Modified solar central receiver in concentrated solar power system

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Abstract— **As in recent times solar thermal power has been came out as promising source of renewable energy this thesis is focused on improvements in design of solar thermal central receiver used in solar thermal power generation with the purpose of increased power output using steam-gas dual cycle by obtaining homogenous higher solar flux. Incongruently it is still challenge how maximum power can be extracted from system with optimum thermal losses and design parameters of receiver. The major characteristics of suggested configuration includes combined cavity-external receiver with separated boiler-receiver configuration including molten salt latent heat storage system. Numerical calculations carried out explain the increase in heat transfer efficiency and reduction in receiver height thus heliostat size as compared to some of the suggested receiver configurations in the literature**

Index Terms—**Solar thermal power generation, Central receiver, Heat transfer, Rankine cycle, Brayton cycle.**

I. INTRODUCTION

The recent energy crisis and environmental burden are becoming increasingly urgent and drawing enormous attention to solar-energy utilization. Solar technology has made huge technological and cost improvements, but more research and development remains to be done to make it cost and power competitive with fossil fuels. Costs can be reduced by increasing demand for this technology worldwide, as well as through improved component design and advanced systems. Advancements in the technology and the use of low-cost thermal storage will allow future concentrating solar power plants to operate for more hours during the day and shift solar power generation to evening hours. Research is basically focused on developing lower cost solar concentrators, high-efficiency engine/generators, and high-performance receivers. The goal is to further develop the technology to increase acceptance of the systems and help the systems penetrate growing domestic and international energy markets.

Over 90% of the currently installed solar thermal power plant capacity is still based on parabolic trough technology, initially developed over 20 years ago during the late 1980s. These power plants employ Rankine cycle power blocks with low-temperature steam-turbines. Still cost of power generation from such plants remains high. A focus can be placed on optimising existing designs, reducing parasitic electricity consumption, which serve to increase the annual electrical output of the power plant.

A final focus can be placed on new power plant concepts. This can involve moving to more efficient thermodynamic cycles (generally requiring higher temperatures), new receiver designs and improved collector field layouts. Various prior research articles, patents in the field of solar thermal power generation have been studied and modifications in the some of the existing systems of solar boilers are suggested in this project. Specifically in this project, two configurations suggested by patent EP 2631555 A1 and patent US 2008/0078378 A1 are studied and combined in different way so as to obtain benefits of both configurations. The configuration suggested in EP 2631555 A1 concerns a configuration of the receivers in tower solar concentration plants with a physical separation between the evaporator, super heater, and the part for adaptive dynamic control of the heliostat field, in order to obtain superheated steam in an efficient and controlled manner.

II. BACKGROUND OF SUBJECT

The solar thermal power generation using desalinated sea water and steam power generation in combination with gas power generation is the combination proposed during this project.An object of this paper is to provide an improved hybrid electric power generating system by incorporating a steam power unit and parallel gas power unit with single solar tower configuration. High temperature preheated air is generated in boiler region of staged molten salt heating fluid working boiler with a configuration of saturated and superheated steam solar modules in a tower.

This work concerns a configuration of the receivers in tower solar concentration plants with a physical separation between the evaporator, superheater, and the part for adaptive dynamic control of the heliostat field, in order to obtain superheated steam in an efficient and controlled manner as well as parallel gas power generation unit with air as working fluid, said configuration ensuring continued durability and normal operation of said solar plant in its various application of electricity generation. The solar energy flux is not a constant or controllable during the operating hours. It should also be able to tolerate the un-even solar flux from different azimuth angle.

There are some shortcomings when literature regarding solar thermal power was reviewed such as

- The solar flux various according to condition energy density on central receiver is not constant, and is depending on the azimuth angles.

- A high performance solar central receiver must be able to tolerate a large number of thermal shock cycles during its' lifetime.
- The problem associated with central receiver system is the height of the tower and bulkiness of receiver as the power generation capacity of system increases.
- Generally capacity of Solar thermal power plant is limited central tower system is used to produce power output about 100-200 MW.
- Convective losses associated with external type of receivers and Cavity type receiver has limited acceptance angle, hence block solar flux received from concentrator.

With separated boiler and super-heater architecture, the boiler can be designed to work only below the critical temperature; it can have effective Water circulation system to keep the water in side boiler at different locations within a close temperature range to avoid un-wanted stress. The difficulty of solar technology for the generation of superheated steam lies in the demanding temperature conditions in which the receiver must operate. The walls of its pipes are continually subjected to thermal cycles between room temperature, the temperature of the steam supplied to this receiver (250 to 310ºC), and the wall temperature (higher than 600ºC) required for generation of superheated steam at 540ºC.

