DEVELOPMENT AND EVALUATION OF SOLAR PHOTOVOLTAIC OPERATED CREAM SEPARATOR

A thesis submitted to the

DR.BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI – 415712, Maharashtra State (India)

In the partial fulfillment of the requirements for the degree of

MASTER OF TECHNOLOGY

(AGRICULTURAL ENGINEERING)

in

RENEWABLE ENERGY SOURCES

By

MR. NAWALE ABHISHEK NARENDRA

(Regd. No. ENDPM -2016/0101)

DEPARTMENT OF ELECTRICAL AND OTHER ENERGY SOURCES
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Approved by the advisory committee

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CANDIDATE'S DECLARATION

I hereby declare that the experimental work and its interpretation of the thesis entitled " Development and Evaluation of Solar Photovoltaic Operated Cream Separator" or no part there of has been submitted for any other degree or diploma of ant university, nor the data have been derived from any thesis / publication of any university or scientific organization. The sources of material used and all assistance received during the course of investigationhave been duly acknowledged.

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This is to certify that the thesis entitled, **"Development and Evaluation of Solar Photovoltaic Operated Cream Separator"** submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist.Ratnagiri (Maharashtra State) in partial fulfillment of the requirement of award of degree of **Master of Technology (Agricultural Engineering)** in**Renewble Energy Sources,** embodies the result of piece of bonafied research work carried out by **Mr. Nawale Abhishek Narendra (**Reg. No.: ENDPM 2016/0110) under my guidance and supervision. The result embodies in this project report has not been submitted to any other university or institute for the award of any degree or diploma.

The assistance and help received during the course of this project work and sources of the literature have been duly acknowledged.

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The assistance and help received during the course of this investigation and source of the literatures have been duly acknowledged.

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ACKNOWLEDGEMENT

I especially feel immense pleasure in expressing my deepest sense of gratitude to my research guide **Dr. A.G Mohod***, Professor and Head, Department of Electrical and Other Energy Sources, College of Agricultural Engineering and Technology, Dapoli for his precious guidance, valuable suggestions, constant encouragement and help throughout the research work.*

I mention my sincere gratitude **Dr. Y. P. Khandetod***, Dean, Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli for their valuable suggestions from very inception and constant interest in this research work and for giving me an opportunity for undergoing this research work and providing me necessary facilities whenever needed for the same.*

I would like to extend my sincere thanks to **Dr.K.G Dhande** *Assistant Professor, Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Dapoli for his valuable advice, guidance and cooperation throughout the research work. I am thankful to* **Er. R.M Dharaskar***, Assistant Professor, College of Agricultural Engineering and Technology, Dapoli. I am also thankful to* **Mr. Ade (***Ph. D. Scholar), Department of Electrical And Other Energy Sources, CAET, Dapoli for their valuable advice, guidance and cooperation during research work..*

I place on record my deep sense of gratitude to all my course teachers and scientists of College of Agricultural Engineering and Technology, Dapoli for their help and involvement during the course of study.

I am especially thankful to my friends ***Nitin, Raviraj, Nitin, Sandip, Sachin, Manish, Mayur, Ajinkya, Suyog, Shraddha and Kiran*** *for the constant encouragement and timely helpduring this research work.*

I am very much thankful to supporting staff ***Shri.Vaibhav Pimplekar, Shri. ShekharKokamkar, Shri. Santosh Bhuvadand, Shri. Sachin More*** *and others of the Department for their kind co-operation and help during the entire course.*

No wards can adequately express our indebtedness to workshop members, ***Mr. Gimhavanekar N. S., Mr. Kadam S. R., Mr. Mahadik S. V., Mr.Ruke R. P, Mr. Shinde. M, Mr. Sabale. S, Mr.Holkar. P, Mr. Pawar C.M.*** *who have been a source of immense help to me during the course of this project. I am thankful to to* ***Shri. Chogale H. G.*** *Foreman Supervisor for their advice and help.*

My words and feelings will be insufficient to express my heartiest gratitude to my beloved mother ***Mangal*** *and father* ***Narendra,*** *brother* ***Rushikesh, Grandfather and Grandmother*** *for my master studies and other family members for their inspiration, encouragement and providing me opportunities in building up my career.I express my sincere thanks to all those directly and indirectly extended help during the research work.*

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(Nawale A.N.)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

Abbreviations	**Description**
Agril.	Agricultural
ASTM	American Society for Testing of Materials
Amp	Ampere
BCR	Benefit cost ratio
BIS	Bureau of Indian Standards
cm	Centimeter
Cal	Calorie
D.C.	Direct Current
Dr. B. S. K. K. V.	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
E	East
Engg.	Engineering
EOES	Electrical and Other Energy Sources
et al.	Et. Alia (and other)
etc.	Etcetera
Fig.	Figure
Hrs	Hours
hr/kg	Hours per kilogram
I_{sc}	Short circuit current
I_m	Current at maximum power
i.e.	That is
kJ	Kilo Joule
kJ/hr	Kilo Joule per hour
kJ/kg	Kilo Joule per kilogram
Ltd	Limited
PV	Photovoltaic
Rs	Rupees
kW	Kilo Watt
m/sec	Meter per second
m^2	Square meter

Min	Minute
M. S.	Mild steel
MT	Metric tonne
M	Meter
M.C	Moisture content
N	North
No.	Number
Rs.	Rupees
S	Second
SPV	Solar photovoltaic
Sr. No.	Serial Number
V	Volt
V_{oc}	Open circuit voltage
V_m	Voltage at maximum power
W	West
W/m^2	Watt per square meter
$W/m^2\,^oC$	Watt per square meter degree Celsius
Wt.	Weight

LIST OF SYMBOL

Symbols	Description
@	At the rate
.	Full stop
,	Comma
+	Addition
-	Subtraction
×	Multiplication
%	Per cent
&	And
^0C	Degree Celsius
^{0}	Degree
$	US Dollar
λ	Lambda
η	Nita

ABSTRACT

DEVELOPMENT AND EVELUATION OF SOLAR PHOTOVOLTAIC OPERATED CREAM SEPARATOR

by

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2018

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The milk is an important nutritive food for human being worldwide. There are over 264 million dairy cow's worldwide, producing nearly 600 million tons of milk every year. The global average for milk production is approximately 2,200 liters per cow. India is the second largest milk producer, accounting for 27.7 % of world production and producing nearly 166.3 million tons of milk in 2017. Maharashtra state contributes about 6.5% productions in countries total milk production

India has poor electrification rate in rural areas. In 2016, only 55% of rural household had access to electricity and 85% rural household depended on solid fuels. The interrupted power supply to the house hold processor is difficult and leads to loss of milk.

India has tremendous scope of generating solar energy almost throughout the year. The solar photovoltaic system converts solar radiation into electricity at house hold level. The photovoltaic powered skim milk separator eliminated the problem of interrupted power supply at rural level processing of milk. Keeping this view, the projects entitled 'Development & evaluation of solar photovoltaic powered cream separator' had undertaken.

In this research 74 Watt solar panel was used for operating 60 watt D.C. motor. The photovoltaic panel converts solar energy into electricity. The generated electricity was used to operate centrifugal disc assembly with the help of D.C. motor. The centrifugal disc bowl revolves at a speed of 3000 to 4000 rpm and centrifugal force was generated which out ways the gravitational force due to which separated (skimmed) milk being heavier goes towards periphery. Cream being lighter comes towards the centre. The capacity of the cream separator was 60 lit/h.

The overall output of skim milk and cream obtained the after separation was 89 to 92 % and 10 to 13 %. The separation efficiency of SPV operated cream separator for cow and buffalo milk was ranged between 87 to 92 %. SPV operated cream separator was found to be 0.56 Rs./lit for the feed rate 60 lit/h which is less than electric operated cream separator 0.67 Rs./lit and hand operated cream separator 0.52 Rs/lit.Thus the performance of SPV cream separator (for feed rate 60 lit/h) is economically feasible than other cream separator.

I. INTRODUCTION

The milk is an important nutritive food for human being worldwide. There are over 264 million dairy cow's worldwide, producing nearly 600 million tons of milk every year. The global average for milk production is approximately 2,200 liters per cow. India is the second largest milk producer, accounting for 27.7 % of world production and producing nearly 166.3 million tons of milk in 2017. Maharashtra state contributes about 6.5% productions in countries total milk production*(Global Dairy Sector: Status and trends* 2017*).*

The milk production in the country during 2016-17 has achieved a remarkable progress by showing 20.13% growth as compared to 2013-14. Further, the productions have been estimated to be increased by 6.4% in 2016-17 over 2015-16. Thus, there is concurrent high growth rate maintained over the past three years. Aligning with this progressive picture in the current year (2017-18), the dairy sector has gradually picked up its momentum towards the projected target of National Action Plan for Dairy Development (*National Dairy Development Board*2017*).*

In India, out of total milk producers, only 68% people are connected to modern dairy and remaining 32% were out of reach of modern dairy. Dairying has become an important secondary source of income for millions of rural households engaged in agriculture. Nearly 80 per cent of India's milk production is contributed by small and marginal farmers, with an average herd size of one to two milch animals. Indian yield is still much lower than that in the United State, New Zealand and Germany. These countries certainly have an advantage on the cattle breed, and also benefit from extensive mechanization and larger herd size. The success of the dairy industry has resulted from the integrated co-operative system of milk collection, transportation, processing and distribution.

India has the largest population that does not have access to electricity. India has poor electrification rate in rural areas were only 67% of rural household have access to electricity and 85% rural household depend upon solid fuel. Milk is a highly perishable food because of which it is necessary to process it in short period. The processing or storage of milk requires continues electricity for cooling purpose and for making value added products. The uninterrupted power supply to the house hold processor is difficult thus leading to loss of milk. *(Anonymous 2016)*

The supply of secure and uninterrupted electricity power to the remote rural areas could be possible with the help of nature free solar energy. With recent developments, solar energy systems are easily available for industrial and domestic use with the added advantage of minimum maintenance. Solar energy could be made financially viable with government tax incentives and rebates, a solar cell, or photovoltaic cell (PV), is a device that converts light into electric current using the photoelectric effect. The photovoltaic cell is a solid-state device composed of thin layers of semiconductor materials which produce an electric current when exposed to light. Photovoltaic power generation employs solar panels comprising a number of cells containing a photovoltaic material. Materials presently used for photovoltaic include mono-crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride and copper indium selenide/sulfide. Due to the growing demand for renewable energy sources, the manufacture of solar cells and photovoltaic arrays has advanced considerably in recent years.

India being an energy deficient country should consider every possible way to replace conventional energy resources with renewable energy. Among the renewable energy resources, solar energy is the most promising option in food processing applications. There are many opportunities for applications of solar thermal and solar photovoltaic technology in dairy processing plant. It could greatly add to energy savings during the production processes in the dairy sector. This move will contribute to the prosperity of the Indian dairy sector.

The separation of skim milk and cream is the major important operation by using principle of centrifugal force. Centrifugal separation is the mechanical fractionation of a fluid mixture of two or more immiscible phases of differing densities by the imposition of a centrifugal acceleration field. Cream separation works on this phenomenon by which the milk is separated in to cream and skim milk. The centrifugal force is thousand times greater than gravitational force. The milk enters the rapidly revolving bowl of the separator. It is then acted upon by centrifugal force. The inflow of milk is channelized to the outer wall of the bowl and fills it from outside towards the centre. The centrifugal force keeps on continuously acting on the milk to separate the serum and cream. The milk serum has higher specific gravity (1.036) than that of fat (0.9). So, the serum is thrown towards the outer periphery and channelized to skim milk outlet, while the cream is channelized to the central core and forced out through cream outlet.

