PROJECT REPORT OF MAJOR - II

Feasibility Study of Concentrated Solar Thermal Steam Cooking System: An Application in DTU Hostel

Submitted in partial fulfilment of the requirement for the award of degree of

Master of Technology
In
Renewable Energy Technology

Submitted by

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CANDIDATE’S DECLARATION

I, hereby declare that the work which is being presented in this dissertation, titled **“Feasibility Study of Concentrated Solar Thermal Steam Cooking System: An Application in DTU Hostel”** towards the partial fulfillment of the requirements for the award of degree of **Master of Technology** with specialization in RENEWABLE ENERGY TECHNOLOGY from Delhi Technological University Delhi, is an authentic record of my own work carried out under the supervision of **Dr Rajesh Kumar (Associate Professor) and Dr J.P. Kesari (Associate Professor)**, Mechanical Engineering Department, Delhi Technological University, Delhi.

The matter embodied in this dissertation record has not been submitted by me for the award of any other degree.

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CERTIFICATE

This is to certify that the work embodied in the dissertation entitled **“Feasibility Study of Concentrated Solar Thermal Steam Cooking System: An Application in DTU Hostel”** by Vikas Kumar Tomar (2K15/RET/17) in partial fulfilment for the award of degree of Master of Technology in Renewable Energy Technology, is an authentic record of student’s own work carried out under my guidance and supervision.

It is also certified that the report has not been submitted to any other institute/university for the award of any degree.

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ABSTRACT

Feasibility study of Concentrated Solar Thermal Steam Cooking System has performed for climatic conditions of Delhi by taking the case of DTU boys hotel mess to replace LPG cooking system. Energy requirement for mass cooking in DTU mess is calculated to be 288981 KWh which till now is fulfilled by 15 LPG cylinders each of capacity of 14kg. An attempt is made to fulfill this requirement with solar energy using Scheffler Dish, although it is also known that complete energy requirement cannot be fulfilled due to unavailability of solar radiations at night, in monsoon and sometimes in winter. Almost 50% of energy requirement i.e.143880 KWh can meet by this system using 25 Scheffler Dish of 16m^2. Calculations for CO_2 emission due to burning of LPG in DTU hostel mess is also done which comes out to be 189 tonne and it is shown that with implementation of such a cooking system almost 50% of CO_2 emission can be controlled. There is variation in output of Scheffler collector system with change in DNI. System efficiency affected by optical efficiency and temperature difference of feed water an steam and show decreasing slope with increase in temperature difference. A small comparison of efficiency between Parabolic Dish and Scheffler Dish is done in which former prevails but have disadvantage of moving focus which in turn required a flexible piping system for flow of steam and water. Cost of this project that is bear by DTU is around 62 lakh with payback period of 2.84 years. This system has proposed with keeping in mind that it could prove a model to encourage other institutions in Delhi for implementing this technology for mass and collective cooking.

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NOMENCLATURE

CEA	Central Electricity Authority
MNRE	Ministry of New and Renewable Energy
CST	Concentrated Solar Thermal
Mtoe	Million tons of oil equivalent
NISE	National Institute of Solar Energy
KWh	kilo Watt Hour
ISR	Indian Solar Resource
MW	Mega Watt
GW	Giga Watt
LPG	Liquefied Petroleum Gas
DTU	Delhi Technological University
GHG	Green House Gas
DNI	Direct Normal Irradiance
GHI	Global Horizontal Irradiance

CHAPTER 1

INTRODUCTION

1.1 WORLD ENERGY SCENARIO

Last century was the era of consuming conventional power sources for power generation in order to fulfill the energy demand which arises due to industrialization. Some countries like USA and other European countries consumes more than their share of conventional energy in order to become develop as a result of which the developing countries of present world has to bear the load. This process continues till now only the energy consumers have changed. At present the total energy demand of world has risen to 13147.3 mtoe (according to the table 1.1 As given below) but this demand does not have equal share of all countries in world.

***Table 1.1: Primary Energy Requirement Of Different Countries (in mtoe)*[1]**

Country	Oil	Natural gas	Coal	Nuclear energy	Hydro-electric	Renewable	total
USA	851.6	713.6	396.3	189.9	57.4	71.7	2280.6
China	559.7	177.6	1920.4	38.6	254.9	62.7	3014.0
India	195.5	45.5	407.2	8.6	28.1	15.5	700.5
Japan	189.6	102.1	119.4	1.0	21.9	14.5	448.5
Saudi Arabia	168.1	95.8	0.1	-	-	-	264.0
Brazil	137.3	36.8	17.4	3.3	81.7	16.3	292.8
Russia	143.0	352.3	88.7	44.2	38.5	0.1	666.8

South Korea	113.7	39.2	84.5	37.3	0.7	1.6	276.9
Germany	110.2	67.2	78.3	20.7	4.4	40.0	320.6
Canada	100.3	92.2	19.8	93.6	86.7	7.3	329.9
World	4331.3	3135.2	3839.9	583.1	892.9	364.9	13147.3

During second half of 20th century USA was the main consumer of conventional sources but today China has surpasses the USA energy demand and consuming around 1.5 times of USA present demand as shown in above table 1.. India is at the third position with the total energy demand of about 7010.5 mtoe. Till 2015 oil and coal plays the lead role as primary fuel for power generation with a share of about 70 percent. But as these fuels prove to be the main cause of degradation of our environment, various countries has shown their concern in renewable energy sources. Presently around 364.9 mtoe of power is being generating from RES. Hydro and nuclear power are also have their contribution in world energy generation but it is not comparable to conventional energy sources with both have a combined contribution of 3135 mtoe. Natural gas with a part of 3135 mtoe is at the third place in world energy generation. [1]

1.1.1 Energy Crisis

Energy is the backbone of world economic development and is the vital element for gradual growth of world economy. The sustainable growth of Indian economy depends upon the energy which can be harvested from those sources which are economical, accessible and renewable in nature. Over consumption of conventional energy sources by developed and developing countries in the past few decades results in serious problems to environment like global warming and acid rain and has become a subject to ponder upon. Over the last few decades, sharp rise has been marked in the energy demand by the developing countries like India and China and it assumes significant part of their annual budget.

The development of IC engines bestowed the world in Nineteenth century but also becomes a major source of environmental degradation. In past few years various conventions and protocols have been signed by the various countries to promote the use of renewable sources of energy. Diesel engine has higher efficiency among the present technologies which makes them a perfect candidate for agriculture, transport and power sector. Since India is a developing country and has agrarian economy, it is highly dependent on diesel engines. On the other hand this technology has causes the environmental pollution and harmful emissions which demands the urgent need to switch to some renewable energy source.

At present the solar energy seems to be the solution to the problem of energy crisis and environmental degradation. Various technologies have been developed to generate power and thermal energy using Sun light. Scheffler Dish is one of those technologies which was developed by Wolfgang Scheffler in 1990.

1.1.2 Future outlook

World energy request is anticipated to develop by 1.3% p.a. from 2015 to 2035. Practically the greater part of this development originates from rising economies, with China and India representing over a large portion of the expansion. Global vitality power (the proportion of vitality request to GDP) is anticipated to decay by 2% p.a. over this period – speedier than in any 20-year time frame since 1965. Gas becomes quicker than coal and oil, (1.6% p.a.), overwhelming coal to turned into the second-biggest worldwide fuel source by 2035. Oil remains the prevailing worldwide fuel and keeps on growing (0.7% p.a.) however at an abating pace. Coal development moderates forcefully (0.2% p.a.), well underneath the normal development of the past 20 years (2.7% p.a.). Coal request tops in the mid-2020s. Nuclear, hydro and other renewable together record for half of the development in vitality supplies throughout the following 20 years, with their offer in essential vitality ascending from 15% to 23% by 2035.

Solar and wind are the two quickest developing energizes, with sunlight based rising more than eightfold and wind more than fourfold.

Almost 66% of the expansion in worldwide vitality request is for control era, as the world economy proceeds to electrify. Global fluids request (oil, biofuels furthermore, different fluids) increments by around 15 Mb/d to achieve 110 Mb/d by 2035. The vehicle area represents around two thirds of this expansion sought after. Global oil creation progresses toward becoming geologically more focused as minimal effort makers pick up offer. The Middle East, US, and Russia represent 63% of oil generation in 2035, up from 56% in 2015. Shale gas represents around 66% of the development in worldwide gas supplies over the Outlook and a fourth of worldwide gas supplies by 2035. Liquefied petroleum gas develops almost three times quicker than universal gas exchange, so by 2035 LNG represents around half of all all around exchanged gas. CO_2 discharges from vitality utilize keep on growing, ascending by 13% by 2035. This is in spite of discharges developing at not exactly a third of the rate found previously 20 years (0.6% p.a. versus 2.1% p.a.). [2]

1.2 Indian Energy Scenario

India stands at third position in world in total energy demand, whereas around 70 percent of its primary energy demand is being fulfilled through the imports in the form of natural gas and oil. India has increased its installed power generation capacity from 1362 MW to 319,606 MW since independence. India is a country with more than 1.27 billion people speaking to for over 17% of world's masses. India is arranged as seventh rank as far as territory though fourth most elevated on the planet as far as vitality use. There are parcel of energy issues confronted by Indian power area and enterprises that is the reason Indian government now concentrates on different activities to advance "make energy from inexhaustible sources". Limit of energy plants have been increased like megawatt to gigawatt to spare the nation from energy crunch. Absence of power and energy neediness is one of the significant issues confronted by Indians. In recent years, energy utilization in India has expanded at a for the most part snappier rate because of population expansion and fiscal headway, in spite of the way that the base rate may be to some degree low.[3]

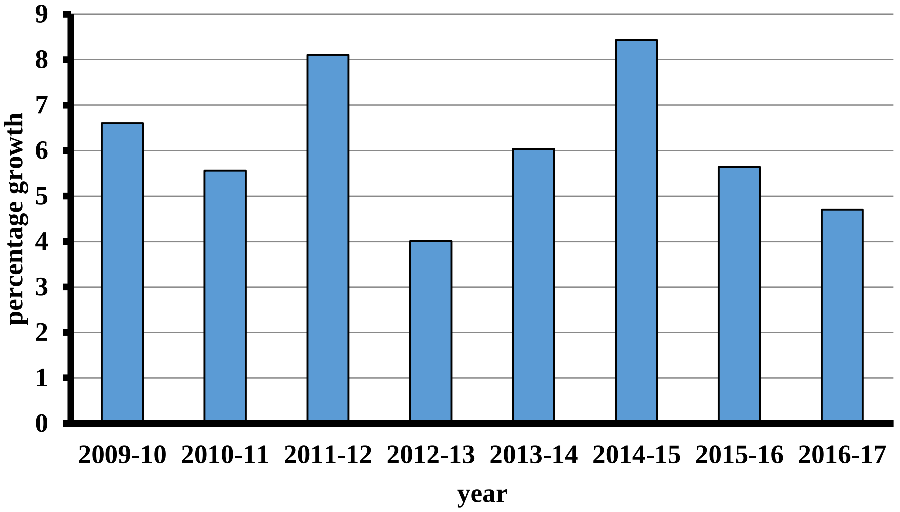


Fig. 1.1: percentage growth in power generation

India, which needs to develop its framework to keep pace with the monetary and social changes, confronts an impressive test. Power necessities have risen strongly lately, and this pattern is probably going to proceed within a reasonable time-frame. As on April 2017, total installed capacity of India is 319.6 GW, with coal at the first place as source of energy, followed by hydroelectric power. Renewable energy is at the third place with 15.6% of total installed capacity.

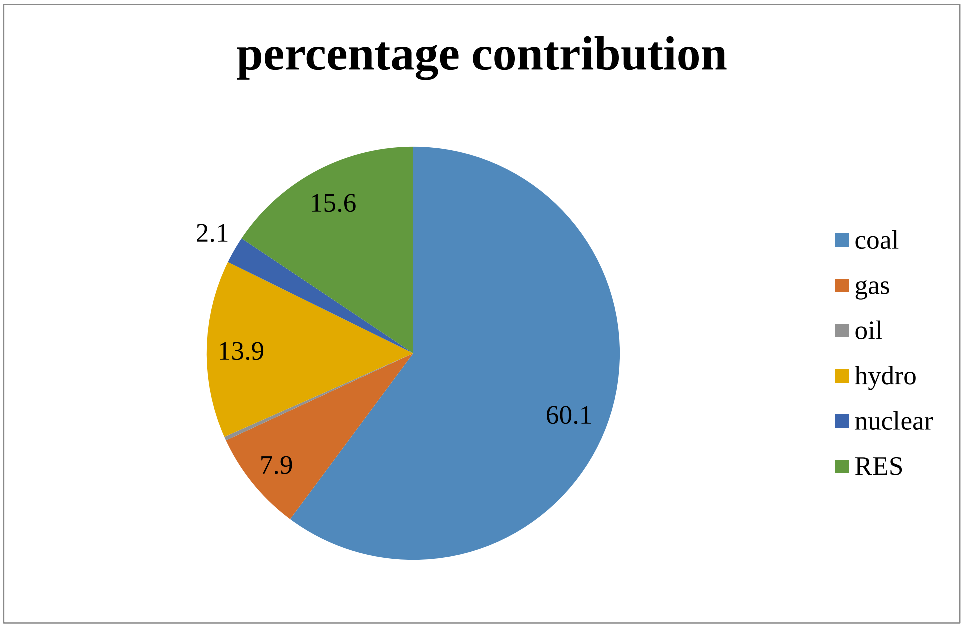


Fig1.2: Share of various sources in power generation in INDIA [5]

Today India is one of the topmost leading countries in terms of energy production. According to the data published by Indian power sector as on 31 Jan 2017 (Table 1.1), private sector has shown a remarkable change as it contributed almost 40% of the total power generation. As compared to the previous data state government also presented a appreciable change because it contributed around 35% of the total production and also reduced the load on central government in terms of power distribution and other financial facts. Till now central government has not contributed towards the production of power using renewable energy sources.

Table 1.2: Total installed utility power generation as on 31 JAN 2017 [2]

Sector	**Coal**	**Gas**	**Diesel**	**Nuclear**	**Hydro**	**RES**	**Grand Total In (MW)**
Central	51930	7490	0	5780	11651.43	0	76852.16
State	64195.5	7257.95	363.93	0	29418	1976.67	103212
Private	72362.38	10580	473	0	3120	48041	134577.81
All India	188487	25329.15	837	5780	44189.43	35776.96	314642.17

1.3 Renewable Energy Sources

The capacity of practical power sources is epic as they can deal with the world's energy demand. Renewable power sources, for instance, biomass, wind, sun, hydro power and geothermal can give a system free from polluting elements, in light of the use of routinely available indigenous sources. A move to feasible based imperativeness systems is looking logically likely as their costs rot while the cost of oil and gas continue fluctuating. In the past 30 years sun based and wind control systems have experienced brisk arrangements growth, declining capital costs and costs of energy

created, and have continued upgrading their execution qualities. Frankly, oil based good and practical power source expenses, and social and biological costs are heading in opposite orientation and the financial and game plan segments anticipated that would support the extensive dispersal and viable markets for economical power source systems are rapidly creating. It is ending up plainly obvious that future development in the vitality division will be fundamentally in the new administration of sustainable power source, and to some degree gaseous petrol based frameworks, not in the traditional oil and coal sources. In light of these improvements advertise opportunity now exists to both advance and to exploit developing markets to advance sustainable power source innovations, with the extra help of government and well known assumption. The improvement and utilization of sustainable power sources can upgrade differing qualities in vitality supply markets, add to securing long haul practical vitality supplies, help lessen neighbourhood and worldwide climatic discharges, and give financially appealing alternatives to meet particular vitality benefit needs, especially in creating nations and rustic ranges making new business openings there.