The research focuses on changes in design of solar central receiver so as to increase convective surface area of receiver so as to achieve homogeneous heating of boiler and super heater. The effort has been made to utilize area exposed to radiation of sun reflected from heliostat to heat air and generate power by the use of gas turbines hence this research basically combines steam power and gas power unit in single separated receiver. The majority of today's commercial concentrating solar power (CSP) plants generate steam to support steam turbine electric power generation. The steam generated by these state-of-the-art commercial CSP plants is limited to a maximum temperature of 400ºC, yielding approximately 40% thermal efficiencies. This project aims to increase the temperature capabilities of the CSP tower air receiver and gas turbine to 500ºC and achieve higher energy conversion efficiency.

The purposes served during making this project are

- To increase the Radiation heat transfer to the solar thermal receiver.
- To minimize the Heliostat field required for concentrating solar radiations on the receiver.
- Decrease the bulkiness of Receiver structure.
- Increase in power output using combined steam-gas power cycle.
- Separation of boiler and superheater module to achieve controlled heat transfer.
- Inclusion of latent heat storage system in receiver configuration.
- Combination of external and cavity receiver in suggested configuration to minimize convective heat loss.

III. DESIGN THEORY

The central receiver system is illustrated. A solar tower central receiver assembly contains a boiler and a steam super heater. A drum interconnects the boiler and super heater, and is for separating the steam from water. With well-controlled thermal dynamic properties and income solar flux density, the receiver is designed to take much higher energy density. The basic design of boiler consists of angular blocks with cavity in between two adjacent blocks making angle approx. 50 degree with centre. Boilers arranged on circular platform. Super heater arrangement is similar as boiler except super heater is located above boiler and in between cavity of two adjacent boilers. The boiler has feature composing of one or more areas of orientation with respect to heliostat field thus making maximum use of the incidence of solar radiation. Each boiler module is exposed to radiation such that radiation heat is received on three curved surface areas.


[1]Fig: Modified Solar Receiver

A. The Boiler Configuration:

In the boiler region the water chamber is located at bottom of the boiler feed water is fed to in the boiler chamber with the help of pumps located at bottom side of boiler module. Desalinated water is heated up while flowing through pipes located inside boiler module. Boiler module is designed in such a way that heat is transferred to water gradually from heating fluid (molten salts).Arrangement of pipes is vertical and extends from centroid point of module and running towards surface walls of boiler module in all the three exposed directions.
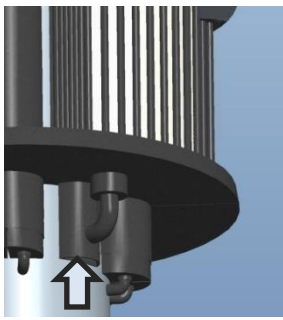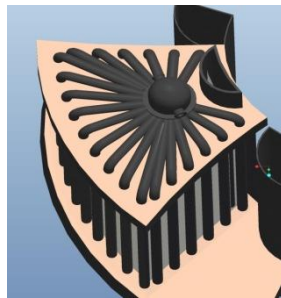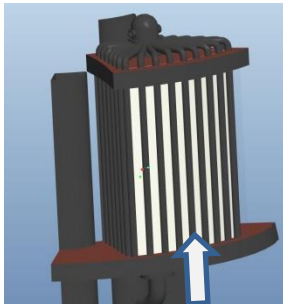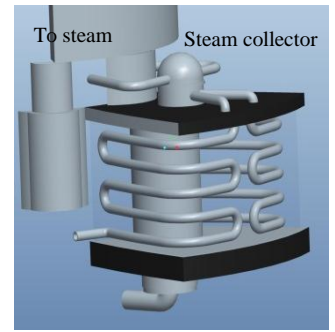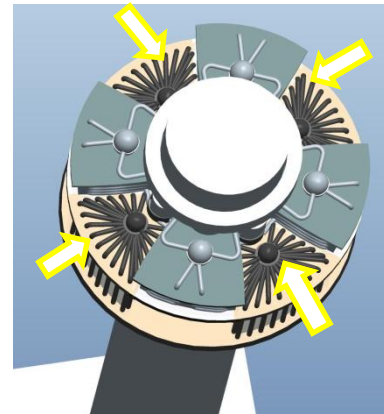
Water inlet
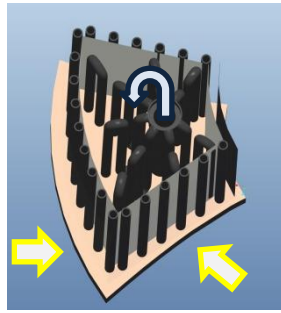
Boiler water flow