In the mechanically operated cream separator, the separation of fat is achieved by application of centrifugal force. The centrifugal force acting on the system is about 3000-4000 times greater than the gravitational force. In hand operated cream separator, centrifugal force has to be generated by hand cranking which causes drudgery also the operator could not work continuously for a long time. This results in low efficiency. In electrically operated cream separator, the centrifugal force is created by supplying electric power source.

In rural areas due to interrupted electricity supply it becomes difficult to process the milk at household level. The timely operation of cream separation could be achieved if secure power supply is available at remote area. The use of solar energy is the best solution to overcome the above said problems. Also, using a clean renewable resource with zero emission for cream separation has potential to use the solar photovoltaic system at the rural household levels. Therefore, the project entitled 'Development and evaluation of solar photovoltaic powered cream separator' has been undertaken with following objectives

Objectives-

1) To develop solar photovoltaic powered cream separator for household level.

2) To evaluate the performance of developed solar photovoltaic powered cream separator

II. REVIEW OF LITERATURE

This chapter deals with the reviews or the work done in past by various investigators on the topic taken under study. The reviews are categorized into following subheading.

1. Physical properties and chemical composition of skim milk and cream
2. Development and evaluation of cream separator
3. Solar photovoltaic system and its utilization

2.1 Physical properties and chemical composition of skim milk and cream

Scott*et al.*,(2003) described physical properties of raw milk like color of milk ranging from bluish-white to golden yellow and slightly sweet in test. The pH of milk was 6.6, freezing point varied between -0.53 to -0.57 ^{0}C, boiling point of milk was 100.17 ^{0}C, density of milk and specific gravity were 1.032 and 1032kg/m^{3},respectively. The viscosity of milk was1.5 to 1.7 times more than water.

Tessema *et.al.,* (2004) studied the effect of milk temperature on cream separation. The freshly drawn milk was ideal for skimming i.e. most of cream was easily separated. If milk was below(22^{0}C), some of fat became solid and skimming efficiency was greatly reduced where as milk heated at 45^{0}C gave best skimming efficiency.

Bolling *et.al.*, (2004) described processing effects on physicochemical properties of cream formulated with modified milk fat. It was observed that, ultra-high-temperature-pasteurized natural and reformulated creams were significantly more viscous than high temperature short time pasteurized natural and reformulated creams, indicating that viscosity was highly influenced by thermal process. Homogenization sequence affected the type and amount of surface-active agents at the milk fat interface. Creams homogenized after pasteurization contained more protein and less phospholipids oriented at the milk fat surface. Creams formulated with buttermilk and butter-derived aqueous phase most closelymimicked the physicochemical properties of natural cream.

Singh (2006) reported that average chemical composition of skim milk were moisture 89-92 percent, fat 0.05- 0.1 percent, protein 3.3-3.5 percent, lactose 4.7-5.3 percent and lactic acid 0.5-1.1 percent.

Jangale (2009) reported the average chemical composition of skim milk as fat 0.48 per cent, protein 3.41 per cent, total solids 9.21 per cent and acidity 0.41 per cent and it was in close agreement with the values observed during the research.

Prabhudesai (2010) stated that buffalo skim milk contained an average total solids of 9.15 per cent, fat 0.45 per cent, protein 3.46 per cent and acidity 0.15 per cent.

Anonymous (2011) estimated that characteristics of milk. The average size of a milk fat globule was about 3μm in diameter, but varied from 1 to 18 μm. The milk fat globules were the largest particles in milk but also the lightest. The fat globules have a lower density than milk serum, so the globules float on the surface, which was separated at cream. The density difference was used to separate milk fat from whole milk in high speed, continuous flow and centrifugal separators.

De (2015) reported an average chemical composition of skim milk with moisture 90.6 per cent, fat 0.1 per cent, protein 3.6 per cent, lactose 5.0 per cent and ash 0.7 per cent.

Gantner *et. al.,* (2015) reviewed that the overall and fat composition of milk of various species. They estimated the composition of women, mare, donkey, buffalo, cow, goat, ewe milk.

Table 2.1 Overall milk composition from different animal species - interval values

Milk	TDM (g/100 g)	Fat (g/100 g)	Protein (g/100 g)	Lactose (g/100 g)	Ash (g/100 g)	Energy (kJ/100 g)
Woman	10-13	2.1-4.0	0.9-1.9	6.3-7.0	0.2-0.3	270-209
Mare	9-12	0.4-7.2	1.3-2.0	6.0-7.2	0.3-0.5	109-210
Donkey	8-12	0.3-1.8	1.4-2.0	5.8-7.4	0.3-0.5	160-180
Buffalo	16-17	5.3-15.0	2.7-4.7	3.2-4.9	0.8-0.9	420-480
Cow	12-13	3.3-6.4	3.0-4.0	4.4-5.6	0.7-0.8	270-280
Goat	12-16	3.0-7.2	3.0-5.2	3.2-4.5	0.7-0.9	280-290
Ewe	18-20	4.9-9.0	4.5-7.0	4.1-5.9	0.8-1.0	410-440

Deosarkar (2016) studied various types of cream. It was found that, light cream contained 18 to 20 per cent fat, whipping cream contained 30 per cent fat, heavy cream or heavy whipping cream contained 36 to 38 per cent, double cream contained 48 per cent fat, clotted cream contained 60 to 70 per cent fat and plastic cream contained 65 to 85 per cent fat.

Anonymous (2017) estimated fat content of skim milk. Skimmed milk wasmilk from which sufficient milk fat has been removed to reduced its milk fat content to less than 0.5 percent.

2.2 Development and evaluation of cream separator

Laval (1877) developed a cream separator by using principleof centrifugal force. A drum was used which was rotated and after turning for a time period,the higher fat content of milk (cream) and lower fat content of milk (skim milk) were obtained separately.

Bechtlsheim (1888) developed separator with number of separation zones through a ‘disc stack’. The discs were conical in shape. (Cone angle 60^0) with holes in them to channel milk through identical discs stacked one on top of the other with spacers, fitted on the upper surfaces to provide a gap between adjacent discs.

Anonymous (1906) studied the factor affecting separation and skimming efficiency. The temperature of separation at 45-55^o C gavegood results. Skimming efficiency was quite adequate at moderate speeds of 3000-4000 rpm. The space between disc was important to maintain laminar flow conditions to obtain maximum efficiency of separation. For narrow spacing’s (< 0.2 mm), separation efficiency was independent of disc spacing.

Melick (1906) studied the amount of acid in the milk which caused an irregular variation in the test of cream. The acid in the milk reached a high point i.e. 3 to 4 percent, and the separator was used continuously for an hour or more, it eventually clogged the same as in the case of cold milk. The cream then became thicker until the separator was entirely clogged. The extent of the clogging was depended on the amount of acid in the milk and the size of the machine.

Maitra (2005) discussed the concept, theory and application of centrifugal separation. Several formulae were used to determine the centrifugal force, critical diameter,rotational speed, gravitational force, force in centrifuges, and rate of settling of particles in fluid.

Anantakrishnan*et al.,* (2010) studieda centrifugal cream separator which consisted of principal parts like driving motor, axis, separator bowl, cream spout, skim milk spout, regulating float, faucet and supply tank. Whole milk was introduced into the separator bowl through the faucet. With the help of milk distributor, milk got distributed over the separating disc in the form of thin film. The bowl revolved at a speed of 3000 to 4000 rpm and generated centrifugal force which overcame the gravitational force due to which separated (skimmed) milk being heavier went towards periphery. Cream being lighter came towards the centre of disc. The cream got collected separately through the holes with the help of cream spout. The skim milk was separated by the individual discs which ultimately come out through the skim milk openings provided at the bowl top.

McCarathy (2011) explained aboutcentrifuges and separators with their application in dairy industry.The main types of centrifugal separators used in the dairy industry were the disk bowl centrifuge, the decanter centrifuge, the scroll-screen centrifuge and the cyclone separator.The development of the modern dairy industry began with the introduction of the centrifugal separator. Its use enabled theefficient concentration of milk fat, and then considered theonly milk component of significant value, into the creamstream while minimizing fat loss to the skim milk. Thereplacement of gravitational separation by centrifugalseparation resulted in enormous increases in throughputand efficiency.

Anonymous (2011) derived asimple mathematical formula used to state the minimum requirement of cream percentage from whole milk. A sample of 100kg milk was taken having6 percent fat content. As per the requirement, 40 per cent of fat was to be recovered from the cream found in the sample. The quantity of cream obtained was calculated using mathematical formulae i.e.(6/40)*100 gave 15 kg of cream.

Anonymous (2016) designed a hand operated cream separator for extracting cream from raw milk. The machine was designed for a capacity of 60 liter per hr. The capacity of the tank used was 5 liter. Total 9 discs made of stainless steel were used for separation. The machine was operated at 60 rpm provided by hand cranking. The number of revolution per minute provided for the operation. The dimension of machine was 380mm X 320mm X 500mm.

Anonymous (2016) reported an electrically driven cream separator for whole milk separation into cream and skimmed milk with simultaneous cleansing. It consisted of case with mechanical drive, drum, skim milk receiver, cream receiver, float, float bowl, milk receiver and tap. Milk productivity rate of the machine was 80 l/hr with drum rotation frequency of 10500±1000 rpm. The maximum fat content of skim milk was 0.05 %, the milk was separated at a temperature between 35-40°C and the overall weight of the machine was 75 kg. The single phase electric motor was used in electrical driven cream separator having power 0.25 hp.

Anonymous (2017) described the working and principle of centrifugal cream separator. On application of centrifugal force, the skim-milk particles, having higher specific gravity (1.036) , were forced againstthe bottom side of each disc, traveling toward the periphery of the bowl, while the creamparticles having lower specific gravity (0.9) moved along the upper side of each disc toward the center of the cream separator. The centrifugal force was thousand times greater than gravitational force.In the mechanically operated cream separator, the separation of fat was achieved by application ofthe centrifugal force. Centrifugal force was obtained when the milk obtained desired velocity which was called sedimentation/ floatation velocity. The stroke's low was applied for determination of sedimentation / floatation velocity of milk.

Anonymous (2017) described the various types of cream separator and there working and principal like open design, semi enclosed design, self desludging cream separator and cold milk separator.The open design is the simplest and used only in small capacity machines. Milkenters through a stationary feed tube which projects at least halfway down the depth of therotating bowl. In Semi-enclosed (paring disc) design the entry of milk into such separator was same as for opentype. In operation, each of the separated liquid products (cream, skim milk)rotates at the same speed as the bowl.The limited running time of separators led to the development of amechanism for automatically removing the sludge without interrupting the operation of themachine. Such separators were called 'self-desludging' or 'self-cleaning' separators.Cold cream separators were available that operate at feed temperature of 4-5°C.These allowed separation of milk as it was received at the factory, and although fat losses to skimmilk are somewhat higher, they allow substantial savings in energy and capital costs.

2.3 Solar photovoltaic system and its utilization

Jozef *et. al.*,(2011) described that, photovoltaic technology converts solar energy into electrical energy. Solar radiations fall on semiconductor material. Incident photons transfer their energy making electrons and holes excite, itwas necessary that the electric field is made in semiconductor, which will isolate electrons and holes from each other. This kind of field was acquired by PN junction equipment that can use this effect which is called a photovoltaic (solar) cell.