As now, total installed capacity of renewable power in India is about 50 GW in which wind power assumes the highest contribution with around 29 GW. Solar energy which is considered as the primary source of energy on Earth is at the second position with a contribution of about 9 GW. Undoubtedly, Solar energy required more attention and lot of research for improving the available methods of harnessing Solar energy.

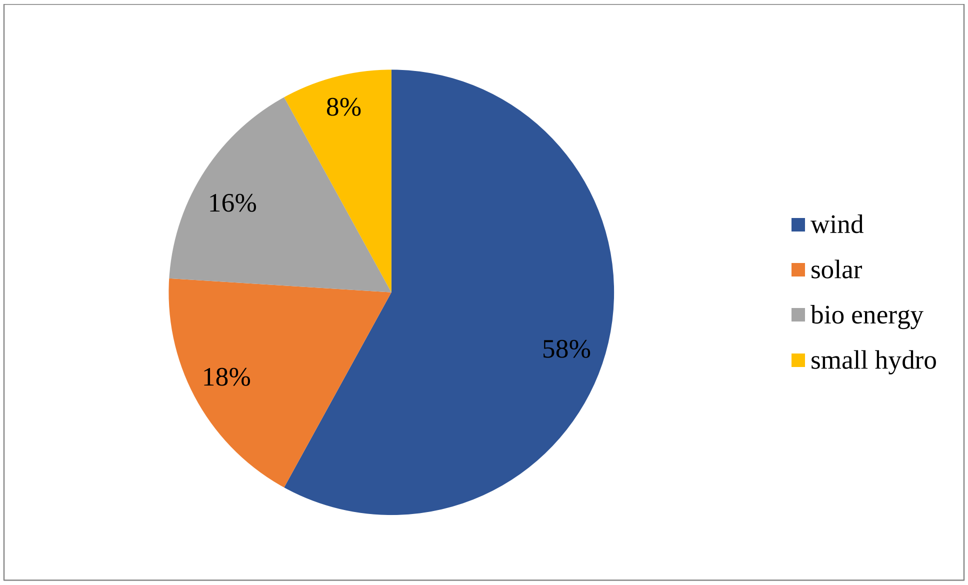


Fig 1.3: installed renewable power capacity in GW

1.4 Renewable Energy Target and Potential

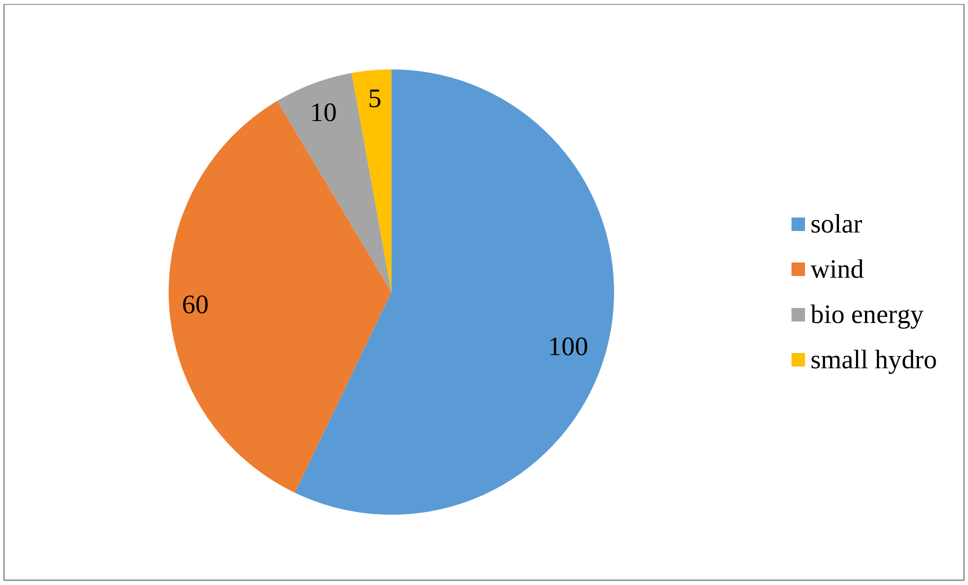


Fig 1.4: renewable energy target by 2022 in GW

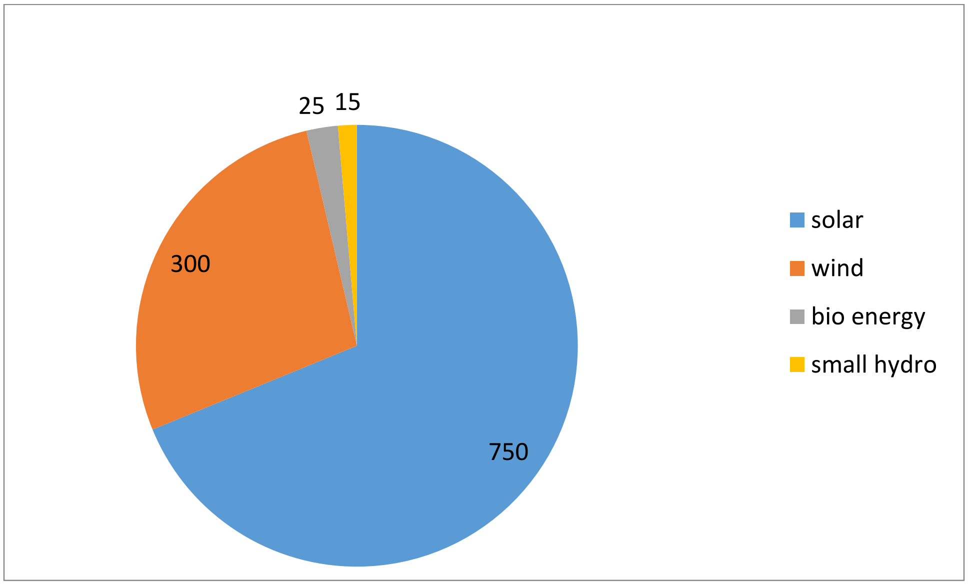


Fig 1.5: renewable energy potential in India

India lacks in numbers in terms of installed RE capacity from countries like USA, Germany, China and others. It needs more attention for the implementation of policies made by Govt. for increasing the installed capacity of RE in Indian energy demand. India is a country with more than 300 sunny days on its geographical area and also have sufficient source for Bio-energy and Wind energy which makes it to have a total potential of more than 1000 GW of RE. But this requires correct policies and improved technologies for implementation. Indian Govt. has decided a target of 175 GW of RE till 2022 wand Solar energy will lead the table with around 100 GW followed by Wind energy as shown in figure 1. Presently RE has a contribution of about 10% in energy demand which will increase to 19% in2022. An exponential trend has seen in growth of RE since 2002 but this trend need to be maintain till we achieve the targets and utilize RE to its maximum potential.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Review of Literature

Patil et. al. **[5]** performed parametric analysis of Scheffler Collector system for improvement in thermal efficiency. Scheffler reflector of size 2.7 m^2 has been used for experimentation. In this system receiver was installed at focus point. Thermal efficiency of receiver is calculated on the basis of parameters like shape of receiver, initial heating of inlet water, tilting of receiver, and receiver with glass cover for steam pressure up to 3 bars. Cylindrical and Conical shape receiver of 8 liter capacity has been used for experiment which serves dual purpose of absorber and steam storage device. Cylindrical receiver has maximum efficiency 56.64% in case of initial heating of water (50^{o}C) and conical receiver has maximum efficiency 76.04% in case of tilting of receiver (45^{o}C). Response surface method is used to optimize the thermal efficiency of receiver. A general mathematical model for thermal efficiency has been developed for both receivers.

Patil et. al. **[6]** studied the performance of Scheffler reflector. In this system storage reservoir was installed at Focus point. It has a single large diameter drum which serves the dual purpose of absorber tube and storage tank. The drum is sized to have a storage capacity of 20 liter for experiment. The tests were carried out with this set-up and were repeated for several days. Performance analysis of the collector has revealed that the average power and efficiency in terms of water boiling test to be 1.30 kW and 21.61%, respectively, against an average value of beam radiations of 742 W/m2. The maximum water temperature in the storage tank of 98 °C has been achieved on a clear day operation and ambient temperature between 28 °C to 31 °C.

Jilte et. al. **[**7] investigated numerical three-dimensional studies of the natural convection and radiative heat loss from cavity receiver of different shapes with and without mouth-blockage under isothermal wall condition. Convective heat loss is found to decrease for cavities having mouth blockage created by reducing aperture area whereas it enhances when mouth blockages are introduced by increasing the cavity dimensions and keeping the same aperture area. Convective loss is characterized by using the convective zone area. Conical cavity yields the lowest convective loss whereas hetro-conical cavity gives the highest convective loss among different shapes investigated. Radiative loss is independent of cavity inclination and is found to be nearly constant for all cavity shapes and cavity configurations (with or without mouth blockage) so long as the aperture area remains the same; it is proportional to the aperture area.

Kumar S et. al. **[8]** investigated a 2-D-model for the approximate estimation of the natural convection heat loss from an actual geometry of the modified cavity receiver (hemisphere with aperture plate) of fuzzy focal solar dish concentrator. The analysis of the receiver has been carried out based on the assumption of the uniform and maximum solar flux distribution in the central plane of the receiver. The total heat loss from the receiver has been estimated for both the configurations ‘‘with insulation’’ (WI) and ‘‘without insulation’’ (WOI) at the protecting aperture plane of the receiver. The convection heat loss of the modified cavity receiver was estimated by varying the inclinations of the receiver from 0° (cavity aperture facing sideways) to 90° (cavity aperture facing down). The convection heat loss is maximum at 0° and decreases monotonically with increase in angle upto 90°. The effect of operating temperature on convection heat loss for different orientations of the receiver was studied. The results of the numerical analysis are presented for a modified cavity receiver ‘‘with insulation’’ (WI) and ‘‘without insulation’’ (WOI) in the form of Nusselt number correlation. The maximum convection heat loss occurs at 0° inclination for both cases of the receiver, which is 63.0% (WI) and 42.8% (WOI) of the total heat loss, though the heat loss in WI configuration is lower than that of WOI configuration. Upon increasing the inclination of the receiver, the convection heat loss reduces to a minimum of 12.5% (WI) and 24.9% (WOI) of the total heat loss at 90°.

Dafle et. al. **[9]** evaluate the Design, Fabrication and Performance for 2 bar pressure and 110^{o}C temperature cooking application using 16 m^{2} Scheffler reflector. The Scheffler along with mild steel absorber plate of size, 18 cm diameter and 2.5 cm thick was evaluated for performance in month of February 2012 at composite climate zone. During the performance it was observed that solar radiation over the day varies from 620 W/ m^2 to 937 W/ m^2. The instantaneous efficiency decreases with increase in radiation. Absorber plate temperature varies from 138^{o}C to 235^{o}C, while maximum steam temperature achieved was 107^{o}C at the outlet of the boiler. The overall efficiency achieved was 57.41 % which appears on higher side as compared to parabolic trough devices. The paper conclude achievement of concentrating solar thermal devices using Scheffler technology for water heating and low pressure, temperature steam applications in industries as textiles, dairies, food industry etc.

Ruelas et. al. **[10]** developed a new mathematical model for estimating the intercept factor of a Scheffler-type solar concentrator (STSC) based on the geometric and optical behaviour of the concentrator in Cartesian coordinates, and the incorporation of a thermal model of the receptor is performed using numerical examinations to determine the technical feasibility of attaching the STSC to a 3 kWe Stirling engine. A numerical validation of the mathematical model is determined based on the experimental results reported for the WGA500 concentrator and the CNRS-PROMES system receiver. The numerical results allow for the design of the STSC and a comparison with a parabolic dish that provides the same thermal demand. Our findings show that the highest concentration was obtained with an edge angle of 45°, which was observed in the parabolic dish as well, but the STSC receiver shows a 7% increase in the thermal efficiency compared with the efficiency of the parabolic dish receiver. Finally, the STSC is appropriate for regions where the solar height allows for a reduction of convective thermal loss.

Ruelas et. al. **[11]** presented the geometric aspects of the focal image for a Scheffler-type solar concentrator (STSC) using the ray tracing technique to establish parameters that allow the designation of the most suitable geometry for coupling the STSC to a Stirling engine of 3 kWe. The results of the ray tracing software are validated through thermographic images of the STSC solar concentration after modifying the image to establish the geometric areas with the highest temperature. When performing the simulations using the ray tracing software, we found that the most suitable solar image geometry has variations within an elliptical area of 14.25 cm^2 on average with a circular aperture area reflector. While this result is appropriate, the geometry of the receiver would need to be modified to fit a Stirling engine. Finally, when validating the ray tracing results with the image provided by the thermography camera, it was found that the area tends to be elliptical but with an area greater than 36%; this result must be taken into consideration to improve the heat transfer by radiation at the receiver of the STSC.

Mangesh et al. **[12]** studied the performance of 2.7 m^2Scheffler reflector. Vessel stores 10 litre of water for the purpose of experimentation. Performance analysis of the reflector revealed that average power and efficiency in terms of water boiling tests to be 550 W and 19%. Dimensional analysis and mathematical modelling was done to correlate dependent and independent variables. Comparative analysis of theoretical values and experimental values was done with the help of graphs. The dimensional analysis shows that generated water temperature is determined primarily by ratio of product of angle and Dish area to the wind speed.

Kashyap et. al. **[13],** designed Scheffler reflector to supply sufficient heat energy to the crematorium by concentrating solar energy. It was assumed that 100 kg of wood is required for cremating a single corpse in 1 to 2Hrs if heat loss is optimized to minimum value by effective insulation of combustion chamber. Since calorific value of wood is 19700kJ/kg. The “P” power (in MJ/hr) required to burn completely the body in combustion chamber is determined. From this reflector was designed to cremate a dead body in 2hrs. It was observed that scheffler reflector is definitely be able to cremate a corpse through solar crematorium built with a well-designed Scheffler reflector and an efficient combustion chamber.

Chandak et. al**. [14],** designed and experimented with multistage evaporation system for production of distilled water. Two Scheffler concentrators of 16 sqm each were used for generating steam in the first stage at 8 bar pressure and the pressure is gradually brought down to 1 bar, in four stage distillation unit. Heat of condensation in the last stage was dissipated in a solar dryer to enhance its performance. In further testing this heat of condensation in the last stage and also sensible heat of the condensate in all the stages was used for preheating of water in the next batch. Results of the project demonstrated that there exists huge potential of projects of nature for applications like generating distilled water for food processing, pharmaceutical and other industries on moderate scale. The project also has high potential in areas of salt concentration systems, thickening of salt fruit juices, jams, pulps, sauces and similar applications where water is evaporated on large scale. Evaporating water for thickening of effluent of industries is other promising area.

Akhade et. al. **[15].** designed and performed an analysis of Scheffler reflector of 2.7 m^2 surface area. The Scheffler reflector studied with typical experimental plan of simultaneous variation of independent variables. Experimental response data is analyzed by formulating dimensional by formulating dimensional equations. The test were carried out in the month of May, 20 liter of water was kept at the fixed focus. The experimental data were recorded during fixed time interval. The performance analysis reveled average power and efficiency in terms of boiling test.

Barlev et. al. **[16]** focuses on innovation in CSP technologies over the last decade. A multitude of advancements has been developed during this period, as the topic of concentrated solar power is becoming more mainstream. Improvements have been made in reflector and collector design and materials, heat absorption and transport, power production and thermal storage. Many applications that can be integrated with CSP regimes to conserve (and sometimes produce) electricity have been suggested and implemented, keeping in mind the environmental benefits granted by limited fossil fuel usage.

