(4) Heat Losses due to Convection and Radiation:

i) Heat losses due to convection:

$$Q_c = h_c . A_1 (t_w - t_a) \times \frac{45}{60} \text{ Kcal}$$

$$= 4.58 \times 0.29029 \times (109.85 - 35) \times \frac{45}{60} \text{ Kcal}$$

= 76.63638 Kcal

ii) Heat losses due to radiation:

$$Q_r = \sigma . \epsilon . A \left[(T_w)^4 - (T_a)^4\right] \times \frac{45}{60} \text{ Kcal}$$

$$= 4.9 \times 10^{-8} \times 0.7 \times 0.29029 \; \left[(109.85 + 273)^4 - (35 + 273)^4\right] \times \frac{45}{60} \text{ Kcal}$$

$$= 91.23272 \text{ Kcal.}$$

Total heat losses due to convection and radiation (Q_{c+r})

$$= Q_c + Q_r$$

$$= (76.63638 + 91.23272) \text{ Kcal}$$

$$= 167.8691 \text{ Kcal}$$

Heat losses with steam and condensate leaving the vat

(Q_{s+c}) = Heat with condensate (65% of total steam consumption) at 96°C and heat with steam (35% of total steam consumption) at 116.5°C.

$$= 3.9195 \times 96 + 2.1105(116.5 + 0.5 \times 528) \text{ Kcal}$$

$$= 1179.3173 \text{ Kcal.}$$

(Dryness fraction of steam leaving vat, x = 0.5)

Substituting all these values in equation (A.1)

$$\therefore 3891.762 + 140.058$$

$$= 2494.731 + 167.869 + Q_{ps} + 1179.317.$$

$$\therefore Q_{ps} = 189.9026 \text{ Kcal}$$

$\therefore$ Heat loss from product surface = 189.9026 Kcal

Now, actual amount of heat utilized for processing

$$= 2494.731 - 140.058$$

$$= 2354.673$$

Similar calculations were carried out for determining energy consumption and heat losses for ghee and paneer processing.

APPENDIX - B

HEAT TRANSFER COEFFICIENT OF MILK DURING KHOA MAKING

Type of milk = Buffalo milk

Amount of milk = 5 kg

Initial temperature (t_i) = 30.12°C

Final temperature(t_o) = 80.98°C

Time interval = 0 to 5 minutes

Steam temp.(t_s) = 119.50°C.

Surface temperature of vat (t_w) = 85.75°C.

Heat gained by milk = M.S.Δ t.

= 5 x 0.74 x (80.98 - 30.12)

= 188.182 Kcal.

Rate of heat transfer, Kcal/hr. = $188.82 \times \frac{60}{5}$

= 2258.184 Kcal/hr

$$Q = U.A_2.\Delta t_m \qquad \text{........(B.1)}$$

Here, A_2 = 0.2640 m^2

Δt_m = L.M.T.D. = 62.4432

$$U = \frac{Q}{A_2.\Delta t_m} = \frac{2258.184}{0.2640 \times 62.4492}$$

= 136.9709 Kcal/m^2-hr-°C

$$\frac{1}{U} = \frac{1}{h_s} + \frac{1}{h_p} + \frac{X}{K_1} \qquad \text{........(b.2)}$$

Calculations for steam side film coefficient (h_s):

Steam pressure = 0.50 kg/cm^2

Steam temperature $= 119.50^{\circ}C$

The properties of steam at mean temperature of $\frac{t_s + t_w}{2} =$

$$= \frac{119.50 + 85.75}{2} \ {}^{\circ}C$$

$$= 102.625^{\circ}C.$$

$$\rho_{f_1} = 958.82 \ kg/m^3$$

$$\rho_{v_1} = 0.6781 \ kg/m^3$$

$$K_1 = 585.545 \times 10^{-3} \ Kcal/m\text{-}hr\text{-}^{\circ}C$$

$$\nu = 0.2867 \times 10^{-6} \ m^2/sec.$$

$$h_{fg} = 537.027 \ Kcal/kg$$

$$\therefore Nu = 0.803 \left[\frac{g(\rho_f - \rho_v) . h_{fg} . D^3}{K . \nu . (t_s - t_w)} \right]^{0.25} \qquad \text{..........(B.3)}$$

where,

$$g = 9.81 \ m/sec^2$$

$$D = 0.41 \ m$$

$$\therefore Nu = \frac{h_s . D}{K_1} = 0.803 \left[\frac{9.81 \times (3600)^2 \times (958.82 - 0.6781) \times 537.027 \times (0.41)^3}{585.545 \times 10^{-3} \times 0.2867 \times 10^{-6} \times 3600 \times (119.5 - 85.75)} \right]^{0.25}$$

$$\therefore h_s = \frac{585.545 \times 10^{-3} \times 0.803}{0.41} \left[\frac{9.81 \times (3600)^2 \times (958.82 - 0.6781) \times 537.027 \times (0.41)^3}{585.545 \times 10^{-3} \times 0.2867 \times 10^{-6} \times 3600 \times (119.5 - 85.75)} \right]^{0.25}$$

$$= 4418.395 \ Kcal/m^2/hr/^{\circ}C.$$

Substituting these values in equation (B.2)

$$\frac{1}{h_p} = \frac{1}{U} - \left(\frac{1}{h_s} + \frac{X}{K_1}\right)$$

$$= \frac{1}{136.9709} - \frac{1}{4418.395} + \frac{2 \times 10^{-3}}{18}$$

$= 5.5878 \times 10^{-3}$ m^2-hr-°C/Kcal

$\therefore h_p = 178.9591$ Kcal/m^2-hr- °C

The physical properties of milk at mean temperature of

$$\frac{80.985 + 30.12}{2} = 55.552°C$$

$\beta = 4.582 \times 10^{-4}$ per °C

$S = 0.74$ Kcal/kg.°C

$\rho = 1019$ kg/m^3

$\mu = 0.99 \times 10^{-3}$ kg.m/sec

$K_2 = 0.537$ Kcal/m-hr-°C

D = characteristic diameter of vat = 0.41 m.

g = 9.81 m/sec^2.

$\Delta t = t_w - t_m = (85.75 - 55.552) = 30.198°C$

$$\therefore Pr. = \frac{\mu . s.}{K_2} = \frac{0.99 \times 10^{-3} \times 3600 \times 0.74}{0.537}$$

$= 6.1722$

$$Gr. = \frac{\beta . g . \rho^2 . (D)^3 . \Delta t}{\mu^2}$$

$$= \frac{4.582\times10^{-4}\times9.81(1019)^2\times(0.41)^3\times30.198}{(0.99\times10^{-3})^2}$$

$$= 9.976\times10^{9}$$

$$\therefore \quad Gr.Pr. = (9.976\times10^{9})\times6.1722$$

$$= 6.1577\times10^{10}$$

$$Nu = \frac{h_p . D}{K_2} = \frac{178.9591\times0.41}{0.537} = 136.635$$

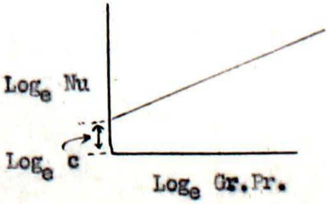
$$Nu = C(Gr.Pr.)^{m}$$

$$136.635 = C(6.157\times10^{10})^{m}$$

Similarly, calculations were done for other time intervals and for other trials of khoa processing and graphs are plotted from which the values of c and m are determined as given below:

$$Nu = C(Gr.Pr.)^{m}$$

$$\log_e Nu = \log_e C + m.\ \log_e (Gr.Pr.)$$



Similar, calculations were done for ghee processing.