Superheater

To steam   Steam collector

Steam separator

[2]Fig: Boiler Module

[3]Fig: Superheater module

Desalinated water is flashed in to steam by receiving heat gradually from molten salt and direct solar radiations .With the use of molten salt chamber gradual and controlled heat addition can be obtained. Steam water mixture while passing through parallel pipes near walls of coated with asphalt salt blackbody so as to absorb large amount of radiation. When the water reached the vaporization temperature, some bobbles will be formed and mixed with water. Because the mixed water and bobbles has lower mass density, they will flow up into the separator drum. In the drum the steam and water will be separated that steam will be at higher half and water at the lower half the steam will flow out through the output pipes on the top of the drum . The water at lower half of the drum will be then circulating through the circulation pipes. Saturated steam coming out from separator drum is then fed to super-heaters.Another feature of boiler module includes preheating cavity for air Boiler module contains a triangular cavity containing low specific heat capacity sand/material which easily gets heated from heat of molten salt and transfer heat to air pipes in which air is passed at lower speed. Air absorbs heat and gets preheated.

B. The Super Heater Configuration:

Super heater is located on upper side of boiler floor in such a way that one superheating module is placed between two adjacent boiler modules. Super heater is given curved shape so that it can be constructed on upper level of boiler and space between two boiler modules is utilized with advantage of design stability. Super heater is having configuration similar to boiler module except its dimensions are smaller compared to boiler module. Super heater modules are exposed to more concentrated photons with the help of controlled heliostat such that temperature available at super heater region exceeds temperature of boiler region.

Saturated steam coming out from boiler drum is passed through super heater to obtain superheated steam for purpose of running steam turbine at higher pressure. The super heater is illustrated. Where the steam and Water separation is located at the bottom of the super heater, and the steam chamber is at the top of the super heater. The absorber is made of helix parallel pipes with one end connected to the drum and another end connected to the steam chamber .The configuration of pipes through which steam is passed is horizontal starting from bottom end running towards front surface area in midway and again running horizontally backward in the zigzag pattern till superheated steam is collected at steam chamber situated on the top of super heater module. Steam then passed to the steam turbine from steam chamber.

The horizontal curved parallel pipes has the better performance on tolerate the thermal stresses. It is free for expansion. In addition, the steam inside of the pipe provides better thermal exchange than straight pipes because of centrifuge force .Inside super heater module heat exchange fluid with higher thermal conductivity is used so that the air piper running at the inner end of module gets heat from conducing fluid.

C. Parallel Gas power system:

The basic problem with solar thermal power system is that they give relatively less power output. As efficiency of steam power system is more than gas power system most of the solar thermal power system uses steam power generation system by using Rankine cycle. With the use of large heliostat superheated steam at temperature approx. $540\text{-}600^0$ C can be obtained at pressure 100 to 160 bar.
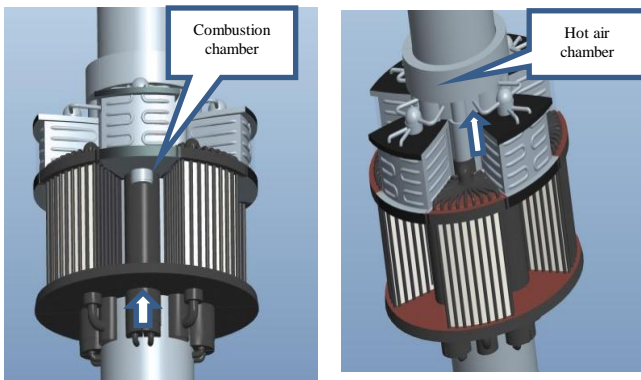
[4]Fig: Gas power system