Sharma(2011) described thatthe global energy consumption was rising rapidly. As a result, a part of the increasingenergy demand is likely to be met by renewable energy sources.Solar thermal and photovoltaic electricity generationare two promising technologies for climate compatiblepower with such enormous potential that, theoretically, they couldcover much more than just the present worldwide demand for electricity consumption.

Maithal (2012) described that opportunities, challenges and strategies for solar energy potential in dairy industries. Several case studies on solar power operated dairy industries were evaluated. Also, the solar energy applications in dairy were found in solar power packs for milk collection centre, small solar hot water systems for milk collection centres and solar hybrid milk chillers.

Kumar*et. al.*(2012) studied solar energy in India. India's solar power reception was about 5000 trillion kWh/ year with about 300 clear sunny days in a year. The daily average solar energy incident over India varied from 4 to 7 kWh/m^{2}with about 2,300–3,200 sunshine hours per year, depending upon location. The daily average global radiation was around 5 KWh/m^2 in north -eastern and hilly areas to about 7 KWh/m^2 in western regions and cold desert areas. The annual global radiation varied from 1600 to 2200 kWh/m^2, which was comparable with radiation received in the tropical and sub-tropical regions.

Anonymous (2013) described the solar energy for dairy farms.The viability of a solar system is highly dependent on the consumption of PV-generated power, and was investigated on an individual basis with a detailed analysis of dairy shed demand and the pattern of solar energy generation. In 2012, systems that might suit a dairy and were connected to the grid ranged from $2,000 to $4,000 for each kW installed, before rebates. At these prices, a 10 kW system would cost between $20,000 and $40,000 and produce 16,000 kWh of electricity each year.

Neerkuzhi(2013) described that feasibility study for the application of solar technologies in dairy plant. Large quantity of wood was used to produce steam in the plant. According to analysis, parabolic trough system was suitable for heating applications in the plant in sunny days. Ecological impacts like, deforestation; global warming etc can be reduced with the reduction of usage of wood (as fuel). By considering the importance of green conservation of our planet and scarcity of energy, it was considered as the future steam boiler for plant.

Desai*et. al.*(2013) described the use of solar energy for sustainable dairy development. There were many different devices used in modern dairy like solar water heater, solar ponds, solar cooker, solar energy for cooling purpose, solar based refrigerator, solar heating for steam generation in dairy, solar drying in dairy operation, solar energy for pumping dairy fluids, solar energy for lighting dairy offices and premises.

Chopade*et. al.*(2015) described a way to prosperity of Indian dairy industries. India being an energy deficient country should consider every possible way to replace conventional energy resources with renewable energy. Among the renewable energy resources, solar energy was the most promising in food processing applications. There were many opportunities for applications of solar thermal and solar photovoltaic technology in dairy processing plant. It could greatly add to energy savings during the production processes in the dairy sector. This move will contribute to the prosperity of the Indian dairy sector.

Patel (2016) described that use of renewable energy in dairy industry. In this context evidences show that the solar and bio-energy was giving the promising results. It was also claimed that if the conventional source of energy used for the working of dairy industries are replaced by renewable sources, the profit margin level will be increase.

III. MATERIALS AND METHOD

This chapter deals with the methodology followed and experimental techniques adopted for conducting experiment. An attempt has been made in the project to develop and evaluates solar photovoltaic operated cream separator at household level to separate cream and skim milk to reduce the dependency on electricity supply as well as to reduce the drudgery. The study deals with the development and performance evaluation of SPV operated cream separator at Department of EOES, CAET, Dapoli.

The stepwise methodology to complete the research work as follow

1. Terminology used in milk and their products.
2. Development of solar photovoltaic operated cream separator.
3. Performance evaluation of developed solar photovoltaic operated cream separator.
4. Economics of developed system.

3.1 Terminology used in milk and their products.

The terminology used to accomplish the task is as below.

3.1.1 Whole milk

It is a raw milk as received basis from milking animal from which no constituent has been removed or added in the milk.

3.1.2 Fat content

The fat content of milk is the proportion of milk, by weight, made up by butterfat. The fat content, particularly of cow's milk, is modified to make a variety of products. The fat content of milk is usually stated on the container, and the colour of the label or milk bottle top varied to enable quick recognition.

3.1.3Cow milk

The whole milk produced from milking cow. The average fat percentage of cow milk ranged between 3 to 5 %.

3.1.4Buffalo milk

The whole milk produced from milking buffalo. The average fat percentage of buffalo milk ranged between 4 to 5 %.

3.1.5Skim milk

Milk from which the cream has been removed, Skim milk contains 0.5 to 0.8percent fat.

3.1.6 Cream

The thick white or pale yellow fatty liquid which rises to top when milk is left to stands, Cream contains 40 to 60 percent fat depending upon the method of separation.

3.1.7 Solid Non Fat (SNF)

The substance in the milk other than the butter fat and water is solid non fat. They include casein, lactose, vitamins and minerals.

3.1.8 Total solid

Total solid is a measure of the suspended and dissolved solid from whole milk.

3.1.9 Pasteurized milk

In pasteurization the milk that has been exposed the briefly to high temperature to destroy microorganism and prevent fermentation.

3.1.10 Skimming efficiency

The skimming efficiency defined as the percentage of total fat in whole milk recovered in the cream separated from it

3.1.11Optimum feed rate

The maximum feed rate at which reasonable skimming efficiency can be obtained.

3.1.12Output capacity

The weight of cream and skim milk received per hour at cream and skim milk outlet of cream separator

3.2 Principal of Separation of Cream

On application of centrifugal force, the skim-milk particles, being heavier, were forced against the bottom side of each disc, traveling toward the periphery of the bowl, while the cream particles moved along the upper side of each disc toward the center of the cream separator. In this way there was no conflict of cream and skim-milk, for easy discharge through two different outlets placed one over the other. Cream separation is a phenomenon by which the milk is separated in to cream and skim milk by centrifugal force.

The centrifugal force is thousand times greater than gravitational force. The milk enters the rapidly revolving bowl of the separator. It was then acted upon by centrifugal force. The inflow of milk was channelized to the outer wall of the bowl and fills it from outside towards the centre. The centrifugal keep on continuously and act upon to partition the serum and cream. The milk serum had higher specific gravity (1.036) than that of fat (0.9). Obviously serum was thrown towards the outer periphery and channelized to skim milk outlet, while the cream was channelized to the central core and forced out through cream outlet. In the mechanically operated cream separator, the separation of fat was achieved by application of the centrifugal force. The centrifugal force acting on the system was about 3000-6000 times greater than the gravitational force.

Hence the separation of fat, as governed by the Stoke's law, was faster than the gravity separation method. Fat globules of smaller size separate at 6500 times faster in a centrifuge rotating at 3500 rpm than compared to under gravity. The Stoke's law as applied to centrifugal separation process was expressed by the following equation: *(dairy processing handbook/ chapter 6.2)*

$$V = \frac{d^2(\rho_s - \rho_1)\omega^2 \mathrm{R}}{18\eta} \qquad \text{-----------------------------------}(1)$$

Where,

Vg = Settling speed in centrifugal acceleration field (ms^{-1})

d = diameter of fat globule (m)

ρ_s = density of milk plasma, $\frac{\mathrm{kg}}{\mathrm{m}^3}$

ρ_1 = Density in continuous phase, $\frac{\mathrm{kg}}{\mathrm{m}^3}$

η = dynamic viscocity $kg\ m^{-1}s^{-1}$

R = distance from axis of rotation (m)

ω =angular velocity (s^{-1})

Generally, the milk was preheated to 37-50^{o}C before separation for optimum results. This makes the process easier and more efficient as the warm milk was less viscous than the cold milk. In-flow of milk was regulated by adjusting the milk inlet valve to the separator. As the disk stack revolves, the cream moves towards the center of the bowl and the skim milk was directed outwards towards periphery by the centrifugal force. Under normal conditions it produced skim milk and cream in the ratio of 90:10 variations in cream richness will vary these proportions.*(Milk separation and pasteurization 2014).*

3.3 Development of SPV operated cream separator

A solar photovoltaic operated cream separator consist of different components viz; photovoltaic panel, DC motor, milk tank, cream separator, stand etc.

3.3.1 Solar photovoltaic (SPV) panel

The average power required 60 watt motor for cream separation, while considering 20 per cent safety factor, the total voltage comes 72 watt hence 74 watt panel available in market was selected for project. The photovoltaic (PV) or solar panel of 12 V, 74 W capacity configured to trap and convert the sun's energy into the useful power was used to perform the work of cream separation from whole milk.

3.3.2 D.C. Motor

A 12 volt, 60 watt, 6 ampere D.C. motor was used to rotate disc bowl of cream separator, a compact size, rust proof, easy to clean and low electric consumption motor was used, and fitted in stainless steel casing.

3.3.3 Coupler shaft

Coupler shaft was used to connect DC motor to disc bowl assembly pin through coupling.

3.3.4 Cream separator bowl assembly

A bowl was rotated at a high speed (3000-4000rpm) by means of suitable gears and power transmission mechanism, arrangement for supplying milk to the bowl, receiving the cream and skim milk.

i. Rubber ring/gasket

It fitted in the bottom of the bowl base and makes the bowl leak proof when bowl hood was placed on its top.

ii. Bowl base

This housed the milk distributor as well as all of the discs on it. It has openings at the bottom of the spindle attached to the body at the centre, from where the milk being fed flows through.

iii. Milk distributor

It distributed the milk into the three notches present at the bottom periphery.

iv. Bottom disc

It was different from the other discs. It has rivets/caulks on the outer as well as on inner surface; all the discs have three holes in them. The discs were known as separating disc. The discs were conical in shape (cone angle approx. 60o) with holes in them to channel milk through.

v. Intermediate discs

They were several in numbers. They were similar to the bottom disc except that these discs do not have rivets on its bottom side. They have rivets on the top side of disc only. The number of discs decided the capacity of the cream separator machine.

Top disc: It was also referred to as ‘Dividing disc’ since the distinction between the skim milk and cream outlet is made possible by this disc. The disc has a passage for the cream to come out from its neck. During separation the cream collected near the axis of the bowl, oozes out from the cream outlet. This disc has got a screw at its neck which can be manipulated to lower or increase the fat content of cream.

vi. Bowl hood

It fited over the top and covered the entire bowl parts and fits into the bowl base at the bottom.

vii. Bowl nut

It was fastened onto the bowl hood using a spanner. This keeps the entire assembly of bowl intact and maintains proper passage between each disc, if properly tightened.

3.3.5 Skim milk spout

The skim milk from the bowl moves between the top disc and inside wall of the bowl hood. Finally, the skim milk passes out through the space provided between the top disc and bowl hood, which connects with the skim milk outlet.

3.3.6 Cream spout

The cream coming out from cream screw located in the top disc was collected in the cream spout and let out to a container.

3.3.7 Float

It allowed only a definite quantity of inflow of milk into the bowl, housed in a regulator.

3.3.8 Supply can

It holds the milk to be separated.

3.3.9 Supporting Stand

Supporting stand was designed to support whole cream separator assembly. The supporting stand was made of mild steel. The schematic view of SPV operated cream separator is shown in Fig 3.1, Fig 3.2 and Plate 3.1 respectively.