Kaneko et. al. **[17]** investigated the addition of MOx (M: di- or tri-valent transition metal ion) into cerium dioxide (CeO2) enhanced the ability of CeO2for the oxygen(O2)-releasing reaction at lower temperature and swift hydrogen (H2)-generation reaction. CeO2–MOx (M¼Mn, Fe, Ni, Cu) reactive ceramics having high melting points were synthesized with the combustion method from their nitrates for solar H2 production. The prepared CeO2–MOx samples were solid solutions between CeO2 and MOx with the fluorite structure through the X-ray diffractometry measurement. Two-step water-splitting reactions with CeO2–MOx reactive ceramics proceeded at 1573–1773 K for the O2 -releasing step and at 1273 K for the H2 -generation step by irradiation of infrared image furnace as a solar simulator. The amounts of O2 evolved in theO2 -releasing reaction with CeO2 –MOx increased with an increase in the reaction temperature.

Kalogirou et. al. **[18]** presented survey of the various types of solar thermal collectors and applications. Initially, an analysis of the environmental problems related to the use of conventional sources of energy is presented and the benefits offered by renewable energy systems are outlined. A historical introduction into the uses of solar energy is attempted followed by a description of the various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors. This is followed by an optical, thermal and thermodynamic analysis of the collectors and a description of the methods used to evaluate their performance. Typical applications of the various types of collectors are presented in order to show to the reader the extent of their applicability. These include solar water heating, which comprise thermosyphon, integrated collector storage, direct and indirect systems and air systems, space heating and cooling, which comprise, space heating and service hot water, air and water systems and heat pumps, refrigeration, industrial process heat, which comprise air and water systems and steam generation systems, desalination, thermal power systems, which comprise the parabolic trough, power tower and dish systems, solar furnaces, and chemistry applications. As can be seen solar energy systems can be used for a wide range of applications and provide significant benefits, therefore, they should be used whenever possible.

Wu et. al. **[19]** proposed a parabolic dish/AMTEC solar thermal power system and evaluates its overall thermal electric conversion performance. The system is a combined system in which a parabolic dish solar collector is cascaded with an alkali metal thermal to electric converter (AMTEC) through a coupling heat exchanger. A separate type heat-pipe receiver is selected to isothermally transfer the solar energy from the collector to the AMTEC. To assess the system’s overall thermal–electric conversion performance, a theoretical analysis has been undertaken in conjunction with a parametric investigation by varying relevant parameters, i.e., the average operating temperature and performance parameters associate with the dish collector and the AMTEC. Results show that the overall conversion efficiency of parabolic dish/ AMTEC system could reach up to 20.6% with a power output of 18.54 kW corresponding to an operating temperature of 1280 K. Moreover, it is found that the optimal condenser temperature, corresponding to the maximum overall efficiency, is around 600 K. This study indicates that the parabolic dish/AMTEC solar power system exhibits a great potential and competitiveness over other solar dish/engine systems, and the proposed system is a viable solar thermal power system.

Wu et. al. **[20]** presented a comprehensive review and systematic summarization of the state of the art in the research and progress in this area. The efforts include the convection heat loss mechanism, experimental and numerical investigations on the cavity receivers with varied shapes that have been considered up to date, and the Nusselt number correlations developed for convection heat loss prediction as well as the wind effect. One of the most important features of this paper is that it has covered numerous cavity literatures encountered in various other engineering systems, such as those in electronic cooling devices and buildings. The studies related to those applications may provide valuable information for the solar receiver design, which may otherwise be ignored by a solar system designer. Finally, future development directions and the issues that need to be further investigated are also suggested. It is believed that this comprehensive review will be beneficial to the design, simulation, performance assessment and applications of the solar parabolic dish cavity receivers.

Reddy et. al. **[21]** studied combined laminar natural convection and surface radiation heat transfer in a modified cavity receiver of solar parabolic dish collector is presented in this paper. A two-dimensional simulation model for combined natural convection and surface radiation is developed. The influence of operating temperature, emissivity of the surface, orientation and the geometry on the total heat loss from the receiver is investigated. The convective heat loss from the modified receiver is significantly influenced by the inclination of the receiver whereas the radiation heat loss is considerably affected by surface properties of the receiver. The Nusselt number correlations are proposed separately for both natural convection and surface radiation based on large set of numerical data for a given range of parameters of practical interest. It is observed that the convection and radiation heat losses are found respectively 52% and 71.34% of the total heat loss at 0◦ inclination and 40.72% and 59.28% at 90◦ inclination for the modified cavity receiver with an area ratio of 8 and 400 ◦C. The convection and radiation numerical procedure is validated with other models. The results obtained from the present numerical procedure are in reasonable agreement with other well-known open cavity models.

Reddy et al **[22]**analyzed analysis of solar dish modified cavity receiver with Cone, CPC and Trumpet reflectors is presented. Three-dimensional modeling is carried out to estimate the convective and radiative heat loss from the receiver for different angles of inclination and operating temperatures. Incorporating reflectors in the modified cavity receiver for second stage concentration, the natural convection heat losses are reduced by 29.23, 19.81 and 19.16%, respectively. The receiver with the trumpet reflector has shown better performance as compared to other configurations.

Reddy et. al. **[23]** presented techno-economic feasibility analysis of a 5MWe solar parabolic dish collector field is carried out for entire India covering 58 locations. The solar parabolic dish power plant configuration is investigated based on various parameters such as the spacing between dish collectors, land area required, percentage of the shadow and energy yield. The shadow profile around the dish throughout the year at various latitudes (8–35N) for various plant-operating hours is determined. In-line arrangement of the solar dish collector arrays is found to be a better choice in terms of the minimum land area required for setting up the power plant. The generalized correlations are developed for both east–west and north–south spacing distances as the function of latitude and plant operating hours. It is found that the configuration corresponding to the plant operating from 1 h after sunrise to 1 h before sunset with spacing distance in east–west direction equal to the shadow length after 2 h sunrise and in north–south direction equal to shadow length at noon for winter solstice gives the highest energy output with optimum land use. The minimum and maximum average annual power generation at Panaji and Tiruchirapalli are 7.25 GW h, and 12.68 GW h respectively. The minimum levelised electricity cost (LEC) for a stand-alone solar parabolic dish power plant with the clean development mechanism (CDM) is found to be INR 9.83 ($ 0.197, 1$ = INR 50) at Indore with payback period of 10.63 years with cost benefit ratio of 1.48. Based on the financial performance, most of the northern region locations and some of the western and southern region locations are found attractive for power generation by the solar parabolic dish power collector based on the direct steam generation, where direct normal irradiation (DNI) is more than 5 kWh/m2 day.

Wang et. al. **[24]** studied A three-dimensional model of parabolic dish-receiver system with argon gas as the working fluid is designed to simulate the thermal performance of a dish-type concentrated solar energy system. The temperature distributions of the receiver wall and the working gas are presented. The impact of the aperture size, inlet/outlet configuration of the solar receiver and the rim angle of the parabolic dish are investigated. The results show that the aperture size and different inlet/outlet configuration have a considerable impact on the receiver wall and gas temperatures, but the rim angle of the parabolic dish has negligible influence.

Mawire et. al. **[25]** investigated the thermal performance of a cylindrical cavity receiver for an SK-14 parabolic dish concentrator is presented in this technical note. The thermal performance is evaluated using energy and exergy analyses. The receiver exergy rates and efficiencies are found to be appreciably smaller than the receiver energy rates and efficiencies. The exergy factor parameter is also proposed for quantifying the thermal performance. The exergy factor is found to be high under conditions of high solar radiation and under high operating temperatures. The heat loss factor of the receiver is determined to be around 4.6 W/K. An optical efficiency of around 52% for parabolic dish system is determined under high solar radiation conditions. This experimental setup can be used as teaching tool for people with little or no knowledge about solar dish concentrators due its simplicity and the basic mathematical formulations applied. Different types of receivers and different types of deep focal region parabolic dishes can also be tested with the experimental setup.

Haagen et. al. **[26]** designed and installed first SIPH system in Jordan at RAM pharmacy based on linear Fresnel reflector [LFR] solar thermal technology. Principle of direct steam generation was applied. Pharma sector plays an important role in GDP of Jordan i.e. around 20% but on the same time has large heat demand. High Direct Normal irradiance [DNI] values in Jordan and fluctuating fuel prices makes a Jordan industry an important market for solar industrial process heat applications. In pharma industry, 65% of the total energy demand is for heating, ventilation and air conditioning [HVAC]. Central steam generation system produces steam at 160^0C to 180^0C to supply all production processes. Fresnel collector modules are installed on the roof of factory with total aperture of $396m^2$ and 222 KW thermal peak capacity.

Iglauer et. al. **[27]** solar industrial process heating system for sustainable automobile production was proposed. Solar process heat is used in paint shop for curing of automobile paint at 200^0C. Process heat is generated by using linear Fresnel collector based solar thermal technology. Utilizing renewable solar thermal energy can offset fossil fuel consumption up to 70%. Feasibility of the technology had been evaluated on paint shop of automobile factory in India where integration of solar industrial process heat system has reduced energy demand by 14000 MWh and reduction of 2800 tons of carbon dioxide. Payback time occurs within five years depending on irradiance conditions of the site.

Mauthner et. al. **[28]** production of malt and beer requires large amounts of thermal energy which is generally produced by burning fossil fuels. Process temperature required is in range of 25^0C to 105^0C. Solar thermal technologies based on evacuated tube collectors [ETC] are used to integrate solar process heat in production system. Large vessels receive hot pressurized water from solar thermal collectors where production process takes place. 30% solar fraction is achieved with annual generation of 1570 MWh thermal units by solar process heating system. In the above exercise a savings of 38000 tons of carbon dioxide emissions is possible. 1620 m^2 gross collector area was installed at roof top with solar energy storage tank of 350 m^3 volume. Solar process heat is used for pasteurization of canned beer at temperature of 85^0C.

Lima et. al. **[29]** high level of solar insolation in Brazil have made solar thermal energy with very high potential in Brazil industry to provide thermal energy. Most of industrial process needs hot water which can be easily obtained from flat plate collectors.

Technical and financial feasibility of solar water heating system was studied for hospital laundry. System parameters like tilt angle of collector, water flow rate, area of collector and water storage tank size were optimized. Economic analysis was made on the basis of comparing life time saving due to solar water heating system against the current system based on natural gas burner. Finally results showed the consumption in natural gas reduced due to use of solar hot water system and making it a viable option.

Silva et. al. **[30]** use of parabolic trough solar thermal collector to generate process heat for food processing plant in Spain is studied. Solar industrial process heating system was able to produce saturated steam at 7 bar. SIPH system had parabolic trough collector solar field, thermal energy storage and backup steam boiler. Food sector has thermal energy demand in huge quantities with over 90% energy demand in low temperature to medium temperature range. Southern Spain region enjoys high DNI levels of 1700 kWh/m^2/year and above, thus allowing the use of concentrating solar thermal technology to reach high temperature levels with reasonable high efficiency. Solar thermal plant will be integrated with central steam supply system. Total process heat demand is 148MWh per year supplied currently by fuel oil based boiler.

Zahler et. al. **[31]** now a days there is huge pressure on automobile industry to make their manufacturing processes more environment friendly and sustainable in long term. Curing of car paint is the major manufacturing process with highest share in total energy consumption. Temperature in convection ovens are at 200^{0}C which is in range of concentrated solar technology such as Fresnel reflector (LFR). Pilot project system has been installed at Durr campus Germany which consists of 6 modules of LFR with total aperture area of 132 m^2. Fossil fuel fired backup boiler is used in case on non-sunny hours to meet thermal demand of ovens fully. Heat is released in convective ovens through steam air heat exchanger. Energy consumption is around 700-900 KWh per car body which requires huge amount of fossil fuels to be burned.

Calderoni et. al. **[32]** feasibility study of integration of solar thermal collectors in industrial processes in Tunisia is evaluated in this paper. Textile industry manufacturing processes are evacuated i.e. payback period was calculated and amount of fossil fuel substituted by solar energy was also estimated. Huge potential is already there for solar heat for industrial process in Tunisia as 30% of the total industrial heat demand is required at temperature between 100^0C and 400^0C which is in range of concentrating solar thermal technologies. Also highly subsidized fossil fuels in Tunisia have become major cause for low potential of solar thermal in industry. Main industrial processes in textile industry for solar thermal technology integration are dyeing and ironing. Dyeing process needs thermal energy at 98^0C.

Ferin et. al. **[33]** design of solar industrial process heat plant for integration with dyeing process of Benetton facility in Tunisia. Total aperture area is 1000 m^2. Main aim is to optimize solar plant and sizing of other main components is also done. Dyeing process requires huge amount of energy. Hot water is required at 60^0C. Use of solar energy for process heating has a potential of saving of 100MWh annually. 30000 liters of hot water storage is also being built to increase share of solar energy in total thermal energy requirement. Also Government support in form of subsidy to solar thermal plant will help solar process heat market to develop further in Tunisia. Currently high subsidized fossil fuel mainly natural gas is major hindrance in growth of solar thermal Technology.

Lauterbach et. al. **[34]** process heat generation by solar thermal Technology has large potential but remains unexploited. Solar thermal system can achieve very large solar fraction for industrial applications. System set up can be very complex due to presence of different heat consumers, temperature sensors and Hydraulic circuits. Therefore to design and operate solar thermal system optimally, possible faults that can occur in the system are evaluated. Simulation model for solar process heat system is made and validated against actual setup based on data collected during project monitoring. Faults identified and their influence is evaluated on the system. Final result show that reduces load on system is influential and system yield can be maximized if all faults are eliminated. Important factors for plant optimisation are system efficiency, mass flow rate an temperature.

Fuller et. al. **[35]** research and development for solar industrial process heating system has been going on in Australia for last 30 years. Commonwealth science and industrial research organization (CSIRO) is carrying out all these activities. Future of SIPH looks very bright in Australia. For Australia to decarbonize its economy, huge growth of solar industrial process heating system is required at national level for those industries which use huge amount of fossil fuels for producing hot water. Author has reviewed the past installations of SIPH in Australia and analyzed the results to find out problems to optimize the systems to be installed in future.

Bellel **[36]** studied types of cylindrical canister with a spherical hub and other have two types of receptor, the first cylindrical closed and the second coil is a cylindrical Inside a receiver, we are particularly attached to the determination of operating characteristics, the temperature of the absorber, the various power and efficiency. The energy balance is used to determine the thermal characteristics of the absorber in order to calculate the temperature concentrated at the surface captor, in the first absorber, the heat equation is solved by implicit finite difference method and the second from the power output determining a temperature difference between the edges of the coil. The comparison of numerical results with those obtained through an experimental study conducted in parallel, showing good reliability of the computer code developed.

2.2 Research Gap

From the above literature review it was concluded that most of the work on concentrated solar technologies has done in Europe mainly in Germany and Northern America. Some beginning was made in India since 2000 in this direction but still its growing rate is very slow and its implementations are very limited and exist only in some institutions and industries like Shantivan (Mount Abu), Shantivan (Haridwar) and Gajraj Drycleaners (Pune). As India has a large population to feed, it spends a big portion of its annual energy consumption on food cooking. So present study has taken to use CST for mass and collective cooking for DTU hostel mess to show the feasibility of CST system in Delhi. It is first of its kind for any educational institution and it will reduce the dependency on conventional fuel for cooking.

2.3 Objectives of the Present work

Following work has done by keeping in mind the requirement of clean and renewable source of energy in almost every field of production. To check the requirement and feasibility of proposed system, given below objectives are fulfilled in this work

- To review various available concentrated solar thermal technologies and choose the most appropriate technology for mass and collective cooking using steam at DTU.
- To study the basic design and principle of working Scheffler dish system and propose the required P&I layout for steam cooking plant in DTU.
- To calculate the total collector surface area of Scheffler dish required according to thermal energy demand that can be fulfilled using this system.
- To calculate the useful output thermal energy that can be extracted and system efficiency using required relations and to study the effect of some other parameters on performance of system.
- To calculate the amount of CO_2 emit per annum due to burning of LPG for cooking.
- To check the economic feasibility of steam cooking system in DTU under climate conditions of Delhi and to calculate the payback period of system.