In suggested system a parallel gas power system is also employed so as to increase power output and capacity of plant. Parallel gas power system working on Brayton cycle is used to meet peak load demands and maximum utilization of available solar energy. Parallel gas power generation system includes four pipes carrying air and two connecting chambers. Air is fed to system from bottom side of boiler module with the use of air compressors air them passed through vertical pipes which are installed inside of boiler module. By absorbing heat from heat carrying fluid air gets preheated. Preheated air is passed through connecting pipes and thus through parallel asphalt coated pipes located in between two adjacent boiler modules. In between two adjacent boiler modules, pipe carrying air is installed so that it gets exposed to direct solar radiations.
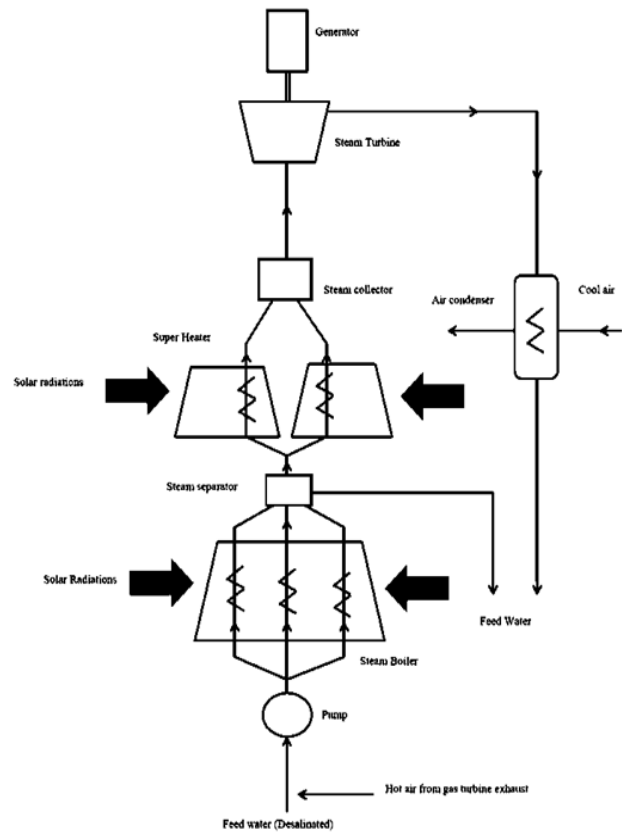
Thus heated air with increase in temperature is allowed to pass through super heater chamber in which a similar arrangement as boiler is made and temperature of air is further increased with transfer of heat at constant temperature in super heater module. Then air is passed through open connecting chamber which is located at upper side of super heater and exposed to solar radiation directly and temperature of air in increased further .Then heated air is passed through fourth piping arrangement which is made in between two super heater modules and temperature and thus high temperature air is made available for turbine inlet and air at temperature 450-500^0 C is obtained so as to run gas turbine and run generators. Power obtained from gas power system is thus used to run auxiliaries and fulfill peak load requirements.

D. Description of process:

Sea water is pumped from the sea and made to pass through the copper tubes lying beneath the absorber plates. Since the entire collector plate system is sealed in a box like arrangement, high temperatures are generated. The hot copper tubes then heat the saline water flowing through it to temperatures above the normal boiling point of water. The high temperature also increases the pressure inside the tubes. The high temperature and pressure generated converts the saline water into a mixture of hot boiling water and steam. This steam and hot water mixture is then passed through the flash tank. Since the pressure inside the tubes is higher than normal atmospheric pressure, the hot water and steam mixture comes surging to the flash tank with the opening of the valves. The hot water circles around the flash tank and is sent back to

the collector tubes through a bottom gating, or alternatively the hot water may be discarded. High velocity steam issues out from the other opening of the flash tank from where it is sent to the turbine. The turbine produces mechanical work by utilizing the high velocity of the issuing steam. The steam is finally collected as condensed water.

[5]Fig: Steam power Cycle Layout
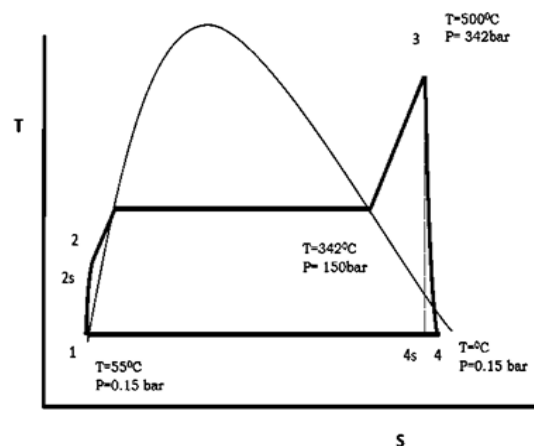
[6]Fig: Steam power cycle

E. Solar gas turbine technology

During making use of gas power system in suggested system another concept of hybrid gas power system is

suggested according to current research scenario in hybrid gas power generation following research can also be implemented while designing solar thermal power plant.

The development of pressurised air receivers for solar tower systems allows the integration of solar heat at high temperatures directly into the gas-turbine circuit, potentially increasing the conversion efficiency of the solar energy. Gas turbines in combined-cycle configuration are currently the technology that offers the highest conversion efficiency for a thermal power generation system. The integration of solar heat directly into the compressed air circuit of the gas turbine also simplifies hybridisation. Solar preheating of the compressor air allows fuel consumption to be dramatically reduced. Hybrid operation is an attractive feature of solar gas-turbine technology, facilitating control and ensuring the availability of the power plant to meet demand whenever it occurs.