3.4 Working of SPV operated cream separator

The SPV operated cream separator with 74 Watt solar panel was used for operating 60 watt D.C. motor. The photovoltaic panel converts solar energy into electricity. The generated electricity was used to operate centrifugal disc assembly with the help of D.C. motor. On /off switch was provided to stop or start the supply of power. The milk feed in to milk tank and it was adjusted through float. Whole milk entered into the separator bowl either through the faucet and regulating float. With the help of milk distributor, milk gets distributed over the separating disc in the form of thin film. The bowl revolves at a speed of 3000 to 4000 rpm and centrifugal force was generated which out ways the gravitational force due to which separated (skimmed) milk being heavier goes towards periphery. Cream being lighter comes towards the centre. Each the cream gets collected separately with the help of cream spout. Skimmed milk hits the inner valve of the bowl top as it was being separated by the individual disc which ultimately comes out through the skim milk openings provided at the bowl top. The capacity of the cream separator was 60 lit/h. The cost of developed SPV operated cream separator as per the prevailing rate was found to be Rs.17,356/-. The technical specification and cost break up of SPV operated cream separator is depicted in Table 3.1 and 3.2, respectively.

Table3.1.Technical specifications of SPV operated Cream Separator

Sr. No.	Component	Specification	Material used
1.	Solar Photovoltaic Panel	Power : 74W, Voltage : 12V Size: 83cm x45cm	Monocrystalline
2.	D.C. Motor	Power :60 W, Voltage :12 volt RPM :3000 to 4000	Brush less motor
3.	Disc bowl assembly	RPM :3000 to 4000	stainless steel
4.	Supply can	Capacity: 5 Lit, Radius= 15.25 cm	Aluminum

		Height= 13.75 cm	
5.	Switch	1 No. on/off	-
6.	Frame		Mild Steel

Table 3.2 Cost of SPV operated cream separator

Sr. No.	Item Name	Cost (Rs.)
1	Solar Panel , 74 W, 12 volt	1776
2	DC Motor, 60 Watt, 12 volt	4660
3	Disc Bowl Assembly, Cream and Skim Milk Receiver	8690
4	Supply Can, 5 Lit	220
5	Stainless steel motor casing	180
6	Fabrication Cost	1560
	Manufacturing cost (Rs.)	Rs.17,356/-
7	Market cost with 30% profit (Rs)	Rs. 22562/-

3.5 Performance evaluation of SPV operated cream separator

The performance evaluation of developed SPV operated cream separator was carried out viz; laboratory and field evaluation.

3.5.1. Laboratory testing of SPV operated cream separator

Laboratory testing of SPV operated cream separator was conducted at EOES laboratory ,CAET, Dapoli to test various operating parameters of SPV operated cream separator.

3.5.1.1 Testing of power characteristics of solar photovoltaic panel

The selected 74 watt solar photovoltaic panel was tested for I-V characteristics. As per standard procedure, solar panel was tested under clear skies, within nine hours of solar noon. Solar cell temperature was allowed to stabilize before being measured. The solar panel was tested from 8:00 to 17:00 hrs for consecutive three days and average value was reported. (Appendix A).The following parameters was measured while testing of solar photovoltaic panel.

1. **Short circuit current (I_{sc}) ,Amp**

   It was the maximum current that SPV panel was produced when panel voltage was zero and no load connected to the module. The Ameter mode was used to measure short circuit current (I_{sc}).

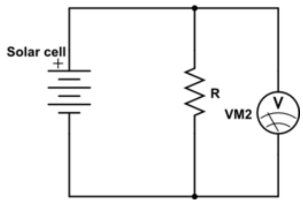


Fig. 3.3 Short circuit current (I_{sc})

2. **Open circuit voltage (V_{oc}) ,Volt**

   It wasthe maximum voltage that SPV panel was produced when the panel current was zero and no loadconnected to the module. The Voltmeter mode was used to measure short circuit current (V_{oc}).

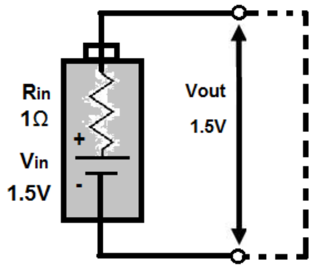


Fig. 3.4 Open circuit voltage (V_{oc})

3. **Current at maximum power (I_m) ,Amp**

   It was current value at maximum power point. It was always less than I_{sc}.

4. **Voltage at maximum power (V_m) ,Volt**

   It was voltage value at maximum power point. It was always less than V_{oc}.

5. **Maximum power point (P_m) , Watt**

   It was the maximum power the panel was produce.

   $P_m = I_m \, x V_m$

6. **Solar intensity , W/m^2**

It was measured with the help of Solarimeter.

3.5.1.2 No load performance of developed solar photovoltaic operated cream separator

The developed solar photovoltaic operated cream separator was tested from 9:00 to 17:00 hrs for four days. The output of rpm of the disc bowl, current and voltage of 60 watt DC motor and solar intensity were recorded.

1. **Solar intensity, W/m^2**

   The solar intensity was measured with the help of solarimeter for whole day at an interval of 1 h on each day.

2. **Voltage, Volt**

   The voltage was measured with the help of multimeter by connecting two terminals in parallel at an interval of 1 h on each day.

3. **Current, Amp**

   The current was measured with the help of multimeter by connecting two terminals in series at an interval of 1 h on each day.

4. **Power, watt**

   The power was measured with the help of multiplication of current and voltage ($P = V \times A$)

5. **RPM of disc bowl**

   The rpm of disc bowl was measured at an interval of 1 h on each day with the help of contact type of tachometer. The suitable time of operation was obtained from the no load testing by consideration the RPM of disc i.e 3500 (Appendix- B)

3.5.2 Load performance of developed solar photovoltaic operated cream separator

The field test was conducted at Department of EOES, CAET, BSKKV, Dapoli. The field testing of SPV operated cream separator was conducted to determine operating parameter of separator using standard test procedure. The SPV operated cream separator was tested separately for standard cow milk and buffalo milk. The cream separator tested from 9 AM to 3:30 PM. Two test for each type of milk was conducted by using 1000 ml of milk for each test. The operating period was recorded along with the corresponding solar intensity, RPM of disc and power consumption the average value of operating parameter for each milk was reported.

The data recorded during the test and average values are summarized in Appendix- C and Appendix- D for cow milk and buffalo milk respectively. The following field parameters were determined during test,

3.5.2.1 Measurement whole milk fat percentage

To obtain best skimming efficiency the standard range of whole milk (cow milk fat is 3 to 5 % and for buffalo milk fat is 4 to 6%) was selected. The whole milk fat percentage was measured by using electronic milk tester before testing. (Plate 3.4)

3.5.2.2 Determination of operation parameters of cream separator parameter

The performance of developed solar photovoltaic cream separator was conducted between 10:00 to 15:00 hr (according to no load test for suitable time period) and at constant feed rate of 1liter /h. The performances were carried out for whole day in winter season from 10:00 to 15:00 hr to evaluate the effect of solar intensity. The milk was controlled by float chamber. The operation time of cream separator was measured in liter per minute (i.e 60 liter per hr). There are two outlet where outlet-1 for cream and outlet-2 for skim milk. The specific gravity of cream is 0.9 and specific gravity of skim milk is 1.28 hence cream was lighter than skim milk hence cream spout was above the skim milk spout.

i. Feed rate

The feed of milk for separation was determined by considering the quantity of whole milk passed with respect to operating time, min

$$\text{Feed rate (ml/min)} = \frac{\text{Quantity of whole milk ,ml}}{\text{Operating time ,min}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

ii. Determination of output quantity of skim milk (ml/min)

The output capacity was determined by measuring quantity of skim milk on hourly basis by noting the quantity of skim milk per unit time using beaker.

iii. Determination of output quantity of cream (ml/min)

The output capacity of cream was determined by measuring quantity of cream on hourly basis by noting the quantity of cream per unit time using beaker. (Plate 3.5)

iv. Determination of fat content of skim milk

The fat content of skim milk was determined by using Gerber Method.It was based on the principle of measuring the volume of fat released from a known volume of milk or known weight of product in a specially devised and accurately calibrated modified cylinder called butyrometer. After taking 10 ml of the Gerber acid (80% concentrated Sulphuric acid) in the butyrometer and 10.75 ml of milk was added to it in such a way that it forms a layer above the acid without mixing with it. Amyl alcohol (1 ml) was added to break the emulsion. The sulphuric acid dissolved the milk fat in it after breaking the fat globule membrane through its coagulating effect on proteins. The fat dissolved in the acid was separated through centrifugal force and read in the stem of butyrometer.

v. Determination of fat content of cream

The fat content of cream was determined by using Gerber Method.15 ml of cream was added to Gerber acid and same method as described above was adopted. (Plate 3.7)

vi. Measurement of energy consumption

The energy consumption for cream separation was measured by multimeter. Total energy used for separation was noted as product of voltage and current used by motor to operate centrifugal disc bowl.

vii. Measurement of separation efficiency

The separation efficiency (E) of a separator is the proportion of the milk fat entering the separator in the whole milk that is recovered in the cream stream. The efficiency equation is derived as a simplified version of the mass balance across the separator. The equation gives very accurate results owing to the large difference between the fat content of the skim milk and whole milk. (Appendix-E)

Calculation of separation efficiency as follow

$$E\ (\%) = 1 - \frac{fs}{fw} \times 100 \text{ -------------------------------------(3)}$$

Where,

E= separation efficiency

$fs =$ skim milk fat content %

$fw = whole\ milk\ fat\ content$ %

Keeping the feed rate and constant RPM during suitable operating time, the effect of solar intensity on output of separator, fat percentage and separation efficiency was observed. *(Milk separation and pasteurization, 2014)*

3.6 Economics of SPV operated cream separator

The economic evaluation of developed SPV operated cream separator was carried in terms of fixed cost, variable cost, total cost and operating cost as Rs./liter of milk. The economical values were compared with different cream separator systems like hand operated cream separator and electrical operated cream separator. The details economical evaluation is summarized in Appendix- F.

3.7 Instrument used during study

The instrument used during the testing of depicted in Table 3.3

Table 3.3 Instrument used during study

Sr. No.	Instrument	Least count	Parameter
1.	Stop watch	0.5 seconds	Time
2.	Solarimeter	1 w/m^2	Solar intensity
3.	Multimeter	-	Voltage and current
4.	Digital thermometer	0.1^{0}c	Temperature
5.	Weighing balance	0.01 gm	Weight of grains
6.	Analogue Tachometer	1 RPM	RPM of Disc Bowl Assembly
7.	i. Measuring tape ii. Scale	1mm 1mm	Dimensions

IV. RESULTS AND DISCUSSION

This chapter deals with the results obtained from the study undertaken with the objectives for development and evaluation of SPV operated cream separator. The results obtained in this study are presented and evaluated under the following sub headings.

4.1Development and working of SPV operated cream separator

4.2 Performance evaluation of SPV operated cream separator

4.3 Operating cost of SPV operated cream separator

4.1Development and working of SPV operated cream separator

The SPV operated cream separator was developed as per the technical specification of components, design values and available material. The working of SPV operated cream separator was observed and different control were installed on the equipment.

