Overview Of Different Solar Receiver on Basis of its Configuration and Heat Transfer Fluid

Ankit Soni[1, a], Akash Patel [1, b], Dr.Mukesh Pandey[2], Anurag Gour[3]
[1] School of Energy and Environment Management UTD, RGPV, BHOPAL-462033
[2] HOD, Energy Department, UTD RGPV, Bhopal- 462033.
[3]Assistant Professor, Energy Department, UTD RGPV, Bhopal-462033.

Abstract- Receiver is an important part of CSP (concentrated solar power) system which is having high radiation absorption capacity and low thermal losses for all thermodynamics process. One of the main goals of solar technology research is the study of existing receivers and development of new designs of receiver to minimize the losses. Development of different configuration of cavity- receiver from last decade's increases scope of unique challenges and to get optimal solutions associated with high-temperature receivers, materials, heat-transfer fluids, and processes that maximize solar irradiance and absorptance. This study also deals with important basic cases of volumetric and tubular receiver which helps to further development CSP technology. Cavity-receiver of different configuration helps to analyze CSP and thermodynamic performance. The study also focuses over the various heat transfers fluids on the basis of their thermodynamic properties applicable for particular receiver.

Keywords: - cavity, concentrator, configuration, focus, parabolic, solar tower radiation, receiver.

I. Introduction

Solar cavity receiver plays a dominant role in the light–heat conversion. Its performance can directly affect the efficiency of the whole power generation system. Receiver located inside the cavity, heat losses are reduced by lowering the heat flux [1]. It is a part of CSP systems where solar energy is focused and increases temperature of HTF (heat transfer fluid). Configuration of receiver decides to get maximum extraction of energy with minimum losses from mirrors, based on geometrical parameters either in tubular type in which gets heated by the radiant flux reflected from the heliostats or volumetric type where solar radiation impinging on the volumetric receivers, is absorbed by the receiver [2]. The geometry of receiver, inner cavity wall temperature tends to influence the heat loss from the receiver. In India, receiver used is evacuated or non-evacuated type comprising of linear absorber constructed of a metallic tube surrounded by a glass tube [3]. Surface heat flux is a key performance parameter of the cavity receiver, which should be calculated according to the sunlight condition in the aperture of the receiver [3].

II. Receiver Development

Central receiver system has been considered sufficiently mature since the demonstration plants built mostly during the 1980s and the wide variety of receivers tested to date. In the USA, the technology was based mainly on solar-only operation with large storage capacities using molten salts as the HTF. In Jülich, Germany, 1.5MWe precommercial demonstration solar tower plant with ceramic volumetric receiver and thermal storage has been in operation since 2009 [4].Volumetric receivers are better than tube receivers, mainly due to their functionality, flexibility and three dimensional configurations. Development of volumetric receiver starts development from 1990 with chronological order based configuration, experimental results [5]. Volumetric receivers are two types open type and closed type;

(1) Open volumetric receiver

(2) Closed volumetric receiver

The basic details of the two receivers are discussed below;

i. Open Volumetric Receivers

Under the initiative of Fricker (1983), the metal absorber volumetric receiver technology development emerged. Sulzer1, purpose feasibility of the wire pack concept, determine volumetric receiver [6]. Jülich tower plant uses a porous silicon carbide absorber design as receiver. The air gets heated up to about 700°C and is used to generate steam at 485°C, 27 bar in the boiler to run the turbine[7]. Principle of volumetric receiver is a porous material that absorbs concentrated radiation inside the volume of a structure and transfers the absorbed heat to a fluid passing through the structure. Solar radiation is converted into thermal energy and then into power generation. Figure (1) shows High Temperature receiver (HiTRec I) was born in 1995 during comparative testing of different ceramic materials in the DLR solar furnace [8]. Encouraged by the test results of the HiTRec I, in 1998, Ciemat, Inabensa and DLR, started the development of the HiTRec II goals of this project were to solve the problems in the stainless steel structure and to demonstrate that the failure was due to a design error.

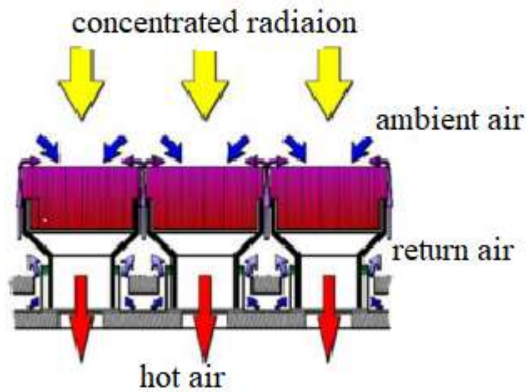

Figure: 1 Schematic of open volumetric receiver

ii. Closed Volumetric Receivers

They are also known as pressurized volumetric receivers, in which the HTF (usually air) is mechanically charged through the receiver by a blower or compressor and the receiver aperture is sealed by a transparent window. The figure (2) shown schematic diagram closed volumetric receiver.HTF will get heated up in the dome shaped portion of the receiver by the concentrated solar energy and the heated air will be used either in a Brayton cycle for power generation or for any other useful purpose. The purpose of the window is to separate the receiver cavity from the ambient air and enable high-pressure operation, minimizing reflection, reradiation and convection losses [9].