IV RESULTS AND DISCUSSION
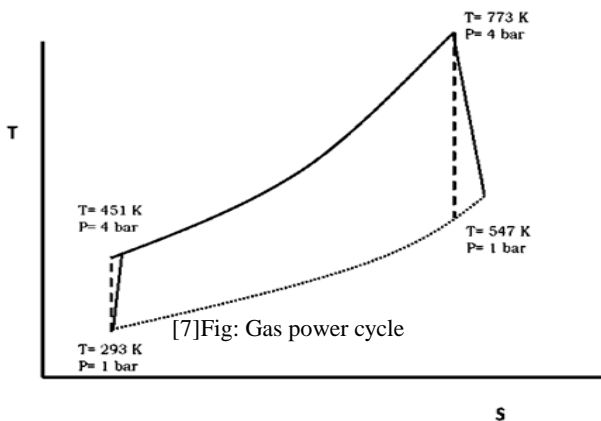
[7]Fig: Gas power cycle

[7]Fig: Gas power system

Schematic layout of solar energy operated gas power generation system
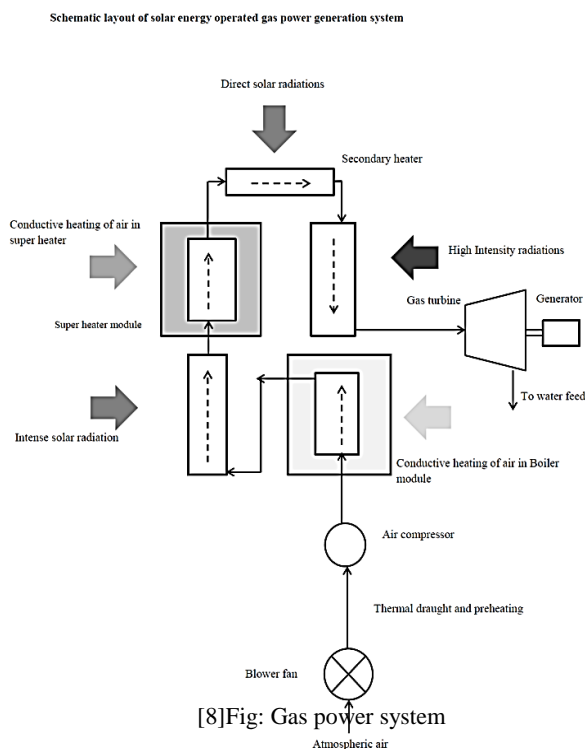
[8]Fig: Gas power system

F. Effect of separation of boiler and super-heater

- A solar tower central receiver with separated boiler and Super-Heater allows better control on the output steam's temperature.

- The boiler takes higher solar flux density and works at lower temperature while the Super-Heater takes lower solar flux and works at high temperature to optimize the cost to performance ratio. The solar fluxes of the boiler and super-heater are adjustable through the pointing of the heliostats. The boiler consists of parallel pipes as solar absorber and the Super-Heater consists of helix parallel pipes as solar absorber.

- With separated boiler and super-heater architecture, the boiler can be designed to work only below the critical temperature; it can have effective water circulation system to keep the water in side boiler at different locations within a close temperature range to avoid un-wanted stress. The boiler can be built by less exotic material at lower cost. Based on thermal dynamics theory, the boiler will absorb over 75% of the solar energy and the Super-Heater Will take less than 25%.

- The super heater is working at higher temperature and the coolant is steam, which is far less effective of cooling than water, but on the other hand, it required taking less energy flux. The thermal shock and thermal stress issues are needed to be paying more attention. When the absorber is cooled with mixed water and steam, the maximum energy density is limited as when it is cooled by steam only.

- With separated boiler and super heater, the boiler can take higher energy density while the super heater takes as steam cooled absorber, the average energy density of the absorber can be easily doubled. The super-heater is made by helix solar radiation absorbing pipes. The size of the receiver and running protocols of the heliostat field is designed to make the solar intensities on boiler and super-heater controllable.

- The receiver configuration proposed can be composed of one or more areas or orientations with respect to the heliostat field, thus making maximum use of the incidence of solar radiation. Each receiver area comprises two or more mutually independent modules. These modules can be aimed at the generation of saturated steam or else at the superheating of this steam.

- The modules are located within either area, placed in such a way that some modules, given their position, would receive radiation both on their front and on

their adjacent sides. The second purpose is to provide energy as homogeneously as possible to minimise thermal stress in the receiver panels. To this end, the heliostat field is oriented towards either module (evaporator or super-heater) in either, area depending on current needs and the radiations available.