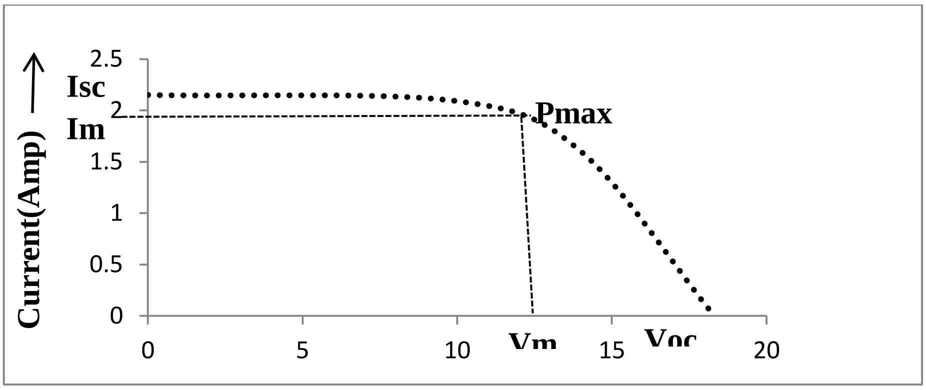
The SPV operated cream separator with 74 Watt solar panel was used for operating 60 Watt D.C. motor. The photovoltaic panel converts solar energy into electricity. The generated electricity was used to operate centrifugal disc bowl assembly with the help of D.C. motor. The On /off switch was provided to stop or start the supply of power. The milk flow from supply tank was adjusted by using float. It allowed only a definite quantity of milk into the bowl. There were two spout one spout for skim milk and other spout for cream. On application of centrifugal force, the skim-milk particles, having higher specific gravity (1.036) , were forced against the bottom side of each disc, traveling toward the periphery of the bowl, while the cream particles having lower specific gravity (0.9) moved along the upper side of each disc toward the center of the cream separator. The newly developed SPV operated cream separator was evaluated for cow milk and buffalo milk separately and compared with conventional cream separator in terms of output, power consumption and cost of operation.

4.2 Performance evaluation of SPV operated cream separator

4.2.1 Laboratory testing of SPV operated cream separator.

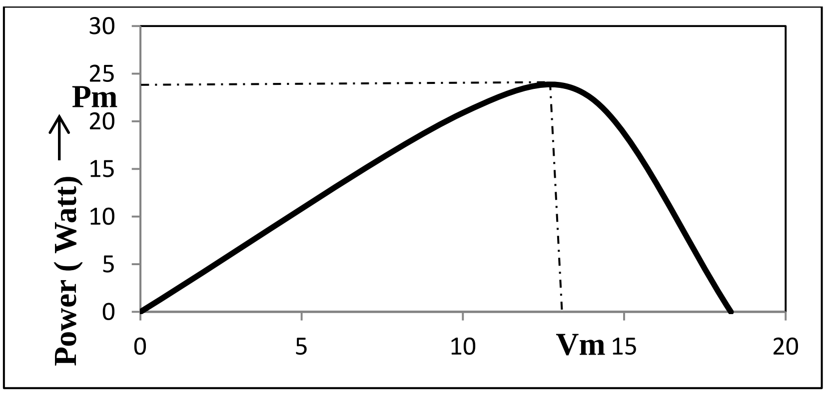
The laboratory testing of SPV operated cream separator was conducted at EOES Laboratory, CAET, Dapoli to test different operating parameters The I-V characteristics and power characteristics of SPV panel and no load performance was carried out for newly developed SPV operated cream separator.

The I-V and power characteristics of the selected 74 watt solar panel were carried out at normal condition on clear sunny day to determine the maximum current, maximum voltage and maximum power developed by solar panel (Appendix- A). The typical I-V characteristic's and power curve of solar panel is shown in Fig.4.1 and Fig.4.2 respectively.



Voltage (Volt)

Fig.4.1 I-V characteristics of solar panel at NTC



Voltage (volt)

Fig.4.2 P-V characteristics of solar panel at NTC

It was observed that, 74 Watt solar panel developed 2.15 amp short circuit current (Isc) and 18.31 volt open circuit voltage. The current at maximum power point (Im) was observed to be 1.6 amp and voltage at maximum power point (Vm) was observed to be 14 volt. The maximum power point of selected 74 Watt panel was found to be 22.4 Watt.

It was revealed that, the selected panel is suitable in terms of current, voltage and power supply to the selected D.C motor for SPV operated cream separator.

The variation of solar intensity and corresponding power from solar panel was recorded for three consecutive days in December. The average values were reported. (Appendix A).The variation of solar intensity and power developed with respect to time is shown in Fig.4.3.

It was observed that, the solar intensity was varied from 88 W/m^2 to 478 W/m^2.The peak value of solar intensity was achieved at 12:00 h (478 W/m^2).Also the power developed by selected 74 Watt solar panel varies from 29.7 Watt to 35.1 Watt. The peak value of power was achieved at 12:00 h (35.1 Watt).

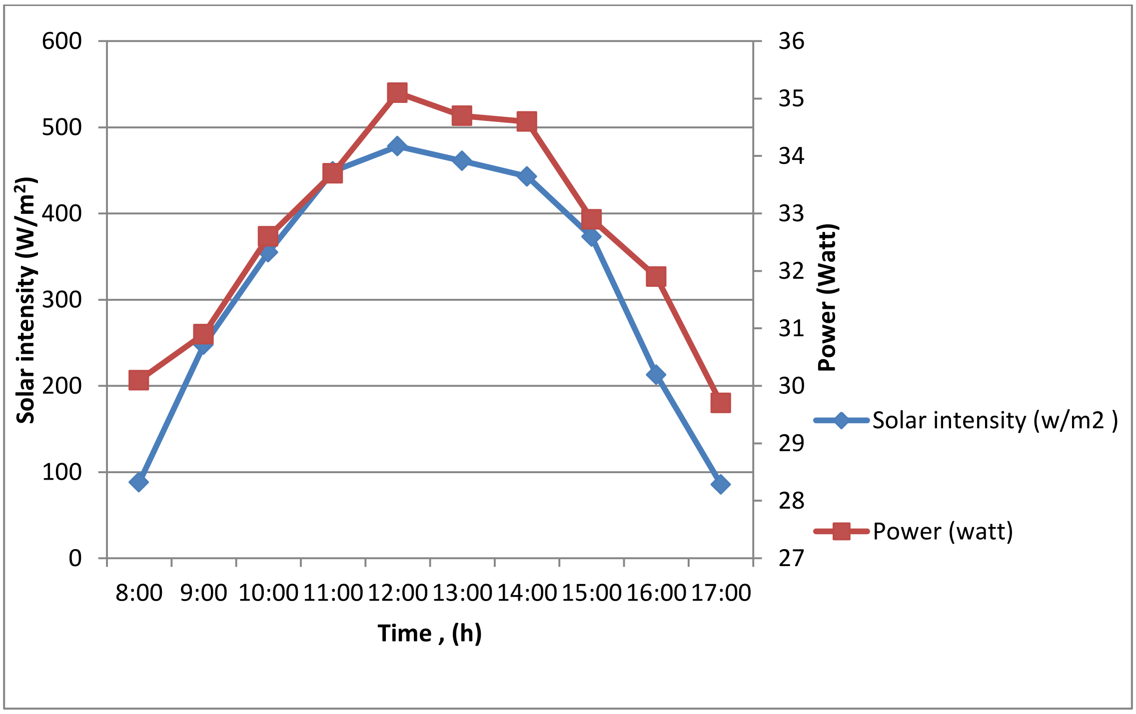


Fig.4.3 Variation of solar intensity and power developed with respect to time

It was revealed that, the power generated by selected solar panel was suitable to operate the selected D.C motor coupled with centrifugal disc bowl.

4.2.1.1 No load performance of developed SPV operated cream separator.

The no load performance of developed SPV operated cream separator was carried on four consecutive days in month of January at energy park of CAET, Dapoli (Appendix-B).Various parameters related to power generation, RPM of centrifugal disc, solar intensity were measured at an interval of 1 h throughout day. The average values of parameters were reported. The result obtained from no load testing is summarised in Table 4.1.

Table 4.1 No load performance of SPV operated cream separator

Time	Solar Intensity (Watt/m^2)	Power (Watt)	RPM
9:00	125	13.44	3036.66
10:00	246.33	14.12	3623.33
11:00	369.66	13.56	3826.66
12:00	416	13.76	3936.66
13:00	414.33	13.56	3940
14:00	401	13.32	3860
15:00	305.33	13.8	3706.66
16:00	208	14.16	3550
17:00	191.66	13.04	3336.66

4.2.1.1.1 Effect of time of day and solar intensity on RPM of centrifugal disc bowl

The effect of time of day on solar intensity and RPM of centrifugal disc bowl were studied to determine the change in RPM of centrifugal disc bowl changed with time and solar intensity. The variation of RPM of centrifugal disc bowl with respect to time and solar intensity is shown in Fig.4.4.

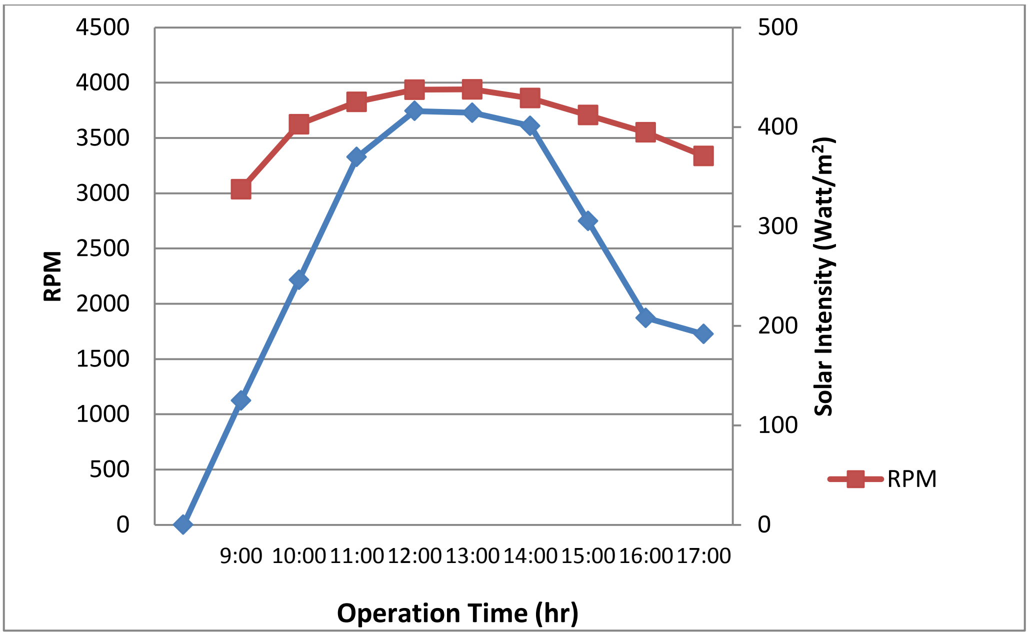


Fig.4.4 Variation of RPM of centrifugal disc bowl with respect to time and solar intensity

It was observed that, the solar intensity directly affect the rpm of centrifugal disc bowl. The maximum solar intensity (416 W/m^2) was achieved at 12:00 h of the day. The maximum rpm of centrifugal disc bowl (3936.66) was achieved at maximum solar intensity. The rpm of centrifugal disc bowl varied from 3100 to 3936.66 with respect to time and solar intensity. The rpm of centrifugal disc bowl increased with increase in solar intensity due to production of higher voltage and current by the solar panel. The required RPM to create centrifugal force for cream separation was 3000 to 4000 RPM. *(Anonymous 1906)*

It was revealed that, the suitable operating period of developed SPV operated cream separator was 10:00 to 15:00hrswith available solar intensity to developed the RPM more than 3500 suitable for cream separation.

4.2.2 Field Performance of SPV operated cream separator

The field testing of SPV operated cream separator was conducted to determine, the different operating parameters as per standard procedure for testing of cream separator.