CHAPTER 3

METHODOLOGY OF CST TECHNIQUES AND PRINCIPLES

CST (Concentrated Solar Thermal) is a technique which can be used to concentrate the solar radiations with the help of mirrors or lenses to produce temperature in the range of 100 to 450°C and even more. For efficient performance, these devices required a tracking system so that the Sun rays can be focused onto the receiver all the time. They can tap only direct normal radiations and not the diffuse. CST systems are useful for medium to high temperature requirements in various industries, commercial establishments and institutions.[37]

3.1 Concentrated Solar Technologies

There are various techniques which can convert solar energy into thermal energy.

- Fixed Focus Elliptical Solar Dish (Scheffler)
- Fresnel Reflector Based Dish
- Linear Fresnel Reflector Concentrator
- Non-Imaging Concentrator
- Parabolic Trough Concentrator
- Paraboloid Dish

3.1.1 Fixed Focus Elliptical Solar Dish (Scheffler)

A Fixed Focus Elliptical Dish also called Scheffler Dish consist of large number of mirrors that can move to reflect the Sun's radiations onto a fixed receiver which contain a working fluid to be heated. Generally water is used as the working fluid but some other suitable fluid can also be used.

The dish which automatically tracks the Sun in E-W direction from morning to evening is called Single-Axis tracking system. In Dual-Axis tracking system, the seasonal variation in the Sun position in N-S direction is also adjusted automatically which is needed to be adjusted manually in former.

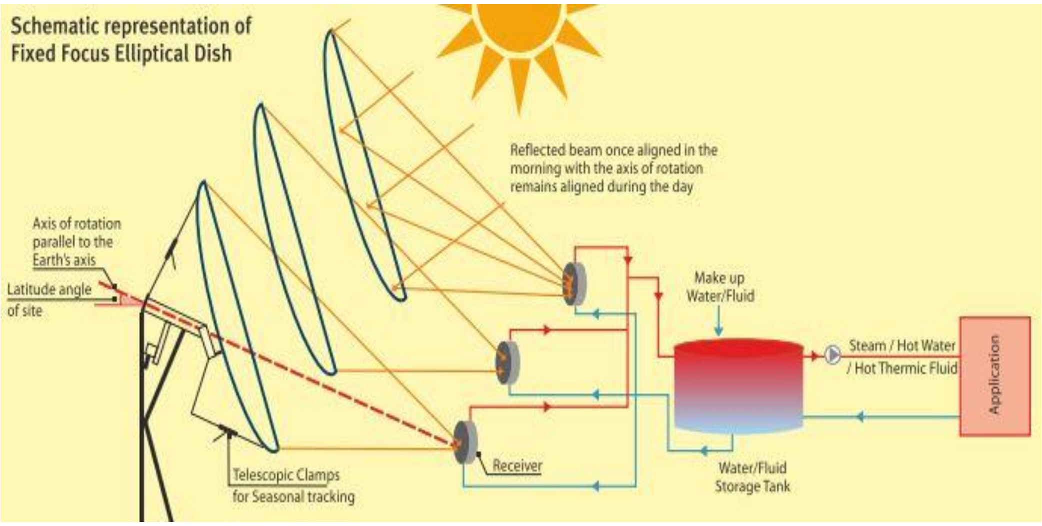


Fig 3.1: Schematic representation of Fixed Focus Elliptical Dish

Key Features

- Proven technology with a number of working installations for community cooking, air-conditioning and other applications.
- As its stationary system mounted on the ground, this system is structurally simple and has no rotating or flexible joint for water and steam.
- It can be installed on roof tops of existing buildings or on the ground.
- This system requires a skilled operator to obtain high efficiency and its efficiency decreases rapidly with increase in operating temperature.
- Scheffler dishes deliver heat only in late morning to early evening and are therefore suitable for operations that use heat during this period.
- Since dish and receiver has to be mounted separately, this system requires larger area as compared to other CST technologies.

3.1.2 Fresnel Reflector Based Dish

Fresnel reflector based dish (Fresnel Dish) is made up from panels of flat mirrors mounted on a frame such that the incident sunlight is reflected on to a cavity receiver which is specially designed to reduce heat losses. The receiver which is insulated on the outside is held in a fixed position in relation to the reflectors by means of a suitable structure so that the entire array and receiver moves together to track the Sun. Cavity receiver allows energy to intercepted through a small opening which result in low losses. Usually Fresnel Dishes are large and could have an aperture area of $100m^2$ or $160\ m^2$.

The reflector and the receiver are moved to track the Sun such that the reflector faces the Sun all the times throughout the year. These systems, because of their size, require careful structural design to withstand their heavy weight and stress that might be caused by strong winds. Fresnel Dishes have high efficiency throughout the year.

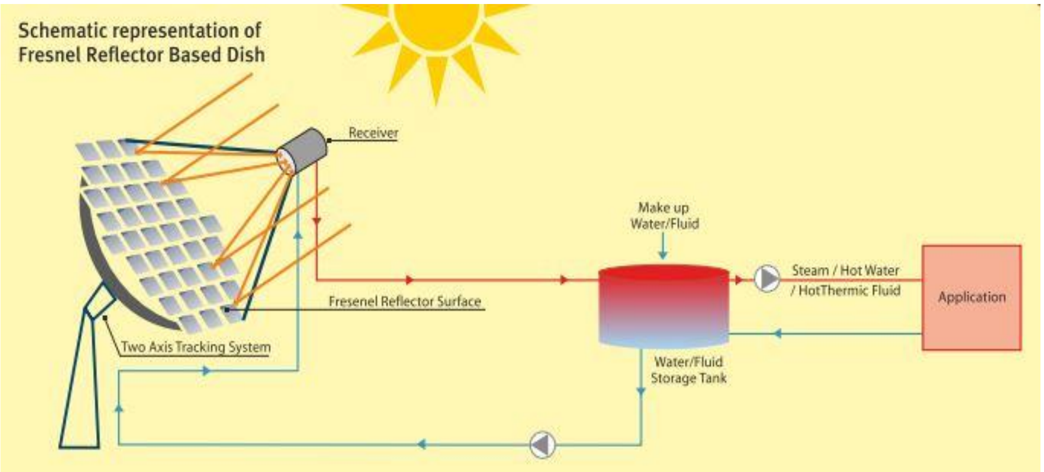


Fig 3.2: Schematic representation of Fresnel Reflector Based Dish

Key Features

- Fresnel dish is a proven technology with number of working installations for process heating and other heating applications.
- Fresnel dish can be mounted on the roof top of an existing building though this requires considerable strengthening of the structure and must be designed by expert.
- High concentration ratio and relatively low losses from the receiver.
- Steam can be generated up to 25 bar g.

3.1.3 Linear Fresnel Reflector Concentrator (LFRC)

LFRC are made from strips of straight reflecting material which could be highly polished reflecting metal or metal coating with reflecting material such as glass mirrors or metalized plastic which can withstand sunlight as well as rain. The surface reflects the incident sun radiations onto a metallic pipe (receiver) that runs above the array of reflectors. The pipe is coated to increase the absorption of the sunlight that falls on them and encased into a glass casing to minimize the convective losses. To increase the efficiency the glass casing may be evacuated and the ends may be sealed. The reflector strips are moved such that they always reflect the sunlight onto the receiver tube.

Several such LFRC's can be connected in series on a common axis. The two common methods of mounting are:

1. Horizontal E-W direction - reflectors are set in a continuous array so that the incident sunlight has the minimum angle of incidence.
2. Horizontal N-S direction – trough are set to track the sun from east to west from morning to evening. These system require a large contiguous area and can provide large quantities of heat. They have efficiency similar to PTCs but have advantage of more robust structure.

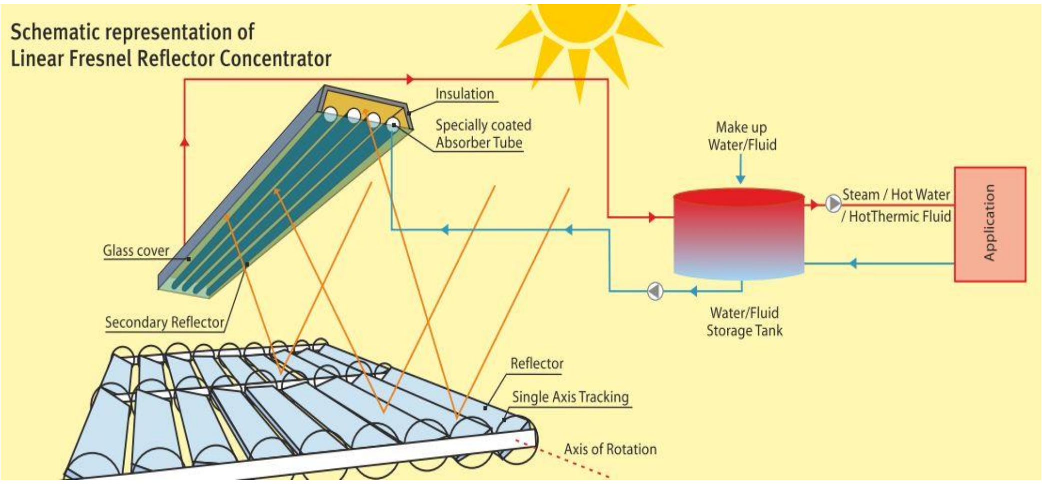


Fig 3.3: Schematic representation of Linear Fresnel Reflector Concentrator

Key Features

- LFRC technology has installed plants for water desalination and power generation.
- Due to long reflectors they should be structurally strong and well supported otherwise their efficiency may suffer.

- LFRCs do not have any leakage problem due to absence of any flexible joint for water and steam.
- Due to medium concentration ratio and losses its operating temperature is limited up to 250°C.
- Large space is required for its installation as compared to other CST technologies.

3.1.4 Non-Imaging Concentrator (NIC)

It is also called Compound Parabolic Collectors (CPC). It consist of specially coated absorber tube which is enclosed in a concentric glass tube to reduce the convection losses. The space between the tube and its cover is evacuated. The tube is placed at the focal length of two parabolic reflectors. The axes of two parabolas are inclined at the acceptance angle which is the angle by which direct light may deviate from the normal and yet allow the reflected light to reach the receiver.

Usually these concentrators are 1m to 6m wide and can have up to 60m^2 of collector area. The working fluid may be water or any other thermic fluid. The most common method of panel mounting is E-W direction with the panel facing in south direction, and inclined from ground at an angle of latitude + 10°.

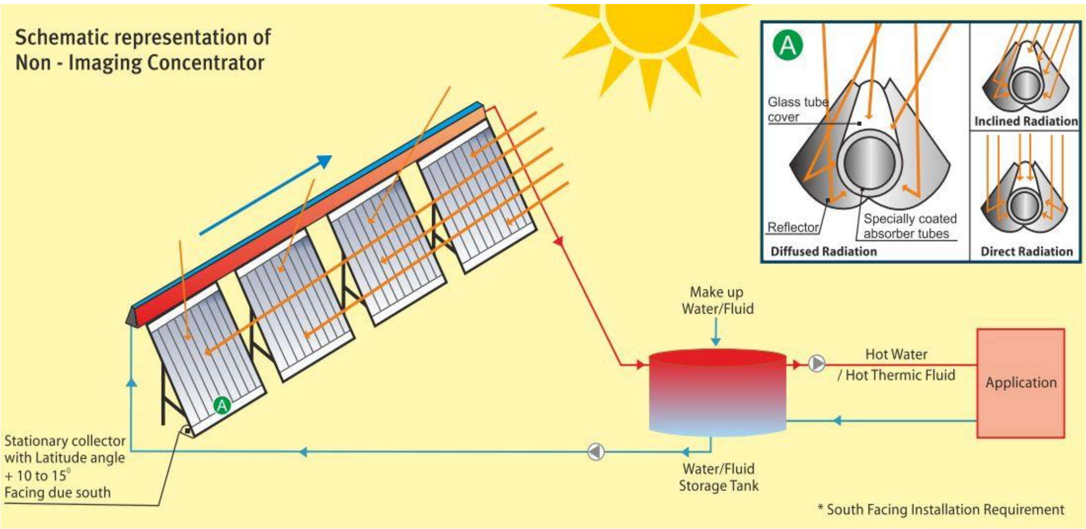


Fig 3.4: Schematic representation of Non-Imaging Concentrator

Key Features

- There is no flexible or rotating joints for working fluid, so no problem of leakage.
- NICs can be installed on rooftop of existing structures.
- It has low concentration ratio and so operating temperature is limited to 120°C.

3.1.5 Parabolic Trough Concentrator (PTC)

PTCs are made from metallic sheet and coated with a reflecting material like highly polished metal (usually Aluminum) or metallized plastic so that it can withstand sunlight as well as rain. The metallic surface (trough) reflects the sunlight on to the receiver surface (metallic collector pipe) that run axially along the trough. Like other systems receiver pipe is coated to increase the absorption of sunlight and encased into a glass tube to reduce the convective losses. Sometimes to increase the efficiency of the system the glass tube is evacuated and the ends are sealed. PTCs can be connected in series on a common axis.

Two common method of mounting PTCs are:

1. In a horizontal E-W direction in which trough are needed to adjust continuously to minimize the angle of incidence of sunlight.
2. In a horizontal N-S direction in which troughs are moved to track the sun from morning to evening from east to west. This mounting required a large contiguous area and generally used when large amount of heat is required.

Key Features

- Currently PTCs have a number of working installations for process heating and power generation.
- Due to long structure, it should be strong enough to withstand distortion which may result of poor efficiency.
- PTCs have rotating and flexible joints for working fluid so these have to be maintain to prevent leakage.

- Its medium concentration ration and relatively high losses from the receiver limits its temperature to 250°C.

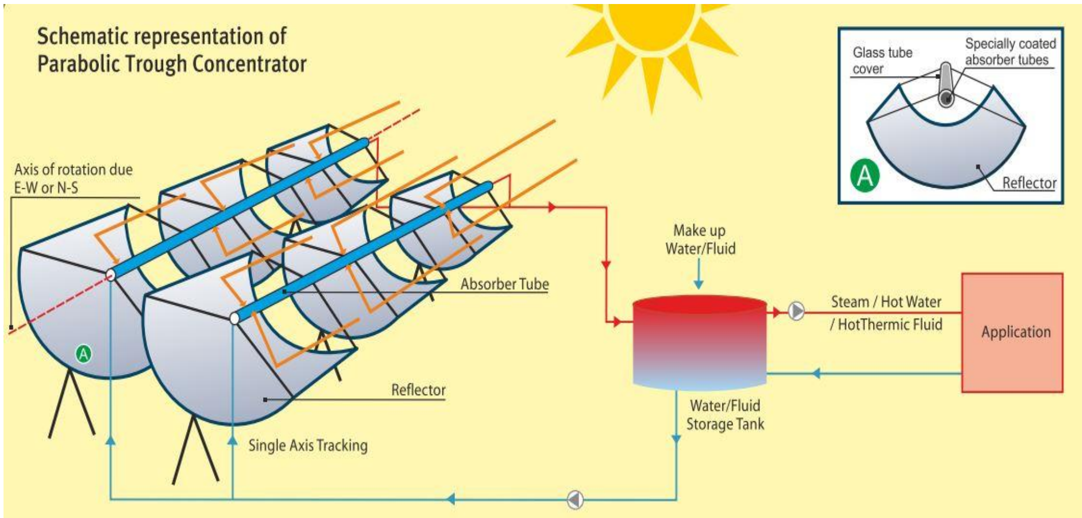


Fig 3.5: Schematic representation of Parabolic Trough Concentrator

3.1.6 Paraboloid Dish

Paraboloid Dish made up from mirrors mounted on a truss in such a way that the incident sunlight reflected on to a cavity receiver which is designed to minimize convective and radiation losses. The receiver is fixed with respect to the reflectors by means of a suitable structure and so the entire structure moves together to track the Sun. the receiver is of cavity type which allows energy to intercept through a small opening to minimize the losses.