• When the modules receive radiation on three sides, for a certain thermal power, the flow peak (W/m2) can be reduced (if panel size is maintained) as the available receiver surface to be irradiated is large (only one of the panel sides was previously used). On the other hand, if the panel size was reduced by half for a certain thermal power, the flow peak would be equal as in the case of a configuration with panels irradiated on one side, In any case, as the module has a more homogeneous heat supply than in the case of incidence on one side only, stress will be lower and deformation will be more uniform, thus achieving a longer service life of the materials.

G. Advantage of Mixed receiver configuration receivers

The receiver transfers the energy from the incoming reflected solar radiation to a heat transfer fluid which runs a turbine. Receivers are positioned at the top of the tower and high above the level of the heliostats on the tower in order to minimize the effect of shadowing and blocking among neighbour heliostats. In this way, the reflected energy from the heliostats is collected as efficiently as possible.

1) External receivers

External receivers usually consist of panels of tubes welded together in a cylindrical fashion. The tubes supply heat transfer fluid that is heated and collected for use in a turbine. External receivers usually have a height to diameter ratio of 1:1 to 2:1. Heat transfer fluids are typically those with high thermal conductivities, such as liquid sodium, water/steam, or molten nitrate salt.

2) Advantages of using external type receiver.

1. It has very wide acceptence angle while the same for cavity type receivers is 60 degrees.
2. The cavity is supported on its external surface while the external receiver is supported on its internal surface, making the supporting structure light and easy.
3. It is easy to repair external receiver.
4. It is easy to design minimal constraint supports and structures for the exterior receiver panels

3) Cavity receivers

The main advantage of cavity receivers is that the heat absorbing surface is placed inside an insulated cavity in order to reduce heat loss to the surroundings. This also allows losses from receiver aperture reflection to be lowered. Cavity receivers generally have a structure between apertures and the ambient called a secondary concentrator, which serves to further concentrate the incoming reflected radiation from the heliostats. .

4) Advantages of using cavity type receivers.

1. Thermal losses are low.
2. The thermal efficiency increases with the ratio of the cavity wall area to the aperture area.
3. It can be of varying types e.g. multiple pass, water steam boiler, open cycle air or closed cycle helium, ceramic tube or honey comb surfaces.
4. Have better thermal control characteristics and tend to protect the panels from wind, rain, snow, hail and low temperature.

Suggested configuration has both the features combined in it.

H. Approximate Heat Transfer analysis of Boiler module and storage system

Boiler module for suggested system can be assumed as angular block as shown in figure and dimensions can be taken approximately as follows.
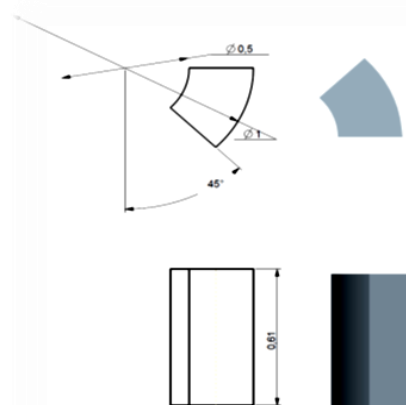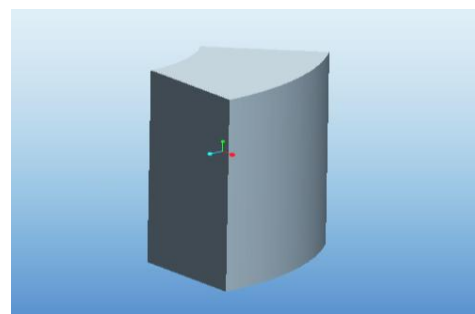
[9]Fig: Dimensions of Module prototype

1) Calculations for convective heat loss

Assumptions:

Temperature of ambient air near receiver = 50 ^{0}C
Material of receiver is assumed silicon carbide whose conductivity is 50 W/m^2
Temperature of receiver walls is approximately 750 ^{0}C
Properties of air at mean film Temperature 400 ^{0}C

T_f =400 ^{0}C,
ρ =0.524 kg/m^3,
μ =33.05 X 10^{-6} Pa-s,
ν =63.03 X 10^{-6} m^2/s,
α =93.111 X 10^{-6} /^{o}c,
Pr=0.678,
C_p=1067,
K=0.05210.

Calculations for Grashoff's number

β = 1/(1023+323)=7.4294 X 10^{-4},

$$Gr = \frac{D^3 \rho^2 g \, \Delta T \, \beta}{\mu^2}$$

Gr = 0.61^{3}x(0.524)^{2}x9.81x7.429X10^{-4}x700 /(33.05x10^{-6})^2

Gr = 291091778.9
Ra =GrPr =197360226.1

$$Nu = \begin{cases} 0.59Ra^{1/4} & 10^4 < Ra < 10^9 \\ 0.1Ra^{1/3} & 10^9 < Ra < 10^{13} \end{cases}$$

Nu =0.59(GrPr)$^{0.25}$
Nu= 69.930

$$Nu = \frac{h\delta}{k} :$$

69.930= (h X 0.61)/0.05210
h = 5.97 W/m^{2}K.