4.2.2.1 Performance of SPV operated cream separator by using cow milk

The field testing of SPV operated cream separator was tested for cow milk using standard procedure the variation of fat content in the cream with respect to solar intensity and time is summarized in fig 4.6

It was observed that, the solar intensity was varied from 177.5w/m^2 to 478 w from 9:00 hr to 13:00 hr. The average value of solar intensity found to be 377.7 W/m^2. It was observed that the output of skim milk and cream was found to be 891.5 to 911 ml and 89 ml to 108.5 ml respectively. The maximum value of cream output was found to be 108.5 ml out of 1000 ml when the solar intensity was 456.5 W/m^2. The percent of fat content in the cream was varied from 41.5 to 43.5 throughout the day. The average output of cream from cow milk was 100.28 ml (10% of whole milk) consisting of 42.56 % fat.

The revealed that the output of cream separation is within the results reported by the earlier investigator. *(Anonymous 1906)*. The average separation efficiency of SPV operated cream separator using cow milk was found to be 87.25 %. The overall output capacity of newly developed cream separator was found to 60 lit / hr for cow milk separation.

The overall result revealed the suitability of newly developed cream separator for cow milk separation using solar energy

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Table 4.2 Average performance of SPV operated cream separator by using cow milk

Sr No	Time	Solar Intensity (W/m^2)	Input (ml)	Output(ml)	
				Skim Milk (% Fat)	Cream (% Fat)
1	9:00	177.5			
2	9:30	203.5	1000 ml	904 (0.6)	96 (42)
3	10:00	283			
4	10:30	320	1000 ml	899 (0.51)	101 (43)
5	11:00	398			
6	11:30	438.5	1000 ml	902.5 (0.52)	97.5 (43)
7	12:00	455			
8	12:30	470	1000 ml	892.5 (0.46)	107.5 (43.5)
9	13:00	478			
10	13:30	456.5	1000 ml	891.5 (0.5)	108.5 (42.5)
11	14:00	447.5			
12	14:30	430	1000 ml	897.5 (0.46)	102.5 (43)
13	15:00	376.5			
14	15:30	346.5	1000 ml	911 (0.54)	89 (41.5)
Average		**377.17**		**905.14 (0.51)**	**100.28 (42.64)**

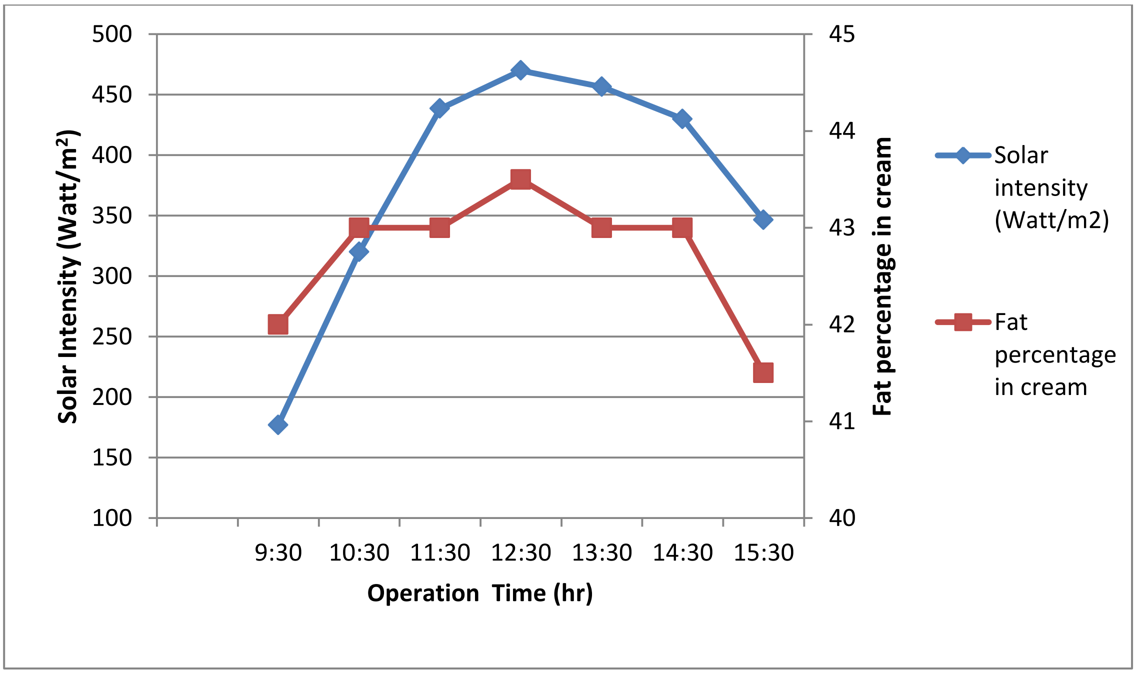

Fig 4.5 Effect of solar intensity and rpm on fat content of cream of cow milk

4.2.2.2 Overall performance of SPV operated cream separator by using buffalo milk

The field testing of SPV operated cream separator was tested for buffalo milk using standard procedure

The variation of fat content in the cream with respect to solar intensity and time is summarized in fig 4.7.

It was observed that, the solar intensity was varied from 188.5w/m^2 to 510 W/m^2 from 9:00 hr to13:00 hr. The average value of solar intensity found to be 391 W/m^2. It was observed that the output of skim milk and cream was found to be 828.25 to 889 ml and 111 ml to 171.5 ml respectively. The maximum value of cream output was found to be 171.5 ml out of 1000 ml when the solar intensity was 317 W/m^2. The percent of fat content in the cream was varied from 58 to 63.5 throughout the day. The average output of cream from cow milk was 139.57 ml (10-13% of whole milk) consisting of 61.21 % fat.

The revealed that the output of cream separation is within the results reported by the earlier investigator. *(Anonymous 1906)*. The average separation efficiency of SPV operated cream separator using buffalo milk was found to be 92.33 %. The overall output capacity of newly developed cream separator was found to 60 lit/ hr for cow milk separation.

The overall result revealed the suitability of newly developed cream separator for cow milk separation using solar energy.

Table 4.3 Overall performance of SPV operated cream separator by using buffalo milk

Sr No	Time	Solar Intensity (W/m^2)	Input (ml)	Output(ml)	
				Skim Milk (% Fat)	Cream (% Fat)
1	9:00 AM	188.5			
2	9:30 AM	215.5	1000 ml	833 (0.45)	167 (58)
3	10:00AM	291.5			
4	10:30AM	317	1000 ml	828.5 (0.45)	171.5 (62)
5	11:00AM	412.5			
6	11:30AM	453	1000 ml	853 (0.50)	147 (62)
7	12:00PM	466			
8	12:30PM	482	1000 ml	862.5 (0.35)	137.5 (62)
9	1:00 PM	510			
10	1:30 PM	506.5	1000 ml	885 (0.5)	115 (63.5)
11	2:00 PM	464			
12	2:30 PM	452.5	1000 ml	872 (0.6)	128 (61)
13	3:00 PM	388			
14	3:30 PM	327	1000 ml	889 (0.40)	111 (61)
Average		**391**		**860.42(0.46)**	**139.57(61.21)**

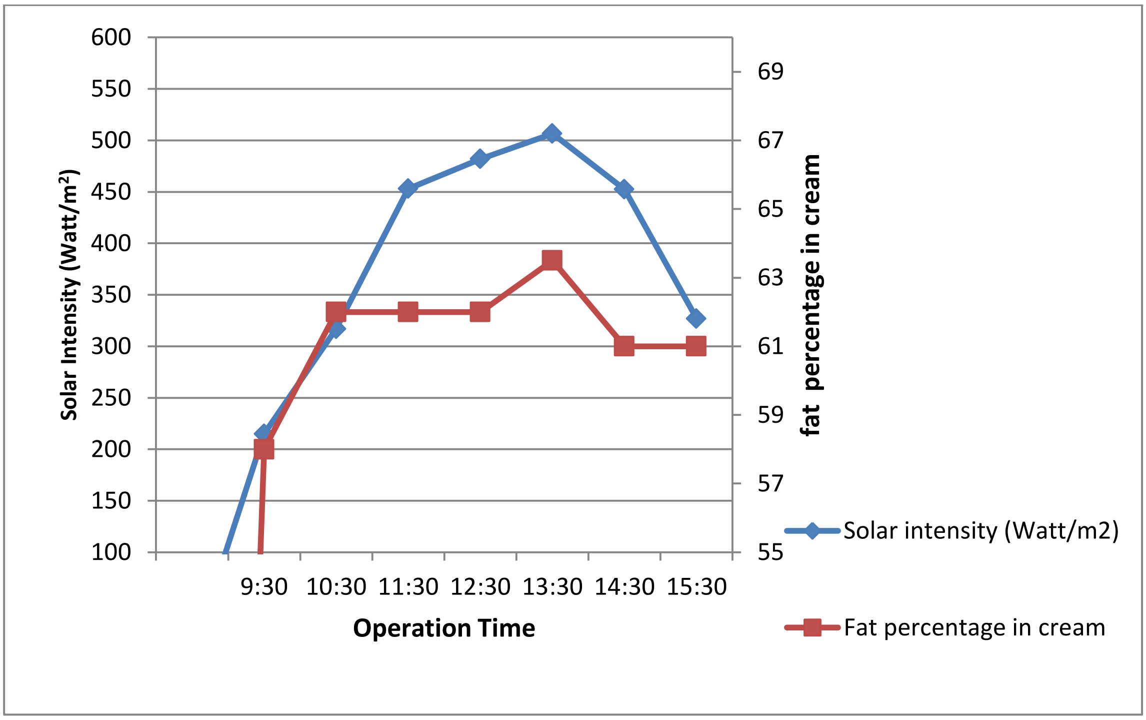

Fig 4.6 Effect of solar intensity and rpm on fat content of cream of buffalo milk

4.4 Operating cost of SPV operated cream separator

The operating cost of SPV operated cream separator for the feed rate of 60lit/h was carried out (Appendix-F).The result obtained is summarized in Table 4.8.

Table 4.4 operating cost of SPV operated cream separator

Sr. NO.	Parameters	Cream Separator		
		Hand Operated	**Electrical Operated**	**Solar Photovoltaic Operated**
1.	Capital Cost, Rs	18333	27500	22562
2.	Output Capacity, Lit/h	60	60	60
3.	Operating Cost, Rs/ lit	0.52	0.67	0.61

It was observed that, the operating cost of SPV operated cream separator was found to be 0.61 Rs./lit for the feed rate 60 lit/h which is less than electric operated cream separator 0.67 Rs./lit and hand operated cream separator 0.52 Rs/ lit . Thus the performance of SPV cream separator (for feed rate 60 lit/h) is economically feasible than other cream separator.

It was revealed that, SPV operated cream separator had low operating cost than electrical operating cream separator. There was no need of electricity to operate the SPV operated cream separator.

The SPV operated cream separator reduces the drudgery in hand operated cream separator and also provide solution for remote area application where electricity is scared community.

V. SUMMARY AND CONCLUSION

5.1 Summary

The project work on SPV operated cream separator was carried out at Department of Electrical and Other Energy Sources, Dr. BSKKV, Dapoli. The newly developed SPV operated cream separator was evaluated for separation of milk into skim milk and cream.

The Photovoltaic (PV) panel of 12V, 74 W capacity configured to trap and convert the sun's energy into the useful power was used to perform the work of cream separation. A solar PV panel was used for operating the cream separator. The motor coupled with centrifugal disc bowl was used to create centrifugal force. On/off switch was provided to stop or start the power supply. The milk tank capacity was 5lit.