The entire structure moves in such a way that the reflector faces the Sun all the time throughout the year. Paraboloid dishes have high efficiency throughout the year.

Key Features

- Paraboloid Dishes are pole mounted and thus required small area for installation.
- High concentration ration and low loss from the receiver allow its maximum temperature to reach up to 350°C.

- Paraboloid dish allow individual isolation and controls and hence can be mounted in a non-contiguous configuration.

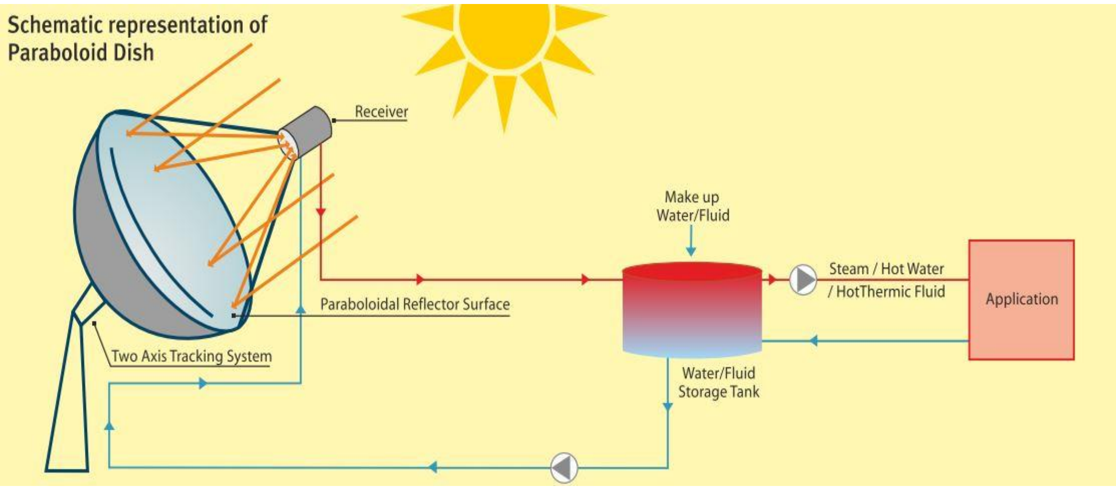


Fig 3.6: Schematic representation of Paraboloid Dish

3.2 Industrial Applications of CST Technologies

CST techniques can generate pressurized hot water, steam or hot thermic fluid as required by the process and can be used for the various applications.

Table 3.1: Applications of various CST technologies in Industries

Industry/Process	Applications
Educational/Religious Institutions	Cooking
Hotels, Hospitals, Offices, Shopping Malls	Air Conditioning, Hot water for bathing, Laundry
Engineering/ Automobile Industry	Component Washing, De-Greasing, Metal Treatment, Paint Drying
Chemical Process Industry	Boiler Feed Water Heating, Other Heating Operations
Food Processing	Drying, Low Temperature Distillation and Evaporation, Extraction
Pulp and Paper Industry	Kraft pulping, Effluent Treatment, Bleaching

Textile Industry	Mercerizing, Drying, Finishing
Food Processing and Dairy	Chilling/Cold storage, Cooking, Extraction, Baking, Pasteurization, Sterilizing, Bleaching, Drying etc
Breweries	Boiling, Mashing, Cold Conditioning, Fermentation etc
Rubber	Heating, Digestion and Washing, Bleaching, Evaporation and Drying
Pulp and Paper	Pulping, Digestion and Washing, Bleaching, Evaporation and Drying
Tobacco	Steam Conditioning, Drying and Softening
Electroplating	Post Plating Treatment, Water Heating, Drying etc
Pharmaceutical	Distillation, Drying, Evaporation, Fermentation, Injection and Molding
Textiles (Spinning and Weaving, Finishing)	Preparing warps, Sizing, De-sizing, Scouring, Bleaching, Mercerizing, Dyeing, Drying and Finishing
Chemicals and Fertilizers	Distillation, Effluent Treatment, Primary Reforming, Ammonia Synthesis, CO_2 removal, Methanation, Steam Stripping
Refining	Desalting, Cooking, Thermal Cracking, Cleaning, Waste Water Treatment
Ceramic Tile and Pottery	Beneficiation, Drying, Presenter Thermal Processing, Glazing
Desalination	Multiple Effect Distillation, Multi Stage Flash Distillation

Plaster of Paris, Steel re-rolling, Cement, Mining	Augmenting Steam to Boilers, Boiler Feed Water Heating

3.3 Scheffler Concentrator Design

The first step in constructing a Scheffler concentrator is to decide the equation of the parabola and then start and end points of dish section for equinox. These parameters are defined by the ratio between the area of the dish and the position of the focus with respect to the dish. Once this ratio is defined, the dimension of the parabola can be adjusted for smaller or bigger dish areas by simply scaling everything up or down. To simplify calculations the parabola is set to have the vertex at the origin, so

$$y_p = m_p x^2 \text{.............}3.1$$

which will then be revolved around the y-axis to form the three dimensional paraboloid. The paraboloid must then be sliced by a plane to define the dish section. The slice will create the dish with an elliptical rim, see Figure 3.7. The following calculation will be made on the 2-D x/y-plane using Equation 3.1 to represent the intersecting plane. The intersection points between the parabola and the line *A* and *B*, represent the lowermost and uppermost ends of the dish section and the slope of the line is represented by the angle β with respect to the x-axis. In this representation, the sun rays are incoming parallel to the y-axis and reflect off the paraboloid toward the focus on the y-axis.[36]

Taking the derivative of yields the equation for the slope, β

$$\frac{dy}{dx} = 2m_p x \text{................}3.2$$

Point C is defined on the parabola as the point with slope of 45°. This point is of interest because it represents the point where the incoming vertical light rays will reflect by 90° and proceed horizontally to the focus. The horizontal light ray from point C to the focus defines the axis of rotation of the physical reflector for the daily tracking of the sun. This characteristic point should be placed very close to the centre of the dish to create a balanced frame with respect to the daily rotation axis. If C is located near the centre of gravity of the reflector then it will be very easy to rotate the reflector, minimizing the need to counter balance.

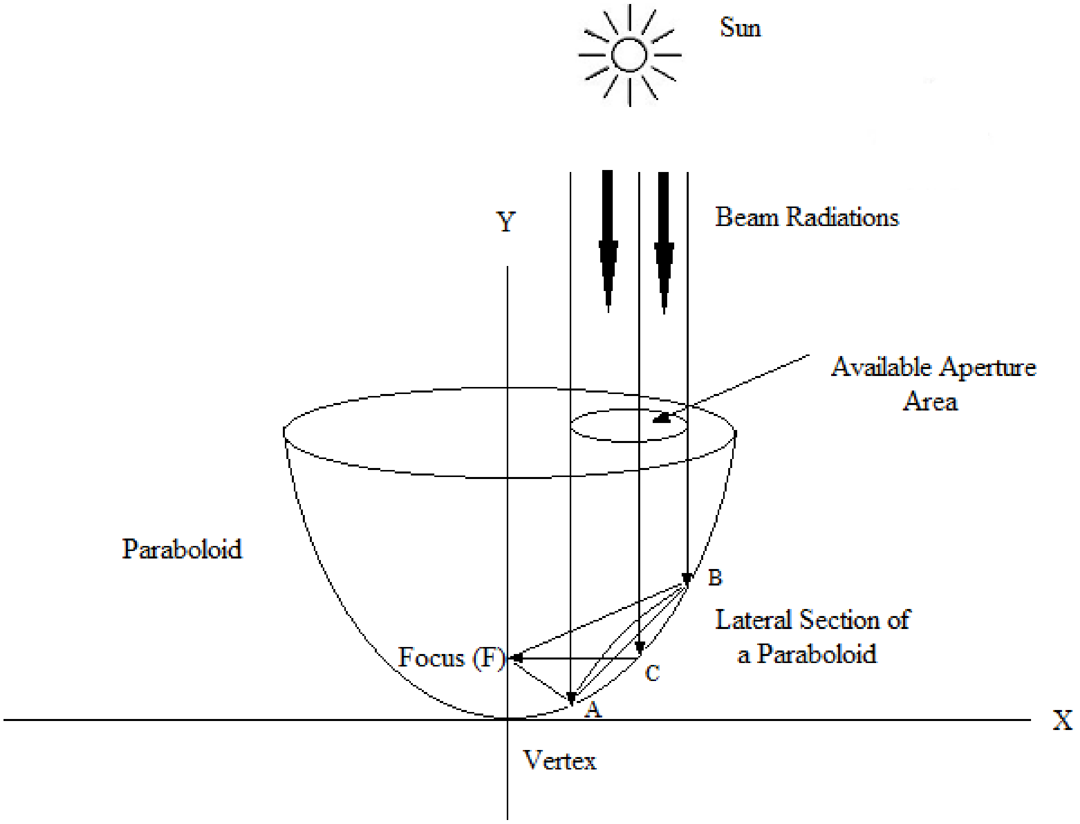


Fig 3.7: Section of a Scheffler Reflector in a Paraboloid

The most important point in the analysis is the focus of the parabola, F, is located on the y-axis at a height

$$y_f = \frac{1}{4m_p} \text{............} 3.3$$

since the vertex was positioned at the origin Equation (3.3) also represents the focal length of the parabola which is defined as the distance between the vertex and focal point along the axis of symmetry. Since we reserve the ability to scale the reflector at a later point, at this stage we will choose parameters that simplify the design of the reflector. For mathematical simplicity, m_p was then chosen to be 0.25, which positions the focus at (0, 1).

$$y_f = \frac{1}{4 \times 0.25} = 1$$

and the 45° point at C = (2,1) from equation (3.1). Yielding a very elegant equation for the parabola to be used in the rest of the project,

$$y_p = 0.25x^2 \text{………….}3.4$$

The start and end point of the dish section, point A and B respectively, are then chosen to be equidistant from C, their distance from each other determines the ratio between the size of the reflector and the distance to the focus. If A and B are placed farther apart, the ratio between the distance CF to the area of the dish will decrease. This increases the curvature of the dish and makes it easier to focus the light at the focus. This is desirable because it will allow for looser tolerances in the manufacturing of the dish making it easier and less expensive to make. If points A and B are chosen to be closer, the focus will be effectively farther away and the dish less curved. This will require tighter tolerances in the production of the dish but will give various advantages such as the ability to focus the sunlight a greater distance away, such as inside a house.

The x-coordinate of A and B were then chosen to be

$$x_A = 1$$

$$x_B = 2.8$$

Arc length between them was about 25% more than the distance from C to the focus. Since the biggest challenge in reducing the cost of the Scheffler design is producing a good reflective dish, we chose to keep the focus closer to the dish. The y coordinates of A and B can be calculated using the parabola equation (3.3). The equation for the arc length on an upright parabola is

$$h = \frac{x}{2} \text{……………….}3.5$$

$$q = \sqrt{f^2 + h^2} \quad \text{……..}3.6$$

where h and q are parameters for describing the two points confining the arc on the parabola, defined by x_1 and x_2. The length of the arc between points 1 and 2 is defined as,

$$\Delta s_{1,2} = \frac{h_1 q_1 - h_2 q_2}{f} + f \ln\left(\frac{h_1 + q_1}{h_2 + q_2}\right) \text{........3.7}$$

where $\Delta s_{1,2}$ is the arc length between point 1 and 2 and f is the focal length of the parabola. The line that connects points A and B is defined as

$$y_l = m_l x_l + b_l \text{...........3.8}$$

with a slope angle of,

$$\beta = \tan^{-1}(m_l) \text{...............3.9}$$

With the known coordinates of A and B, the slope and y-intercept are calculated with,

$$m_l = \frac{y_B - y_A}{x_B - x_A} \qquad \text{.............3.10}$$

$$b_l = y_A - m_l x_A$$

Yielding the following function,

$$y_l = 0.95 x_l - 0.7$$

CHAPTER 4

SYSTEM COMPONENTS AND PROCESS DESCRIPTION FOR MASS COOKING

Sun’s radiations can be used to harness energy for a variety of applications. But these radiations are diffuse in nature so cannot be use directly for these applications. Solar concentrators are the devices that are used to collect this energy and utilize for thermal and power generation.

4.1 Working Principles of a Scheffler Dish System

A Scheffler reflector is a small lateral part of a larger parabola (Fig.4.1), which focus the concentrated solar radiations onto a fixed receiver.

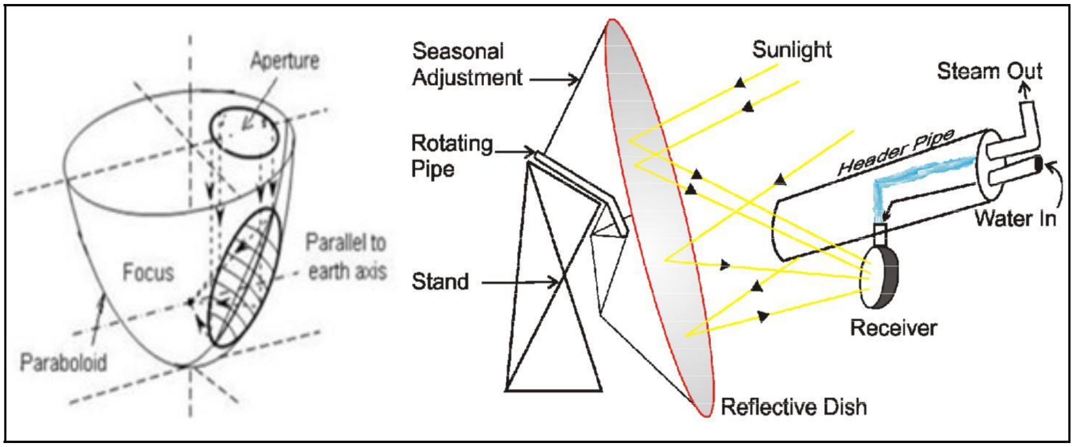


Fig 4.1: Working Principle and Components of a Scheffler Dish System

Scheffler Dish works on the following principle:

1. The Scheffler Dish turns about the North-South axis just parallel to axis of Earth, and track the Sun’s movement from morning to evening (i.e. from East to West).
2. The Scheffler Dish also change its angle of inclination while keep on tracking the Sun to obtain the sharp focal point.
3. Focus of Scheffler Dish lie at the point of intersection of line passing through focus and perpendicular to the axis of larger parabola.

4. Focus remains at fix position and continuously receives the concentrated solar radiations from the collector which is transferred to water to generate steam or hot water.
5. Feed water enters into the receiver through the header pipe using thermosyphon principle. Inside the receiver, the enthalpy of water increases and it converts into steam or hot water and collected into the header pipe which extends to the end use application.

4.2 Specifications of Standard Module

Specifications of a 16m^2 Scheffler dish is given in below table, but these specifications may vary from manufacturer to manufacturer.

Table 4.1: Specifications of 16m^2 Scheffler dish

S. No.	Module Description	Rating
1.	Surface area of collector	16m^2
2.	Aperture area of collector	11.65m^2 (approximate)
3.	Dimension and Shape	Parabolic
4.	Reflectivity	92%
5.	Thermal Output Capacity*	5.5KW
6.	Thermal Efficiency	40%
7.	Ground area required for single dish stand and receiver	35m^2

* It is standard thermal output capacity and it vary place to place.