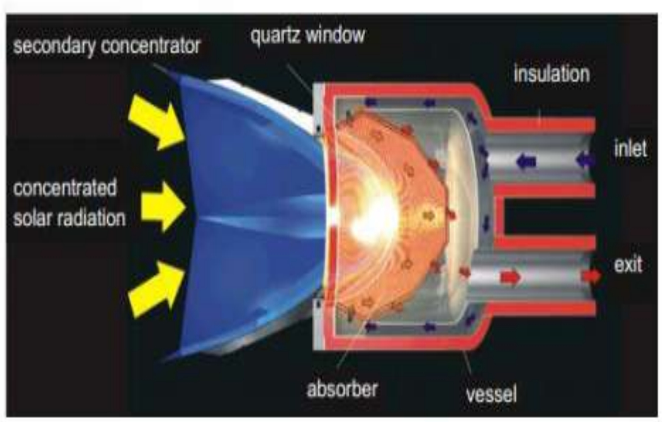

Figure: 2 schematic of closed volumetric receiver

In 1989, DLR designed a Pressure Loaded Volumetric Ceramic Receiver (PLVCR) with a foam absorber and 5 kW_{th} powers [10], which were later, tested atthe Sandia solar furnace. PLVCR-500 receiver was designed as an alternative modular sys-tem with a secondary concentrator at a power of 500 kWth. The design focused on heating up air from ambient temperature to 1000^0C at pressures up to 10 bar (Pritzkow, 1993) [11].

III. Cavity Receivers

The cavity receivers are preferred in parabolic dish collector system for converting concentrated solar energy to heat due to nominal heat losses. Cavity-receivers are typically used in point-focusing solar concentrating systems for dishes and towers to efficiently capture incoming radiation through multiple internal reflections, while providing sufficient heat transfer area for heat removal by a heat transfer medium or by chemical reactions[12]. Tubular cavity receivers are typically used line-focusing solar concentrator systems for parabolic troughs to efficiently absorb incident solar radiation through the application of selective coatings and vacuum insulations. Figure (3) shows the rectangular open cavity receiver stainless steel tube with fluid enters at bottom end and exits at top [13]. Tubular receivers are typically used in line-focusing solar concentrator systems to efficiently absorb incident solar radiation through the application of selective coatings and vacuum insulations.

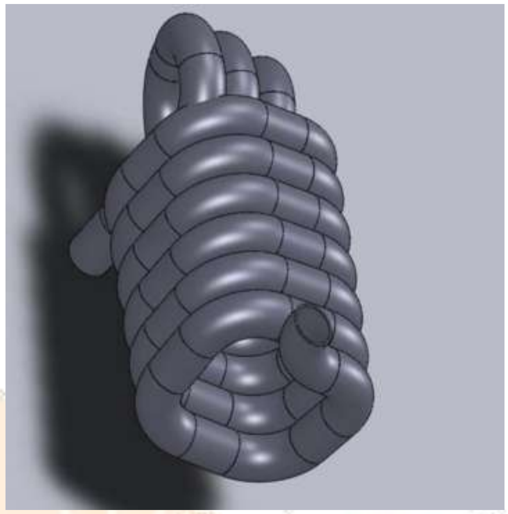

Figure:3 Rectangular open cavity receiver

IV. Tubular cavity Receiver

This comprises of Different configuration corrugated absorber tube with single or double glazed aperture window. A double-glazed window reduces the heat loss compared to a single-glazed window, and its influence increases with increasing HTF temperature, shown in figure: 4 [14]. Tubular receivers are of two types External cylindrical receivers and cavity receivers. Here focused on cavity receiver consist of welded tubes kept inside a cavity in order to reduce convection losses. Prototypes have been developed and tested in recent years. Early receiver designs were for parabolic dish receivers and employed liquid metal heat pipes to improve exchange heat from the solar irradiance to the gas.