Case 1 *When Modified solar receiver configuration is used the calculations for Heat Transfer are given as*

1) Calculation for heat lost due to convection from wall surfaces

Q = 2(h$A_1\Delta$T)+h$A_2\Delta$T
  = [2 x 5.97 x0.1525 x700]+[5.97 x 0.23948 x700]
  = 1274.595+1000
Q = 2275.381W

2) Calculations for radiative heat transfer to the receiver

Generally amount of flux incident on receiver after reflecting from concentrator is in range of 800-1000 kW/m^2
Amount of heat flux incident on receiver surfaces is given as

Q_{in} =Assume (960 W/m^2 X 1000)
Q_{in}=960 X (2 X.1525+ 0.23948) kW.
Q_{in}=522.700 kW.

3) Calculations for radiative heat loss

Absorptivity (α) of silicon carbide wall is 0.9
Reflectivity (r) of silicon carbide wall is 0.03
Reflectivity (ρ) of silicon carbide wall is 0.07
Irradiation (G) on the surface = **960 kW/m^2**

Radiocity (J) of the surface = ρG + α E_b
    = 0.03 X 960 + 0.9 X (5.67 X 10^{-11} X (1023^4 - 323^4))
    = 28.8 + 55.33
  J = 84.133 kW/m^2

Radiation heat loss from boiler surface is = A X J
Q $_{loss\,rad}$ = 45.808 kW

Radiation heat absorption from boiler surface is = A x (J - G)
Q $_{gain\,rad}$ = (2 X.1525+ 0.23948) x (960 – 84.133)
Q $_{gain\,rad}$ = 476.89 kW

Net heat addition to the receiver = Radiative heat addition – Radiative heat loss - Convective heat loss
                = 476.89 – 45.808 – 2.275
    Q_{net} = 428.807 kW

Heat transfer efficiency = Actual heat gain / Heat addition
                = 428.807 / 476.89
                = 0.8991

Case 2 *When conventional External configuration is used the calculations for Heat Transfer are given as*

1) Calculation for heat lost due to convection from wall surfaces

Q = h $A_2\Delta$T
  = 5.97 x 0.23948 X 700
  = 1000.786
Q= 1000.786 W.

2) Calculations for radiative heat transfer to the receiver

Generally amount of flux incident on receiver after reflecting from concentrator is in range of 800-1000 kW/m^2
Amount of heat flux incident on receiver surfaces is given as
Q_{in} =Assume (960 W/m^2 X 1000)
Q_{in}=960 X 0.23948 kW.**Q_{in}=229.9 kW.**

3) Calculations for radiative heat loss

Absorptivity (α) of silicon carbide wall is 0.9
Reflectivity (r)of silicon carbide wall is 0.03
Reflectivity (ρ) of silicon carbide wall is 0.07
Irradiation (G) on the surface = **960 kW/m^2**

Radiocity (J) of the surface = ρG + α E_b
  = 0.03 X 960 + 0.9 X (5.67 X 10^{-11} X (1023^4 - 323^4))
  = 28.8 + 55.33
J = 84.133 kW/m^2

Radiation heat loss from boiler surface is = A X J
                Q $_{loss\,rad}$ = 20.148 kW

Radiation heat absorption from boiler surface is = A X (J - G)

$Q_{gain\ rad}$ = 0.23948 X (960 – 84.133)

$Q_{gain\ rad}$ = 205.811 kW

Net heat addition to the receiver = Radiative heat addition – Radiative heat loss - Convective heat loss