4.3 System components of Steam Generating Plant for Mass Cooking[38]

S.No.	Subsystem	Values	Description
1	**Collector System** (Fig. 4.1)		Collects and reflects the Sun’s radiation at fixed focus.

1.1	Scheffler dish reflecting surface	Solar grade mirror with protective coating.	25 schefflers dishes of 16m^2 concentrate solar radiation onto 25 receivers. Water from header pipe enters into the receiver and gets converted into steam due to concentrated solar radiations.
	Number of Dish	25	
	Total collector area	25*16=400m^2	
	System energy capacity (8 hours)	1854.72MJ	
	Steam generating capacity	60Kg/h	
	Focus	Fixed Focus	
1.2	Receiver (Drum Type) (Fig. 4.2)	• Mild steel receiver coated with black board paint. • It collects the heat and transfers it to the working fluid. • Fixed at the focus of parabola and absorbs the concentrated Sun radiations to heating water to steam. • Works on the principle of thermosyphon in which cold water sinks down from header to receiver and hot water or steam flows up to header due to relatively lower density. • Insulated from back and sides from glass wool to prevent losses due to conduction and convection.	
	Heating media	Water converted into steam	
	Temperature and Pressure	150-180°C 100psi (6.89 bar)	

Fig.4.2: Collector surface of Scheffler Dish

Fig.4.3: Receiver of Scheffler Dish (Drum Type)

2	**Tracking Mechanism**		
2.1	Stand (Fig. 4.4)		Scheffler Dish mounted on a stand which is rotating parallel to polar axis of Earth. Dimensions for stand vary with latitude. All required calculations for stand are shown in Chapter-
2.2	Tracking Scheme (Fig.4.3)	Dual axis tracking E-W (daily tracking) Automatic N-S (seasonal tracking) manual or automatic	Scheffler dish move to track Sun's radiations and direct them to receiver.
	Drive Mechanism (Fig. 4.5)	DC wiper motor (12V)	Scheffler Dishes are interconnected with wire rope going over gear box which is driven by DC wiper motor of 12V.

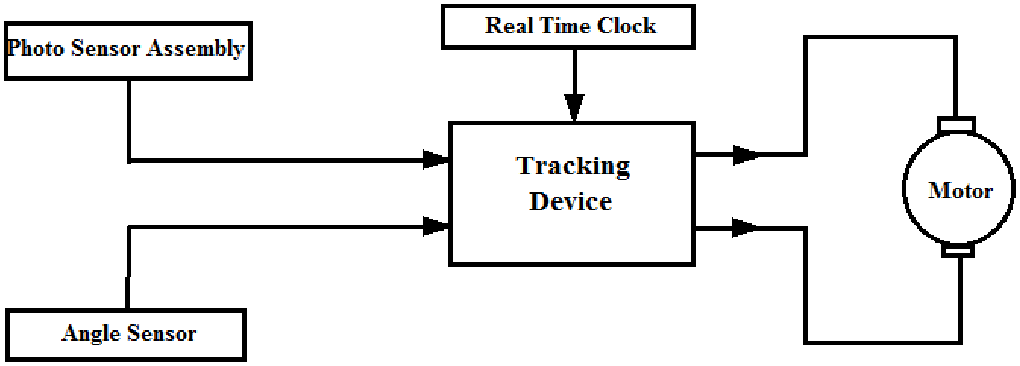


Fig.4.4: Tracking Scheme of Scheffler Scheme

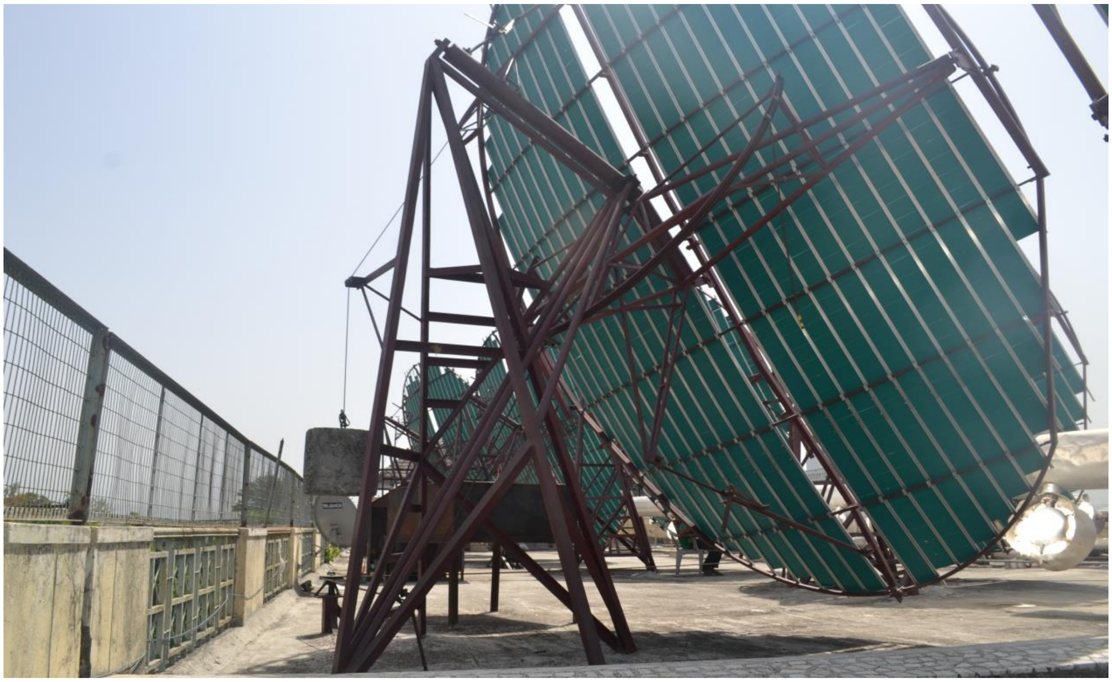


Fig.4.5: Supporting structure of 16m^2 Scheffler Dish

Fig.4.6: Drive mechanism using DC wiper motor of 12V and Chain sprocket assembly

3	**Circulating System**	Function of circulating system is to carry the working fluid and transfer heat to end use application. Fluid circulates at a certain calculated rate for maximize the efficiency of the entire system. It has a number of components like pipes, pumps and valves.
3.1	Fluid composition	DM/RO Water
3.2	Feed water storage tank (Fig. 4.6)	A well-insulated feed water storage tank of capacity 1000 liter, having water at a temperature of 60-70°C. A separate Scheffler Dish is used to heat up feed water.
3.2	Heat Storage System	It is an important part of circulation system which extracts heat from high temperature fluid when temperature is high and supplies when temperature is low.
3.3	Receiver pipe (Fig. 4.7)	It consist of two separate pipes, one for incoming water and other is for outgoing steam. Receiver works as a buffer system having a mixture of steam and water.
3.4	Insulation	Entire circulating system is insulated with glass wool which is protected by wire mesh and aluminium sheet.
3.5	Operating pressure	Pressure reduction valve reduces system pressure to cooking vessel level <1Kg/m^2
3.6	Operating temperature	
3.7	Pressure protection	Safety relief valve ensure that pressure does not go above the system design pressure.

Fig.4.7: Feed water storage tank with separate Scheffler Dish for pre heating water

Fig.4.8: Receiver with supporting structure and inlet and outlet pipes

4	**Control System**		
4.1	Timer	Off Time- 39.3 sec On Time- 3.0 sec	Controls tracking of the dish
4.2	Solar Radiation Sensor	To monitor solar radiations received for monitoring system efficiency.	
4.3	Wind Speed Sensor	To detect storm when wind speed crosses the designed limit.	

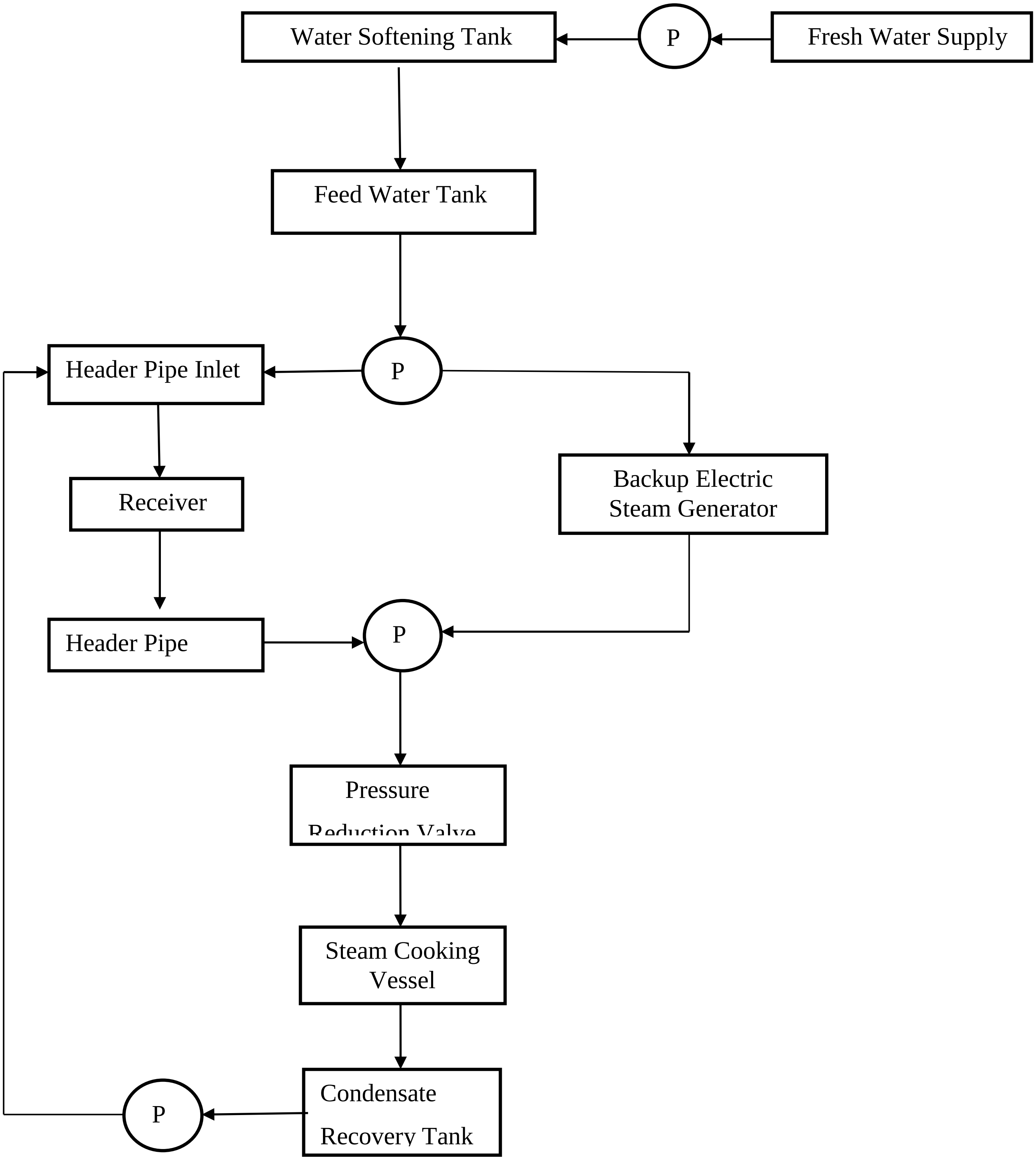
4.4 Steps of Steam Generation and Mass Cooking

Following steps describe the working of Scheffler Dish assisted mass cooking plant using steam.

1. Fresh water which may be ground water, supply line water or may come from some other source is pumped (P1) to a water softening tank which uses any of the method among reverse osmosis, distillation or ion exchange method for softening water.
2. From water softening tank water enters into the feed water tank having capacity of about 1000 liters where one Scheffler Dish is used to preheat water up to 60-70°C.
3. Feed water tank has two outlets one is for water supply line to header and other is for backup electric steam generator. Feed water outlet pipe has a common pump (P2) and a two hand operated gate valve one for each outlet.
4. Water supply line is connected to header inlet pipe through a non returning valve (NRV 1). Header pipe has one safety relief valve, one pressure indicator and one water level indicator. The header pipe must always be half full. Water from the header inlet pipe distributed to the receiver which is fixed at the focus of Scheffler Dish.

5. As water is heated up steam is generated and its temperature increases gradually. When pressure becomes 100psi (6.9 bar) or more, the pressurized steam is allowed to enter into steam line system through a gate valve and non returning valve (NRV 2). There is a steam trap and strainer to remove any impurity or condensate present in the steam.

Flow Chart



6. After strainer steam is allowed to pass through a globe valve which is used to control the flow of steam. There is a pressure reduction valve to reduce the pressure of steam according to the cooking vessel which is followed by a pressure indicator to show the reduced pressure of steam.
7. Then steam goes to cooking unit where each cooking unit is the assembly of cooking vessel and globe valve. Steam supplied from the perforated bottom of these vessels and allows mixing with the food.
8. The condensate from vessels goes through the common outlet pipe and collects into the condensate recovery tank. A steam trap is used in the outlet pipe to prevent any flow of steam to the condensate tank.
9. Water from the condensate tank is pumped to the header inlet pipe having a non-returning valve where required make up water is added to the header pipe and the entire process continues.
10. The other outlet pipe from feed water tank is connected to the backup electric steam generator, which is used to generate steam in case of failure of the system or when there is no Sun light is available. From backup system, steam after achieving the minimum required pressure enters into the steam supply line where the further process is same.

4.5 P&I Diagram of Steam Cooking System

The entire design and layout for proposed system also known as P&I diagram is shown in fig 4.9. Piping system has shown with blue color for incoming feed water and red color pipe shows steam flow. Various hand operated gate valves and gauges are also shown. This is basic layout for any steam cooking plant and number of Scheffler dish will increase or decrease according to size of plant and required energy demand. This system is interconnected with an electric steam generator for steam generation during morning and rainy season. In place of electricity other means like LPG boiler or boiler using briquettes for steam generation can also be used.