The SPV operated cream separator was evaluated in the laboratory and field testing. The laboratory testing included fat content of whole milk, SPV operated panel for I-V characteristics and P-V characteristics, No load performance of SPV operated cream separator. The field testing of SPV operated cream separator using constant quantity of milk at different time at interval of 1 hr to determine the quantity of skim milk and cream obtained, fat content of skim milk and cream also separation efficiency. The overall of cost of the SPV operated cream separator was found to be Rs.17356/-.

It was observed that, the milk which was selected for development and performance of SPV operated cream separator i.e.cow and buffalo had fat content 3 % to 5% and 4% to 6% respectively. It was observed that the selected 74 Watt solar panel was suitable to operate the selected D.C motor coupled with centrifugal disc bowl. It was also observed that, the suitable time of operation for SPV operated cream separator was found 10:00 to 15:00 hrs at rpm of centrifugal disc bowl more than 3000.

It was observed that, in cow milk separation testing the quantity of skim milk and cream obtained varied from 891.5ml to 911ml and 89ml to 108.5ml respectively.

The fat content in that skim milk and cream obtained was 0.4% to 0.7% and 41.5% to 43.5%.

It was observed that, in buffalo milk separation testing the quantity of skim milk and cream obtained varied from 828.5ml to 889ml and 111ml to 171.5ml respectively. The fat content in that skim milk and cream obtained was 0.4% to 0.6% and 58% to 63.5%.

It was observed that, for cow milk the separation efficiency of SPV operated cream separator was 87.25%. Also, for buffalo milk the separation efficiency of SPV operated cream separation was 92.33%.

It was observed that, the operating cost of SPV operated cream separator was found to be 0.56 Rs./lit for the feed rate 60 lit/h which is less than electric operated cream separator 0.67 Rs./lit and hand operated cream separator 0.52 Rs/lit.Thus the performance of SPV cream separator (for feed rate 60 lit/h) is economically feasible than other cream separator.

5.2 Conclusions

- The newly developed portable solar photovoltaic operated cream separator is techno economicaly suitable for separation of skim milk and cream at feed rate of 60 lit/h.
- The overall output of skim and cream obtained at outlet is 89% to 92% and 10% - 13% respectively.
- The overall fat content in obtained skim milk and cream is 0.4% to 0.6% and 40% to 63% respectively.
- The average separation efficiency of cream separator is 89.79% and low operating cost of 0.56Rs./lit.
- The developed SPV operated cream separator provided the solution for cream separation at household level without dependency on natural and secure electric supply.

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Appendix- A

I-V characteristics of solar photovoltaic panel

Test 1 **2/12/2016**

Time	Voc (volt)	Isc (Amp)	Solar intensity (W/m^2)	Power (watt)
8:00	14.8	1.97	84.0	29.2
9:00	15	2.03	245.0	30.4
10:00	15.2	2.13	361.0	32.5
11:00	15.4	2.18	442.0	33.5
12:00	15.9	2.20	464.0	35
13:00	15.8	2.19	455.0	34.6
14:00	15.8	2.19	452.0	34.6
15:00	14.9	2.17	320.0	32.4
16:00	14.7	2.16	206.0	31.8
17:00	13.8	2.18	86.0	30.1

Test 2 **3/12/2016**

Time	Voc (volt)	Isc (Amp)	Solar intensity (W/m^2)	Power (watt)
8:00	14.6	2.05	90	30
9:00	15.2	1.98	247.0	30.1
10:00	15.3	2.13	365.0	32.6
11:00	15.4	2.19	440.0	33.7
12:00	16	2.21	475	35.4
13:00	15.8	2.20	459.0	34.8
14:00	15.8	2.19	433.0	34.6
15:00	14.8	2.22	426.0	32.8
16:00	14.6	2.15	218.0	31.4
17:00	13.9	2.14	87.0	29.8

Test 3 **4/12/2016**

Time	Voc (volt)	Isc (Amp)	Solar intensity (W/m^2)	Power (watt)
8:00	14.8	2.09	90	31
9:00	15.2	2.12	251.0	32.2
10:00	15.4	2.14	340.0	32.9
11:00	15.6	2.17	465.0	33.9
12:00	16	2.19	495.0	35.0
13:00	15.8	2.20	470.0	34.8
14:00	15.7	2.20	445.0	34.6
15:00	14.8	2.26	375.0	33.4
16:00	14.6	2.23	216.0	32.5
17:00	13.7	2.13	84.0	29.2

Average I-V characteristics of SPV panel

Time	Voc (volt)	Isc (Amp)	Solar intensity (W/m^2)	Power (Watt)
8:00	14.7	2.0	88.0	30.1
9:00	15.1	2.0	247.7	30.9
10:00	15.3	2.1	355.0	32.6
11:00	15.5	2.2	449.0	33.7
12:00	16	2.2	478.0	35.1
13:00	15.8	2.2	461.0	34.7
14:00	15.8	2.2	443.0	34.6
15:00	14.8	2.2	373.0	32.9
16:00	14.6	2.2	213.0	31.9
17:00	13.8	2.2	85.7	29.7

Appendix-B

No Load Performance of Solar Photovoltaic Operated Cream Separator

Time	Solar Intensity (Watt/m^2)	Power (Watt)	RPM
9:00 AM	110	13.08	3000
10:00 AM	276	14.04	3760
11:00 AM	370	13.32	3870
12:00 AM	421	13.32	3950
1:00 PM	422	13.32	3940
2:00 PM	402	13.32	3870
3:00 PM	255	14.52	3680
4:00 PM	196	15.36	3620
5:00 PM	190	13.08	3410

Test- 1 **04 Jan 2018**

Test-2 **05 Jan 2018**

Time	Solar Intensity (Watt/m^2)	Power (Watt)	RPM
9:00 AM	105	12.96	3010
10:00 AM	189	13.92	3550
11:00 AM	370	13.32	3870
12:00 AM	421	13.32	3930
1:00 PM	420	13.32	3970
2:00 PM	404	13.08	3840
3:00 PM	325	12.84	3660
4:00 PM	218	13.08	3610
5:00 PM	190	12.6	3210

Test-3 **06 Jan 2018**

Time	Solar Intensity (Watt/m^2)	Power (Watt)	RPM
9:00 AM	160	14.28	3100
10:00 AM	274	14.40	3560
11:00 AM	369	14.04	3740
12:00 AM	406	14.64	3930
1:00 PM	401	14.04	3910
2:00 PM	397	13.56	3870
3:00 PM	336	14.04	3780
4:00 PM	210	14.04	3420
5:00 PM	195	13.44	3390

Average Performance No Load test of Solar Photovoltaic Operated Cream Separator

Time	Solar Intensity (Watt/m^2)	Power (Watt)	RPM
9:00 AM	125	13.44	3036.66
10:00 AM	246.33	14.12	3623.33
11:00 AM	369.66	13.56	3826.66
12:00 AM	416	13.76	3936.66
1:00 PM	414.33	13.56	3940
2:00 PM	401	13.32	3860
3:00 PM	305.33	13.8	3706.66
4:00 PM	208	14.16	3550
5:00 PM	191.66	13.04	3336.66

Appendix C

Average Performance of Solar Photovoltaic Operated Cream Separator Using Cow Milk

Evaluation of solar photovoltaic operated cream separator using cow milk Test- 1

Time	Solar intensity (Watt/m2)	Rpm	Power (watt)	Operating Period (min)	Whole milk Quantity (ml)	Skim milk		Cream	
						Quantity (ml)	Fat Content (%)	Quantity	F Co (
9:00 AM	157	3300	14.4						
9:30 AM	192	3330	15.37	1	1000	915	0.5	85	
10:00 AM	268	3450	15.84						
10:30 AM	325	3500	14.4	1	1000	911	0.4	89	
11:00 AM	376	3510	14.76						
11:30 AM	422	3590	14.76	1	1000	910	0.5	90	
12:00 PM	438	3600	14.76						
12.:30 PM	458	3860	15	1	1000	905	0.4	95	
1:00 PM	446	3820	15						
1:30PM	433	3810	14.88	1	1000	908	0.5	92	
2:00 PM	418	3800	14.88						
2:30 PM	402	3780	14.52	1	1000	913	0.4	87	
3:00 PM	370	3760	14.76						
3:30 PM	346	3710	14.4	1	1000	924	0.5	76	
Average	**360.78**	**3630**	**14.83**	**1**	**1000**	**912.28**	**0.45**	**87.71**	**41**
Date of test:	10/01/2018								
% Fat in whole milk:	4								

Evaluation of solar photovoltaic operated cream separator using cow milk Test- 2

Time	Solar intensity (Watt/m2)	Rpm	Power (watt)	Operation Time (min)	Whole milk Quantity (ml)	Skim milk		Cream	
						Quantity of skim milk	fat percentage in skim milk	Quantity of cream	perc in
9:00 AM	198	3000	14.3						
9:30 AM	215	3500	15.37	1	1000	893	0.7	107	
10:00 AM	298	3760	15.84						
10:30 AM	315	3800	14.4	1	1000	887	0.62	113	
11:00 AM	420	3870	14.76						
11:30 AM	455	3920	14.76	1	1000	895	0.55	105	
12:00 PM	472	3950	14.76						
12.:30 PM	482	3960	14.9	1	1000	880	0.52	120	

1:00 PM	510	3940	14.96						
1:30PM	480	3890	14.88	1	1000	875	0.5	125	
2:00 PM	477	3870	14.88						
2:30 PM	458	3779	14.52	1	1000	882	0.53	118	
3:00 PM	383	3680	14.76						
3:30 PM	347	3620	14.4	1	1000	898	0.59	102	
Average	**393.57**	**3752.78**	**14.82**	**1**	**1000**	**887.14**	**0.57**	**112.85**	**4**
Date of test:		28/02/2018							
% Fat in whole milk		4							

Sr No	Time	Solar Intensity (w/m^2)	Input (ml)	Output(ml)	
				Skim Milk (% Fat)	Cream (% Fat)
1	9:00 AM	177.5			
2	9:30 AM	203.5	1000 ml	904 (0.6)	96 (42)
3	10:00 AM	283			
4	10:30 AM	320	1000 ml	899 (0.51)	101 (43)
5	11:00 AM	398			
6	11:30 AM	438.5	1000 ml	902.5 (0.52)	97.5 (43)
7	12:00 PM	455			
8	12:30 PM	470	1000 ml	892.5 (0.46)	107.5 (43.5)

Average performance of solar photovoltaic operated cream separator using cow milk

9	1:00 PM	478			
10	1:30 PM	456.5	1000 ml	891.5 (0.5)	108.5 (42.5)
11	2:00 PM	447.5			
12	2:30 PM	430	1000 ml	897.5 (0.46)	102.5 (43)
13	3:00 PM	376.5			
14	3:30 PM	346.5	1000 ml	911 (0.54)	89 (41.5)
Average		**377.17**		**905.14 (0.51)**	**100.28 (42.56)**

Appendix- D

Average Performance of Solar Photovoltaic Operated Cream Separator Using Buffalo Milk

Evaluation of solar photovoltaic operated cream separator using buffalo milk Test- 1