= 205.811 – 20.148 – 1

Q_{net} = 184.663 kW

Heat transfer efficiency = Actual heat gain / Heat addition

= 184.63 / 205.811

= 0.8969

Increase in Heat gain due to Module structure of boiler

= 428.807 – 184.663

= 244.144 kW

Increase in heat loss due to Module structure of boiler

= 48.083 – 21.03

= 27.053 kW

Net increase in heat gain for modular configuration

= 244.144 – 27.053

= 217.091 kW

Percentage increase in heat gain with suggested configuration

= 244.144 / 1.84663

= 132.21 %

Percentage increase in heat loss with suggested configuration

= 27.053 /0.2103

= 128.64 %

Overall increase in heat gain with suggested configuration

= 217.091 /1.84663

= 117.56 %

[10] Fig: CAD Model of receiver

REFERENCES

[1] EP 2 549 196

[2] US 2012/0255471 A1

[3] EP 1 930 587 A2

[4] US. Pat. No. 8449726B2

[5] US. Pat. No. 3,936,652

[6] US. Pat. No. 4,016,725

[7] US. Pat. No. 4,118,636

[8] US.Pat.No.4224528

[9] EP 2 631 555 A1

[10] EP 2 634 505 A1

[11] US 2010/0252085 A1

[12] Pub. No.: US 2008/0078378 A1

[13] Patent No.: US 8,449,726 B2

[14] US 2007/0084778 A1* 4/2007 St.Germain et a1

[15] US2008/0149573 Al* 6/2008 Fein et a1.

[16] United States Patent 111 4,224,528

[17] Renewable energy technologies: cost analysis series-*International Renewable Energy Agency*

[18] Hybrid Solar Gas-Turbine Power Plants: A Thermoeconomi Analysis-*James D. Spelling Doctoral Thesis*

[19] The Future of the CSP industry in India-*Belén Gallego; Founder & Director, CSP Today*

[20] How Valuable is Concentrating Solar Power to the Grid?-*By Dave Levitan*

[21] N.G.Worlds.Toughest.Fixes.Series..Solar.Power.Plant.-*National Geographic documentary*

[22] Recent advances in direct solar thermal power generation-*Yue-Guang Deng and Jing Liua_Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, People's Republic of China*

[23] Concentrated Solar Thermal Power -*Anjaneyulu Krothapalli Department of Mechanical Engineering Florida State University, Tallahassee, FL 32310*

[24] Solar Thermal Energy: The Time Has Come -William T. Guiney ,Director, *Solar Heating and Cooling Business ,Johnson Controls, Inc.*

[25] NREL: Concentrating Solar Power Research - Particle Receiver Integrated with a Fluidized Bed - Novel Components to Overcome Existing Barriers

[26] The Florida state university FAMU-FSU college of engineering, A concentrated solar thermal energy system by C. Christopher newton

[27] Small-scale solar central receiver system design and analysis A Thesis presented to *the Faculty at California Polytechnic State University San Luis* By Obispo Daniel, James Murray *June 2012*

[28] Radiation heat transfer in combustion systems R. Viskanta* and m. P. Mengoqt *School oJ Mechanical Engineering, Pttrdue University, West LaJ~tyette, IN 47907, U.S.A.*

[29] Kalogirou S. *Solar Thermal Collectors and Applications*.Progress in Energy and Combustion Science 2004; 30: 231-95.

[30] Eckert, E. R. G., and R. M. Drake Jr. (1972), Analysis of Heat and Mass Transfer, *McGraw~Hill, New York.*

[31] Heat and Mass Transfer by P K Nag ,*Tata-Mcgraw-Hill publications*

[32] Review of high-temperature central receiver designs for concentrating solar power Clifford K.Hon, Brian D.Iverson *Sandia National Laboratories,Concentrating Solar Technologies Department, POBox5800, Albuquerque, NM87185-1127,USA*
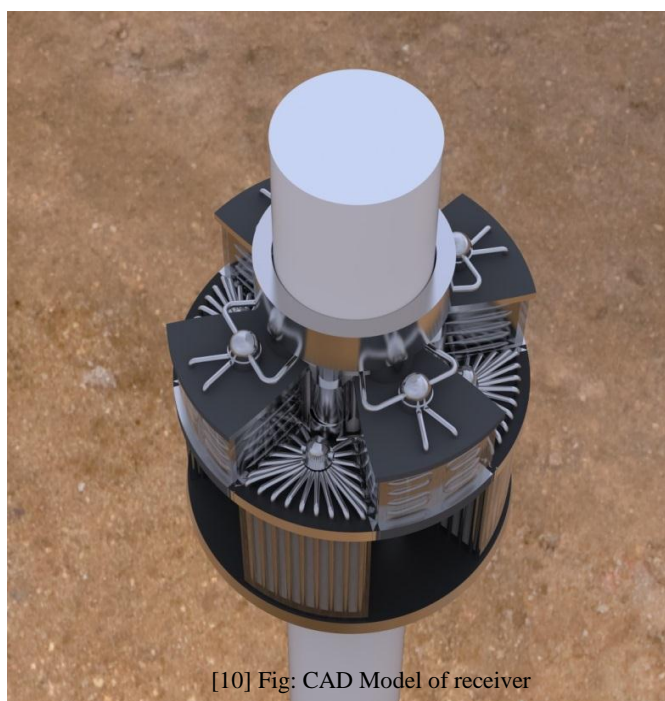
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