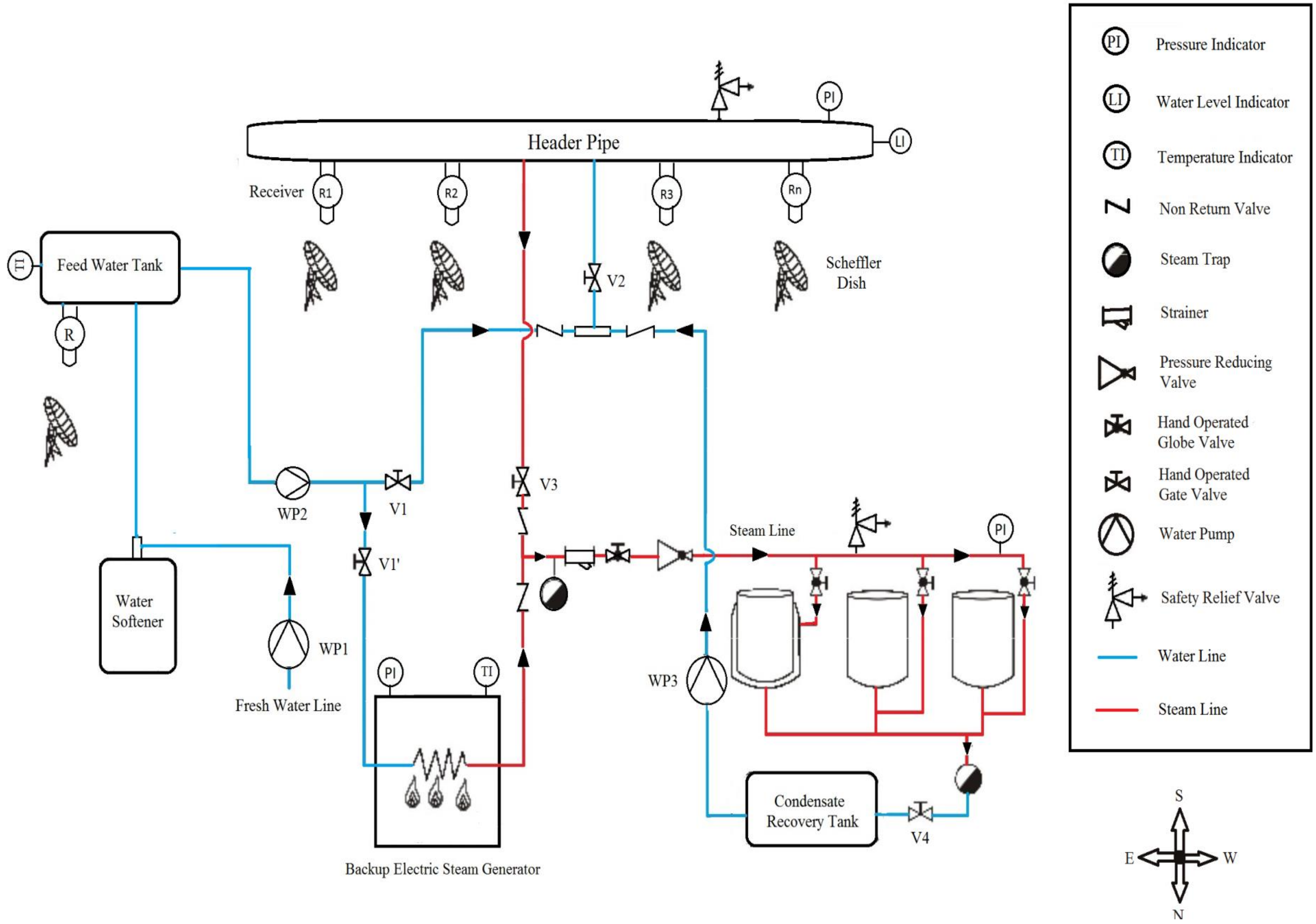


Fig 4.9 Piping and Instrumentation Layout of Steam Cooking System

CHAPTER 5

THEORETICAL ANALYSIS AND REQUIRED CALCULATIONS OF DTU PLANT

An attempt is made to replace DTU hostel LPG cooking system into steam cooking system. All the required calculations have done in this chapter by considering essential data for Delhi from NISE. Case study of Shantikunj, Haridwar is used for the design and concept of DTU plant. This plant is designed to replace three boys hostel mess which are in close vicinity of each other. In all calculations morning meal is not included, since steam cannot be stored till morning.

5.1 Collector Surface Area of Scheffler Dish for DTU Plant

Number of LPG cylinder used in these mess = 9

Since capacity of each cylinder is 14Kg, so total amount of LPG is used = 126 Kg

Calorific value of LPG = 46000 KJ/Kg

So, net energy released by LPG = 5796000 KJ

Efficiency of conventional LPG cooking process = 32%

So, energy utilized in cooking process = 1854720 KJ

For design consideration we have taken minimum efficiency of Scheffler Dish for Delhi i.e. 30%

So amount of energy is require to strike at Scheffler Dish = 1854720×3.33

= 6176217 KJ

Average annual DNI for Delhi = 4.29KWh/m^2/Day

Area of dish required = amount of solar energy strike at Scheffler Dish per Day / average annual DNI

= 6176217/4.29×3600 = 400m^2

Area of one Scheffler Dish = 16m^2

Total number of Scheffler Dish required = 400/16

= 25 Scheffler Dish

5.2 Mass flow rate of working fluid

Total energy required per day = 1854720 KJ

This much of energy will be collected from 9 am to 5 pm i.e. in 8 hours of solar radiations per day

Per second energy required by system = 1854720/8×60×60

= 64.6 KJ/sec

Initial temperature of feed water, T_i = 60°C

Final temperature of steam, T_f = 150°C

Q1 = m×specific heat of water× (100-60)

= m×4.18×40

= 167.2m KJ

Q2 = mL

= 2260m KJ

Q3 = m × specific heat of steam × (150-100)

= m×1.996×50

= 99.8m KJ

Total heat required, Q = Q1+Q2+Q3

= 2527m KJ……………………(i)

Energy strike at Scheffler Dish surface = 6176217 KJ

Optical efficiency of surface η_o = .75

So, energy reflected to receiver = 6176217 × .75

= 4632163 KJ

Conduction and convection losses occurs at receiver, η_{th} = .3

Energy transferred to working fluid = 4632163 × .3

= 1389649 KJ…………………….(ii)

From relation (i) and (ii).

2527m = 1389649

m = 550 Kg

mass flow rate of working fluid, $\dot{m}$ = 19.09 g/sec

5.3 Performance analysis of System

i. $$\frac{Q}{A_P} = DNI \times \eta_o \times Cos\theta \times K\theta_L - a_1 \times (T_m - T_a) - a_2 \times (T_m - T_a)^2$$

where,

Q = Useful output (W)

A_p = Aperture Area (m^2)

η_o = optical efficiency

DNI = Direct Normal Irradiance (W/m^2)

θ = angle of incidence

a_1 = First Degree Temperature Dependence Heat Loss Coefficient for Conduction and Convection (W/m^{2}K)

a_2 = Second Degree Temperature Dependence Heat Loss Coefficient for Radiation (W/m^{2}K)

T_m = mean temperature

T_a = ambient temperature

$K\theta_L$ = longitudinal incidence angle modifier

ii. Optical efficiency, η_o

$$\eta_o = \gamma.\rho.\alpha.\Gamma$$

where,

γ = intercept factor

ρ = reflectivity of reflector surface

α = absorptance of the receiver

Γ = transmittance of glass cover of receiver = 1

Optical efficiency of system can be achieved upto 92% with proper maintenance and cleaning of dish surface. For our case, we have taken it 75%.

iii. Cosine loss ($\cos\theta$)

$$\cos\theta = \cos (43.23° - \text{solar declination} (\partial)/2)$$

$$\partial = 23.45 \sin [2\pi(284+n)/36.25]$$

where,

n = day of year

iv. Incident Angle Modifier $K\theta_L$

$$K\theta_L = \eta_o(\theta) / \eta_o \text{ (on } 22^{nd} \text{ December)}$$

For making calculation simple, we have taken unit incident angle modifier.

v. Thermal Energy Loss

Conduction, Convection and Radiation losses are the reason of decreasing efficiency of the system. These losses increases with increase in temperature difference. To minimize these losses receiver should be covered with thermal insulator. To increase absorption of receiver, it should be painted with black board paint.

$$\text{Thermal Energy Losses} = a_1 (T_m - T_a) + a_2 (T_m - T_a)^2$$

5.4 Efficiency

It is the overall efficiency of a system using Scheffler Dish as the collector. A more efficient substitute of Scheffler Dish is Parabolic Dish collector but it also has some limitations.

$$\eta = \text{output energy/ input energy}$$

$$\eta = \frac{\text{DNI}\times\eta\text{o}\times\cos\theta - \text{a1 (Tm}-\text{Ta)} + \text{a2 (Tm}-\text{Ta)2}}{\text{DNI}}$$

$$\eta = \eta\text{o} \times \cos\theta - \frac{\text{a1 (Tm}-\text{Ta)}}{\text{DNI}} - \frac{\text{a2 (Tm}-\text{Ta)2}}{\text{DNI}} \qquad \ldots\ldots \text{(iii)}$$

Efficiency relation for Parabolic Dish collector is:

$$\eta = \frac{\text{DNI}\times\eta\text{o} - \text{a1 (Tm}-\text{Ta)} + \text{a2 (Tm}-\text{Ta)2}}{\text{DNI}} \qquad \ldots.. \text{(iv)}$$

this relation shows that Parabolic Collectors are free from cosine losses which results in more efficient performance of system.

Theoretical analysis of this system has been done for different parameters by changing the values one by one. Table5.1 and Table 5.2. shows the performance analysis for different parameters in detail. All results are shown graphically in Chapter 6 and discussed thoroughly.

Table 5.1: Calculations for energy loss due to conduction, convection and radiation

S. No.	Month	DNI (W/m^2)	η_o	Cosθ	a_1 ($W/m^2 K$)	a_2 ($W/m^2 K$)	Energy loss (W/m^2)			
							$\Delta T1$= 90°	$\Delta T2$= 100°	$\Delta T3$= 110°	$\Delta T4$= 120°
1	JAN	405	.65	.8289	1.2	.001	116	130	144	158
2	FEB	615	.65	.8350	1.2	.001	116	130	144	158
3	MAR	790	.65	.8398	1.2	.001	116	130	144	158
4	APR	724	.65	.8440	1.2	.001	116	130	144	158
5	MAY	673	.65	.8476	1.2	.001	116	130	144	158
6	JUNE	516	.65	.8500	1.2	.001	116	130	144	158
7	JULY	350	.65	.8518	1.2	.001	116	130	144	158
8	AUG	438	.65	.8525	1.2	.001	116	130	144	158
9	SEP	584	.65	.8523	1.2	.001	116	130	144	158
10	OCT	530	.65	.8512	1.2	.001	116	130	144	158
11	NOV	431	.65	.8490	1.2	.001	116	130	144	158
12	DEC	390	.65	.8462	1.2	.001	116	130	144	158

Table 5.2: Input and Output Energy with Efficiency of system at different ΔT

S. No.	Month	DNI* (W/m^2)	**Output** (W/m^2)				η			
			E_1	E_2	E_3	E_4	η_1	η_2	η_3	η_4
1	JAN	405	102	89	75	60	25	22	18.3	15
2	FEB	615	218	204	190	176	36	33.1	31	25.7
3	MAR	790	315	301	287	273	40	38	36.3	34.5
4	APR	724	281	267	253	239	39	37	35	33

5	MAY	673	255	241	227	213	38	35.8	33.7	31.6
6	JUNE	516	170	156	142	128	33	30.2	27.5	24.8
7	JULY	350	77	63	49	35	22	18	14	10
8	AUG	438	126	112	98	84	29	25.6	22.3	19.2
9	SEP	584	207	193	179	165	36	33	30.7	28.2
10	OCT	530	177	163	149	135	33	31	28	25.5
11	NOV	431	122	108	94	80	28	25	21.8	18.6
12	DEC	390	99	85	71	57	26	21.8	18.2	14.6

5.5 Emission of CO_2 by burning of LPG per annum

Number of mess considered in design = 3

Number of LPG cylinder required by each mess in a day for cooking = 5

Total number of LPG cylinder required in a day = 15

Average number of working days of mess in a year = 300

So, total number of cylinder required in 300 days = 4500

Capacity of each cylinder = 14kg

Total LPG used in one year = 14*4500

= 63000 kg of LPG

Specific Carbon content of LPG = 0.82 kg/kg of LPG

So, 63000kg of LPG has = 63000*0.82 kg of Carbon

= 51660 kg of Carbon

Mass of O_2 required for complete combustion of 12 g of C = 32 g

So, mass of O_2 required for combustion of 820g of C = 2186.7g of O_2

Mass of CO_2 generates by burning of 1kg of LPG = 820+2186.7

= 3006.7 g of CO_2

= 3 kg of CO_2

Total CO_2 generates in 1 year by burning of 63000 kg of LPG in DTU

=189000 kg

= 189 tonne of CO_2

5.6 Economics of Proposed DTU Plant

After proposing the steam cooking plant consist of 25 Scheffler dish of 16 m^2 for DTU boys hostel mess now we discuss the economic feasibility of Steam Cooking System in terms of input solar radiations and the payback period of plant. Total annual energy required for cooking and the potential of Steam Cooking Plant to share the load is calculated.

5.6.1 Total Energy Requirement for Cooking

Annual thermal energy demand of boys hostel mess in DTU is calculated by multiplying number of dish cooked per day with number of working days in month and also with thermal energy required for one dish. Thermal energy required for one dish is calculated by dividing the net thermal energy used for cooking in one day with total number of dish prepared in one day. Following table represents the monthly thermal energy required by mess in KWh.

Table 5.3: Monthly Requirement of Energy for Cooking

Month	No of working days of mess	Thermal energy required per dish(KWh)	Number of dish cooked per day	Monthly thermal units required for mess(KWh)
Jan	31	0.33	2700	27621
Feb	28	0.33	2700	24948
Mar	31	0.33	2700	27621
April	30	0.33	2700	26730
May	31	0.33	2700	27621

June	30	0.33	900	8910
July	31	0.33	900	9207
Aug	31	0.33	2700	27621
Sep	30	0.33	2700	26730
Oct	31	0.33	2700	27621
Nov	30	0.33	2700	26730
Dec	31	0.33	2700	27621
total	365			288981

DTU hostel mess works 365 days in a year. It closed only at night of Friday of every week. In summer vacations of June and July only one mess remains working due to decrease in strength of students. Thermal energy requirement for each dish is calculated to be just 0.33 KWh. Thermal energy requirement in month of June and July is minimum and it goes in favour of the proposed plant as average DNI in month of June and July is very low. Total annual thermal energy requirement is also calculated which comes out to be 288981 KWh.

5.6.2 Estimation of Potential of DTU Steam Cooking System

Energy potential of one dish is calculated by multiplying the average DNI with the overall efficiency of the system and with the surface area of the one dish. Monthly average DNI for Delhi is 4.29 KWh/m^2/day. Rated thermal output for one Scheffler Dish of 16 m^2 is 5.5 KW but it is not considered in proposed design as this value changes from place to place and depends upon the DNI of that place. Monthly thermal units generated by one Scheffler dish of 16 m^2 is calculated to be 7428 KWh. As total 25 dishes are present in proposed design the total thermal output will be 185688 KWh.

Table 5.4. shows the energy estimation potential of every month by the plant. Result of the table is represent in the graphical form with month on X-axis and thermal energy output on Y-axis. Energy generation remains maximum for March then starts decreasing and reaches to minimum in July. Number of days for which sun radiations are available is not constant. The thermal output curve is also compared with the DNI curve on the same graph and follows the same pattern as shown by DNI curve. It signifies that the thermal output of Scheffler Dish depends upon the DNI.As data for monthly thermal unit required for cooking and for the monthly thermal unit generated by the Steam plant has been calculated, solar fraction can be calculated which is defined as the thermal unit generated by plant to the thermal unit required by the process. The annual average solar fraction comes out to be around 50%.