Time	Solar intensity (Watt/m^2)	Rpm	Power (Watt)	Operation Time (min)	Whole milk Quantity (ml)	Skim milk		Cream	
						Quantity of skim milk	Fat percentage in skim milk	Quantity of cream	Fa percen in cre
9:00 AM	189	3800	14.76						
9:30 AM	220	3840	15.84	1	1000	835	0.5	165	59
10:00 AM	294	3860	15.84						
10:30 AM	320	3890	14.4	1	1000	830	0.4	170	61
11:00 AM	410	3900	14.76						
11:30 AM	461	3920	14.76	1	1000	875	0.6	125	63
12:00 PM	472	3840	14.76						
12.:30 PM	487	3890	15.12	1	1000	875	0.4	125	62
1:00 PM	509	3920	15						
1:30PM	512	3940	14.8	1	1000	910	0.5	90	63
2:00 PM	466	3880	14.88						
2:30 PM	451	3830	14.52	1	1000	892	0.6	108	61
3:00 PM	389	3750	14.76						
3:30 PM	320	3630	14.4	1	1000	920	0.4	80	60
Average	**392.85**	**3849.28**	**14.9**	**1**	**1000**	**876.71**	**0.48**	**123.28**	**61.**
Date of test:		05/03/2018							
% fat in whole milk		6							

Evaluation of solar photovoltaic operated cream separator using buffalo milk Test- 1

Time	Solar intensity (Watt/m^2)	Rpm	Power (Watt)	Operation Time (min)	Whole milk Quantity (ml)	Skim milk		Cream	
						Quantity of skim milk	Fat percentage in skim milk	Quantity of cream	F perce in cr
9:00 AM	188	3820	14.64						
9:30 AM	211	3840	15.84	1	1000	831	0.4	169	5
10:00 AM	289	3860	15.84						
10:30 AM	314	3890	14.4	1	1000	827	0.5	173	6
11:00 AM	415	3900	14.76						
11:30 AM	445	3910	14.76	1	1000	831	0.4	169	6
12:00 PM	460	3840	14.76						
12.:30 PM	477	3890	14.4	1	1000	850	0.3	150	6

1:00 PM	511	3920	15						
1:30PM	501	3930	14.8	1	1000	860	0.5	140	6
2:00 PM	462	3890	14.8						
2:30 PM	454	3830	14.52	1	1000	852	0.6	148	6
3:00 PM	387	3750	14.76						

Sr No	Time	Solar Intensity (W/m^2)	Input (ml)	Outp
				Skim Milk (% Fat)
1	9:00 AM	188.5		
2	9:30 AM	215.5	1000 ml	833 (0.45)
3	10:00AM	291.5		

3:30 PM	334	3630	14.4	1	1000	858	0.4	142	6
Average	**389.14**	**3850**	**14.83**	**1**	**1000**	**844.14**	**0.44**	**155.85**	**61.**

Date of test:	07/03/2018
% fat in whole milk	6

Average performance of solar photovoltaic operated cream separator using buffalo milk

4	10:30AM	317	1000 ml	828.5 (0.45)
5	11:00AM	412.5		
6	11:30AM	453	1000 ml	853 (0.50)
7	12:00PM	466		
8	12:30PM	482	1000 ml	862.5 (0.35)
9	1:00 PM	510		
10	1:30 PM	506.5	1000 ml	885 (0.5)
11	2:00 PM	464		
12	2:30 PM	784.5	1000 ml	872 (0.6)
13	3:00 PM	735		
14	3:30 PM	720.5	1000 ml	889 (0.40
Average=		**390.70 (W/m^2)**		**860.42 (046 %)**

Appendix- E

Determination of average separation efficiency

A) Determination of average separation efficiency using cow milk.

Calculation of separation efficiency as follow

$$E\ (\%) = 1- \frac{fs}{fw} \times 100$$

Where,

E= Skimming efficiency

$fs =$ skim milk fat content %

$fw = whole\ milk\ fat\ content$ %

i) Separation efficiency of cow milk, test 1

Solar intensity (w/m^2)	**RPM**	**Power (Watt)**	**Percentage of skim milk**	**Percentage of whole milk**
360.78	3630	14.83	0.45	4

$$E= 1- \frac{0.45}{4} \times 100$$

$$= 88.75\ \%$$

ii) Separation efficiency of cow milk, test 2

Solar intensity (w/m^2)	**RPM**	**Power (Watt)**	**Percentage of skim milk**	**Percentage of whole milk**
393	3752	14.82	0.57	4

$$E= 1- \frac{0.57}{4} \times 100$$

$$= 85.75\ \%$$

iii) Average separation efficiency using cow milk

Solar intensity (w/m^2)	RPM	Power (Watt)	Percentage of skim milk	Percentage of whole milk
376.89	3691	14.82	0.51	4

$$E = 1 - \frac{0.51}{4} \times 100$$

$$= 87.25\ \%$$

B) Determination of average separation efficiency using buffalo milk.

i) Separation efficiency of buffalo milk, Test 1

Solar intensity (w/m^2)	RPM	Power (Watt)	Percentage of skim milk	Percentage of whole milk
392.85	3849	14.90	0.48	6

$$E = 1 - \frac{0.48}{6} \times 100$$

$$= 92\ \%$$

ii) Separation efficiency of buffalo milk, test 2

Solar intensity (w/m^2)	RPM	Power (Watt)	Percentage of skim milk	Percentage of whole milk
389.14	3850	14.83	0.44	6

$$E = 1 - \frac{0.44}{6} \times 100$$

$$= 92.66\ \%$$

iii) Average separation efficiency using cow milk

Solar intensity	RPM	Power (Watt)	Percentage of	Percentage of

(w/m^2)			**skim milk**	**whole milk**
390.99	3849.5	14.86	0.46	6

$$E = 1 - \frac{0.46}{6} \times 100$$

$$= 92.33\ \%$$

APPENDIX F

Cost Estimation

A) SPV operated cream separator

Cost of manufacturing – Rs. 17356/-

Working life – 10 years

Annual use – 90 days = 300 hours

Salvage value – 10 per cent

Insurance cost and taxes – 10 per cent

Maintenance cost – 2 per cent

Cost of housing – 1 per cent

Market cost with 30% profit= 22562/-

Fixed cost per hour

Depreciation (Rs/hr)

$$= \frac{C-S}{L \times H}$$

$$= \frac{(22562+2256.2)}{10\times350}$$

$$= 5.80 \text{ Rs/h}$$

Interest (Rs/hr)

$$= \frac{C+S}{2} \times \frac{i}{H}$$

$$= \frac{(22562 + 2256.2) \times 10}{2 \times 350 \times 100}$$

$$= 3.54 \text{ Rs/h}$$

Insurance and taxes (Rs/hr)

= 10 per cent of initial cost

$$= \frac{(0.02 \times 22562)}{350}$$

= 1.62 Rs/h

Housing

= 1 per cent of initial cost

$$= \frac{(0.01 \times 22562)}{350}$$

= 0.64 Rs/h

Total fixed cost = 5.80 + 3.54+ 1.28 + 0.64

= 11.26 Rs/h

Variable cost

Lubricating cost = 1 per cent of fixed cost

$$= \frac{(1 \times 11.26)}{100}$$

= 0.1126 Rs/h

Operator cost = wages of operator/ working hours

$$= \frac{180}{8}$$

= 22.5 Rs/h

Repair and maintenance cost (Rs/h) = 10 per cent initial cost

$$= \frac{(5 \times 22562)}{(100 \times 350)}$$

= 3.22 Rs/h

Total variable cost = 0.1126 + 22.5 + 3.22

= 25.83 Rs/h

Total operating cost = Fixed cost + Variable cost

= 0.1125 + 25.83

= 37.09 Rs/h

Capacity of machine = 60 lit/h

Operating cost of machine = 0.61 Rs/lit.

Where,

C = Initial cost, Rs

H = Annual use of machine, hr

I = Interest rate, per cent

L = Total life of machine, yrs

S = Salvage value, Rs

B) Hand operated cream separator

Cost of machine – Rs. 18333/-

Working life – 10 years

Annual use – 90 days = 300 hours

Salvage value – 10 per cent

Insurance cost and taxes – 10 per cent

Maintenance cost – 2 per cent

Cost of housing – 1 per cent

Fixed cost per hour

Depreciation (Rs/hr)

$$= \frac{C-S}{L \times H}$$

$$= \frac{18333 - 1833.3}{10 \times 350}$$

= 4.71 Rs/h

Interest (Rs/hr)

$$= \frac{C+S}{2} \times \frac{i}{H}$$

$$= \frac{(18333 + 1833.3) \times 10}{(\,2 \times 100 \times 350)}$$

= 0.29 Rs/h

Insurance and taxes (Rs/hr) = 10 per cent of initial cost

$$= \frac{0.02 \times 18333}{350}$$

= 1.05 Rs/h

Housing = 1 per cent of initial cost

$$= \frac{0.01 \times 18333}{350}$$

= 0.52 Rs/h

Total fixed cost = 4.71 + 0.29 + 1.05 + 0.52

= 6.57 Rs/h

Variable cost

Lubricating cost = 1 per cent of fixed cost

$$= \frac{1 \times 6.57}{100}$$

= 0.0657 Rs/h

Operator cost = wages of operator/ working hours

$$= \frac{180}{8}$$

= 22.5 Rs/h

Repair and maintenance cost (Rs/h) = 10 per cent initial cost

$$= \frac{0.05 \times 18333}{350}$$

= 2.62 Rs/h

Total variable cost = 0.0657 + 22.5 + 2.62

= 25.19 Rs/h

Total operating cost = Fixed cost + Variable cost

= 6.57 + 25.19

= 31.76 Rs/h

Capacity of machine = 60 lit/h

Operating cost of machine = 0.52 Rs/lit.

Where,

C = Initial cost, Rs

H = Annual use of machine, hr

I = Interest rate, per cent

L = Total life of machine, yrs

S = Salvage value, Rs

C) Motor operated cream separator

Cost of machine – Rs. 27500/-

Working life – 10 years

Annual use – 90 days = 300 hours

Salvage value – 10 per cent

Insurance cost and taxes – 10 per cent

Maintenance cost – 2 per cent

Cost of housing – 1 per cent

Fixed cost per hour

Depreciation (Rs/hr)

$$= \frac{C - S}{L \times H}$$

$$= \frac{(27500 - 2750)}{10 \times 350}$$

$= 7.07$ Rs/h

Interest (Rs/hr)

$$= \frac{C+S}{2} \times \frac{i}{H}$$

$$= \frac{(27500 + 2750) \times 10}{2 \times 350 \times 100}$$

$= 0.43$ Rs/h

Insurance and taxes (Rs/hr) = 10 per cent of initial cost

$$= \frac{0.02 \times 27500}{350}$$

$= 1.57$ Rs/h

Housing = 1 per cent of initial cost

$$= \frac{0.01 \times 27500}{350}$$

$= 0.79$ Rs/h

Total fixed cost = 7.07 + 0.43 + 1.57 + 0.79

= 9.86 Rs/h

Variable cost

Electricity consumption = 0.5×7.56

= 3.78 Rs/h

Lubricating cost = 1 per cent of fixed cost

$$= \frac{1 \times 9.86}{100}$$

= 0.0986 Rs/h

Operator cost = wages of operator/ working hours

$$= \frac{180}{8}$$

= 22.5 Rs/h

Repair and maintenance cost (Rs/h) = 10 per cent initial cost

$$= \frac{0.05 \times 27500}{350}$$

= 3.93 Rs/h

Total variable cost = 0.0986 + 22.5 + 3.93 + 3.78

= 30.3086 Rs/h

Total operating cost = Fixed cost + Variable cost

= 9.86 + 30.31

= 40.17 Rs/h

Capacity of machine = 60 lit/h

Operating cost of machine = 0.67 Rs/lit.

Where,

C = Initial cost, Rs

H = Annual use of machine, hr

I = Interest rate, per cent

L = Total life of machine, yrs

S = Salvage value, Rs