Table 5.4: Monthly Energy Estimation Potential of Proposed Plant

Month	**DNI ($KWh/m^2/Day$)**	**No. of Days** **Solar radiation available**	**Thermal Output Energy per Dish ($KWh/m^2/Day$)**	**Monthly Thermal Unit generated by 1 Dish (KWh)**	**Monthly Thermal Unit generated by 25 Dish (KWh)**
Jan	3.24	15	0.97	232.8	5820
Feb	4.92	20	1.287	411.84	10296
Mar	6.32	28	1.896	849.4	21235
Apr	5.79	28	1.737	778	19454
May	5.38	28	1.614	723	18077
June	4.13	25	1.239	496	12390

July	2.79	12	0.837	160.7	4017.6
Aug	3.5	20	1.05	336	8400
Sep	4.67	27	1.401	605	15131
Oct	4.24	25	1.272	509	12720
Nov	3.45	25	1.035	414	10350
Dec	3.12	16	0.936	240	5990
			Total	5755.74	143880.6

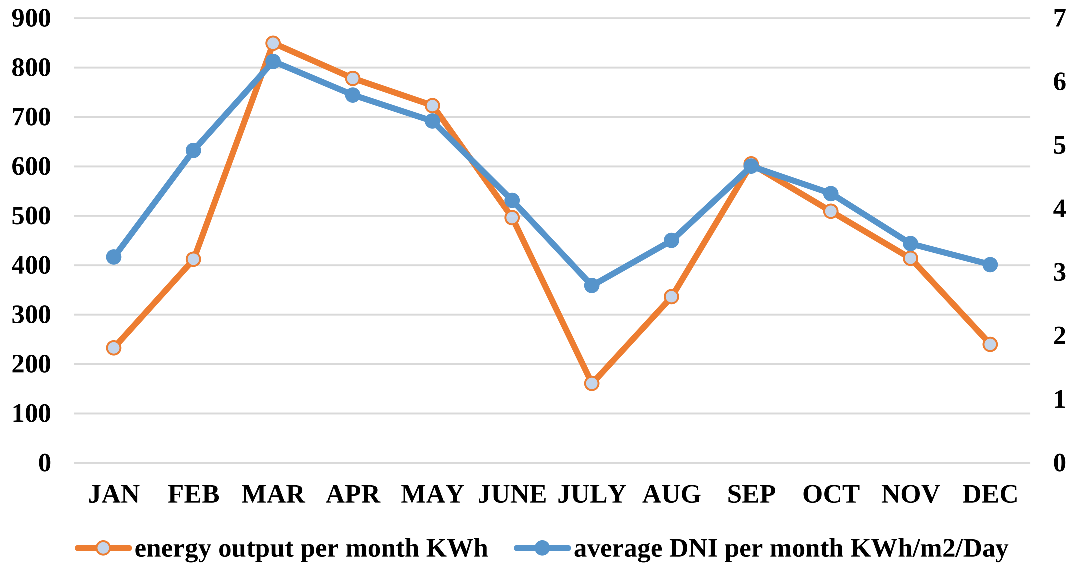


Fig.5.1: Monthly Thermal energy Output and DNI for DTU plant

5.6.3 Payback Period

Calculation for payback period is shown in tabular form with all necessary data.

S. No.	Design Parameter Description	Value
1.	Type of fuel	LPG

2.	Number of LPG cylinder used per day	15
3.	Cost of one cylinder	800
4.	Fuel cost for one day cooking	12000 INR
5.	Cost of fuel in one year	43.8 Lakh
6.	Percentage of fuel save by Steam Cooking System	50%
7.	Money save in one year	21.9 Lakh
8.	Cost of Scheffler Dish per m^2 according to MNRE standards	$18000/m^2$
9.	Cost of one Scheffler Dish of $16m^2$	2,88,000
10.	Cost of 25 Scheffler Dish for DTU plant	72 Lakh
11.	Cost of water treatment, water storage, piping and insulation etc. according to MNRE standards	20% of system cost i.e. 14.4 Lakh
12.	Total cost for installation of DTU plant	86.4 Lakh
13.	Subsidy available for two axes tracking based Scheffler Dish	$6000/m^2$
14.	Total subsidy available for 400 m^2	24 Lakh
15.	Final cost of installation for DTU plant	62.4 Lakh
16.	Payback period	2.84 years

CHAPTER 6

RESULT, CONCLUSION AND FUTURE RECOMMENDATIONS

Detailed study of energy requirement for DTU boys hostel mess has done and design of DTU steam cooking system using 25 Scheffler Dish is proposed to replace conventional cooking system. DTU steam cooking system will be integrated with a backup system for steam generation using electricity of LPG for enabling breakfast cooking and to bear any fluctuation in the solar radiations due to clouds or system maintenance. Calculations for CO_2 emission by burning of LPG has shown in this chapter. An economic analysis including all necessary cost for system development with payback period is also shown to prove the feasibility of DTU steam cooking system.

6.1 Result of present work

This graph shows the monthly variation of DNI for Delhi[41] in W/m^2 with maximum irradiance in March and minimum in July.

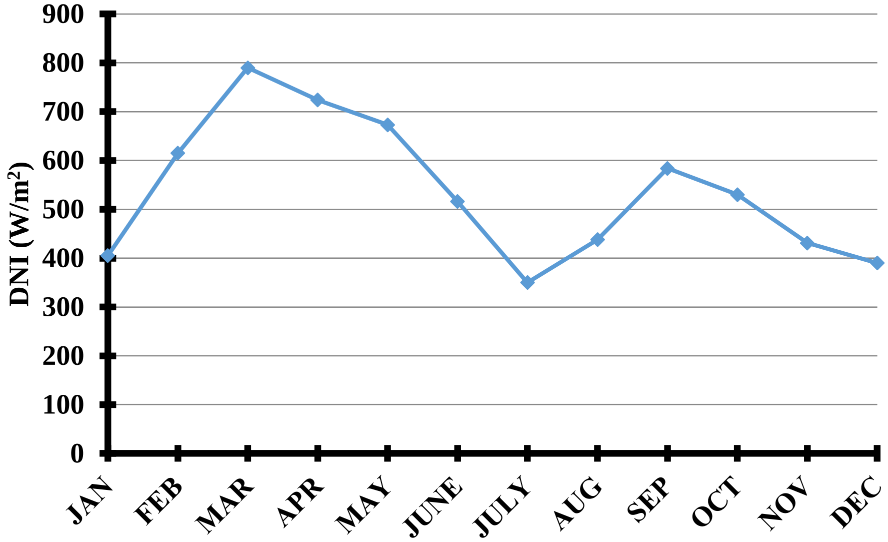


Fig 6.1: Monthly variation in DNI for Delhi

Large portion of solar irradiation lost due to thermal energy loss, optical efficiency loss and cosine loss. Thermal energy losses can be reduce using effective insulation with glass wool at the receiver and pipes and with coating of blackboard paint on receiver front surface to increase absorption. Optical efficiency can be improved by routine cleaning of reflecting mirror and proper tracking system for daily and season tracking. The bar graph based on table 5.1 which shows the comparison between the input energy to reflecting surface and output energy at temperature difference of 90° and 120°.

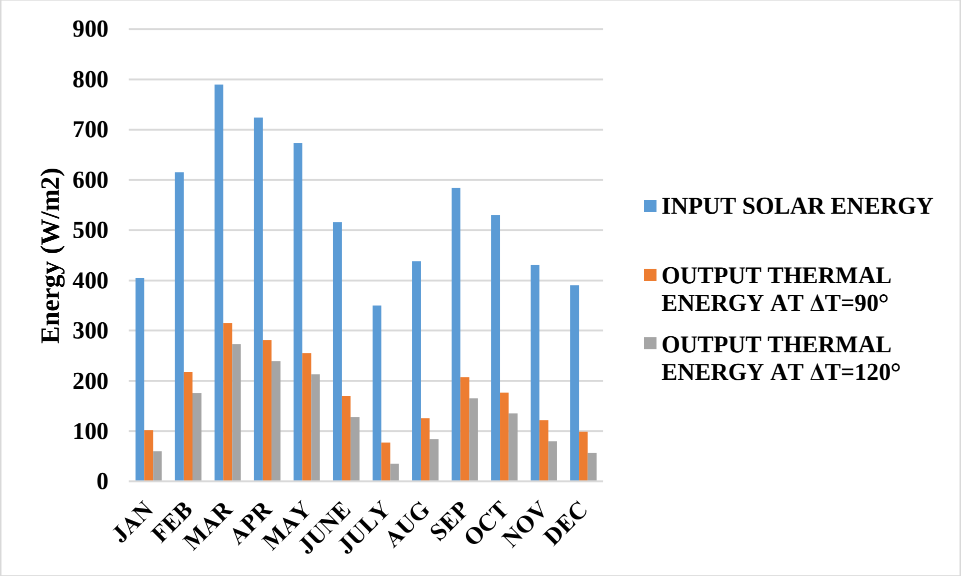


Fig 6.2: Variation in output thermal energy with ΔT

Following bar graph describes the feasibility of steam cooking system for Delhi climatic conditions. Monthly requirement of mess remains constant whereas the thermal energy from sun varies month to month. It is based on the table 5.3 and 5.4 and shows maximum output for March to May and then decreases to minimum in July. From the figure it is concluded that almost half of thermal energy requirement can be fulfilled using such a system for cooking purpose.

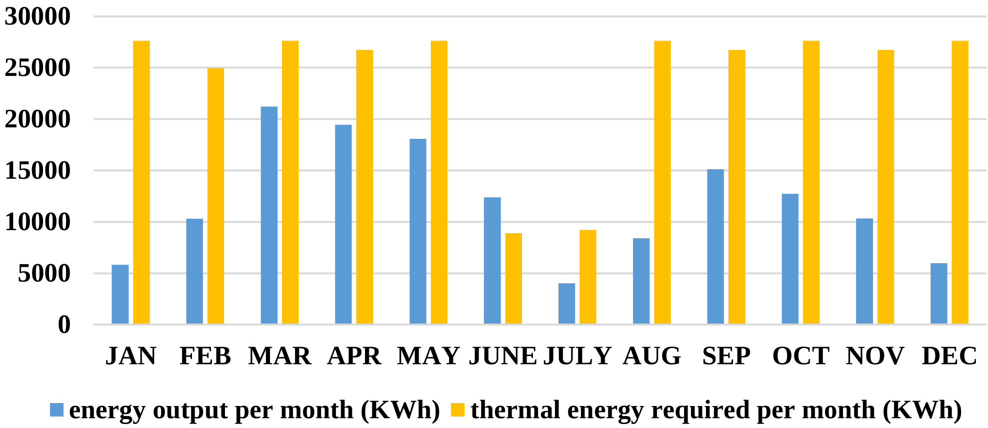


Fig.6.3: Monthly thermal energy requirement vs DTU plant potential

Following graph shows the efficiency variation at different temperature difference with highest efficiency at minimum temperature difference. For Delhi this graph shows the M shape curve with minimum in month of July. System will work most efficiently in almost half of the year with the remaining time the backup system will be required to assist the steam cooking system.

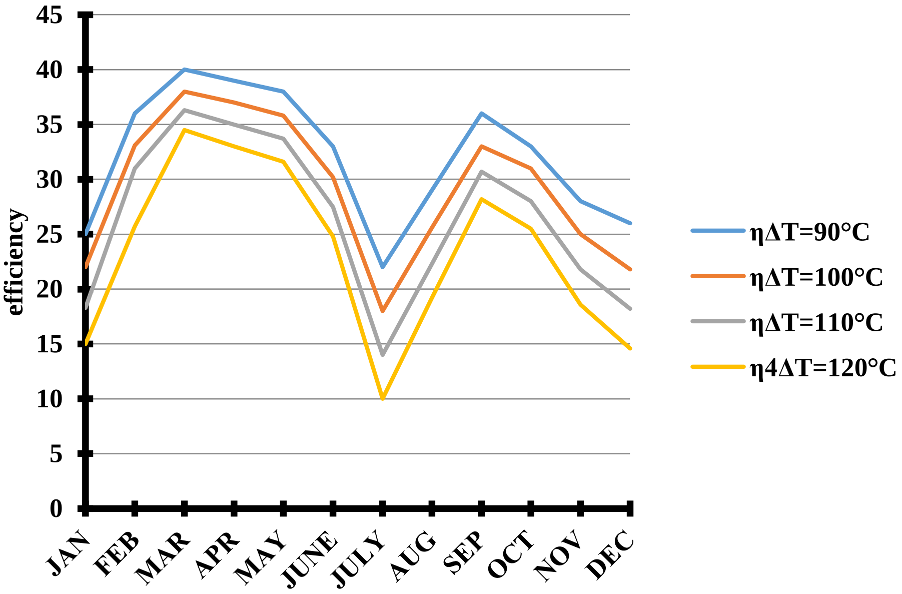


Fig 6.4: variation of efficiency of Scheffler Dish with month at different ΔT

Comparison of efficiency of Parabolic Dish and Scheffler Dish with different temperature difference has shown in following graph. The curve for Scheffler decline more sharply as compared to Parabolic Dish. This is justify by the absence of cosine losses in Parabolic Dish as it always remains at the perpendicular position in respect of reflector surface. But the inherit drawback with Parabolic system for cooking is its moving focus with which a rigid steam distribution system cannot sustain.

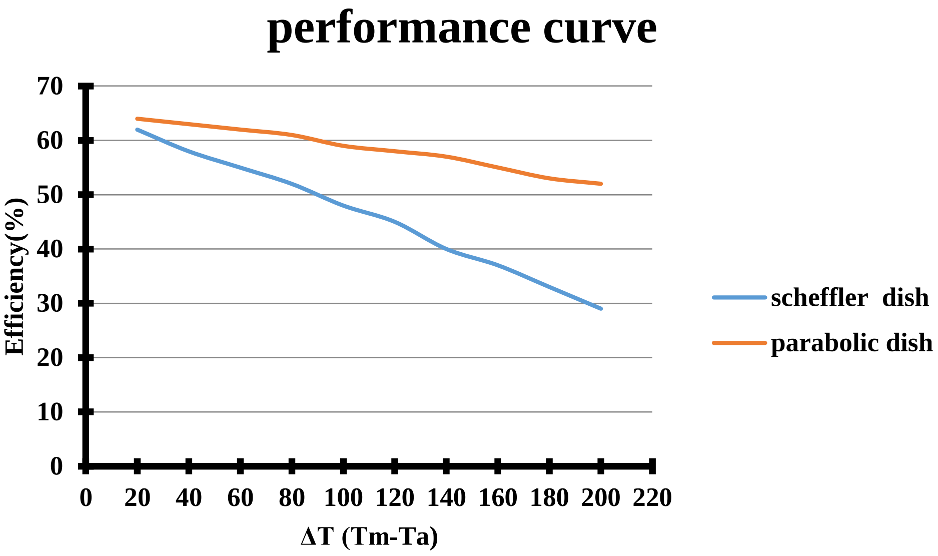


Fig 6.5: change in efficiency of Scheffler Dish and Parabolic Dish with ΔT

Payback period is calculated to 2.84 years without considering maintenance cost since it depends upon monitoring skills. Such cooking systems are working at Shantikunj (Haridwar), Shantivan (Mount Abu) and many other places in India due to proper maintenance of system and skilled labor.

Emission calculation reveals the fact that around 189 tonne of CO_2 is being emitted into atmosphere annually by burning of LPG in hostel mess. DTU steam cooking system may prove to be a model for other institutions and big step to reduce the emission of green house gas.

6.2 Conclusion and Future Recommendations

In context of present work, a steam cooking system for DTU boys hostel mess is proposed with detail discussion. The study includes the energy requirement of mess, efficiency of Scheffler Dish in Delhi, number of Scheffler Dish required, emission reduction of CO_2, and economic analysis. The outcomes of present study are given below.

Energy requirement of DTU boys hostel mess per annum = 288981 KWh

Efficiency of Scheffler Dish in Delhi at ΔT_1 = 32%

ΔT_2 = 29%

ΔT_3 = 26.4%

ΔT_4 = 23.4

Energy required to cook one meal = .33KWh

Number of Scheffler Dish required = 25

Emission reduction of CO_2 per annum = 95 tonne

Cost of project bear by DTU = 62.4 lakh

Payback period = 2.84 years

The efficiency decreases with increase in temperature difference, so it is beneficial to provide good insulation and operate the system at minimum possible temperature difference.

Finally the feasibility of concentrated solar thermal steam cooking system has been studied along with it economical feasibility. This project is recommended with keeping in mind the following properties:

- Reduction in CO_2 emission which is primary GHG and decrease the dependency on conventional fuel.
- Government should take step for encouraging other institution to implement this technology for mass cooking.
- Some research work should done on receiver design to improve the overall efficiency of system.

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