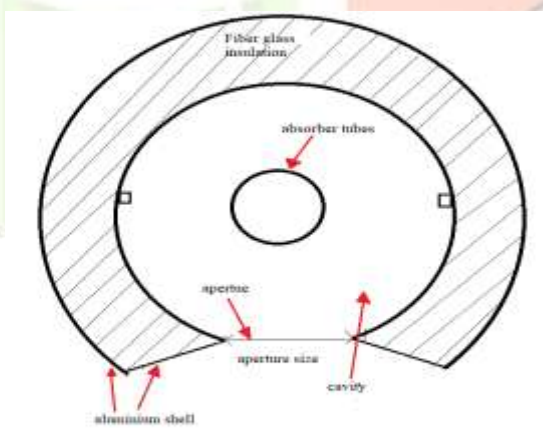

Figure: 4 Tubular receiver

V. Modified cavity receiver

Modified geometrical configuration receiver is used in parabolic dish trough concentrator's. The hemispherical dome cavity receiver depends upon opening ratio, in parabolic dish type and Trapezoidal cavity receiver in linear Fresnel CSP. The natural convection heat loss is found to increase with an increase in opening ratio and wall temperature.

i. Hemispherical cavity receiver

The temperature distribution inside the cavity is presented to understand the effect of wind on the heat loss from the receiver. The geometry of the receiver, inner cavity wall temperature and wind tend to influence the heat loss from the receiver. The concentrated solar energy is focused on the modified cavity such that most of the reflected energy is received by it remain inside the cavity. The heat transfer fluid (fluid flowing through the receiver) flows through the tubes and gains heat energy as it flows and the temperature of fluid increases. The air is considered as the medium surrounding the receiver. A schematic diagram hemispherical cavity receiver with optical window, small circles along the wall is schematic diagram of tubes. The cyan part is quartz glass window, which is placed in aperture cavity as shown below Figure (5) [15].

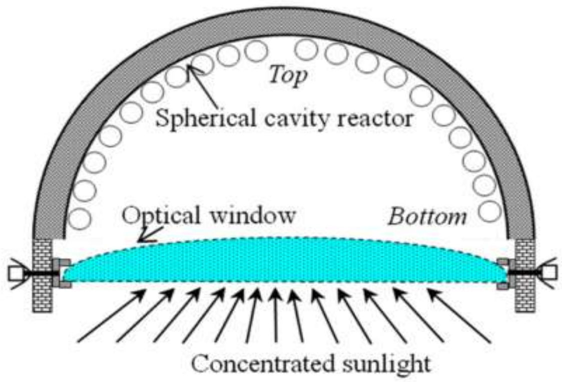

Figure: 5 Hemispherical cavity receiver

ii. Trumpet modified cavity receiver

In this Receiver geometry, copper tubing of trumpet shape is attached to the modified cavity receiver. The trumpet reflector of modified cavity receiver is replaced by receiver tubes. The copper tubes are wound to bring the shape of the trumpet cavity receiver [16]. Comparison of trumpet modified cavity receiver, whereas the radiation heat loss is independent of the inclination of receivers. The modified cavity receiver with trumpet reflector showed the best performance with the fuzzy focal solar dish collector system. The modified cavity receiver showed better heat loss characteristics than trumpet modified cavity receiver for a given area ratio. In Figure (6) Shows outer dome is of ceramic wool (insulation), copper tubes inside and reflector. ”d” is small opening aperture and ”D” is Distance between two side reflectors [17].

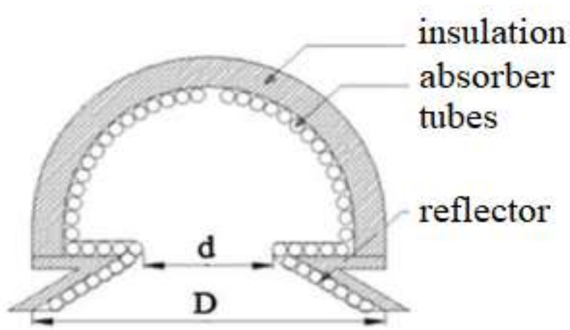

Figure: 6 Trumpet receiver

iii. Trapezoidal cavity receiver

The performance of the LFR significantly depends on the optical performance of the collector and the thermal performance of the receiver. In figure 7 shows trapezoidal cavity receiver which insulated isothermal walls with depending on configuration distance between two bases (*D*), two different widths W_{tc} represents width of top cavity, W_{bc} represents width of bottom cavity and glass cover where concentrated solar radiation enters, makes an angle with insulated wall θ (cavity angle). Cavity angle increases convective and radiative loss increases [18]. Natural convection take place inside cavity, conduction and radiation takes place through glass covers and trapezoidal cavity filled with air. Absorber is enclosed to minimize convection losses through ambient air .

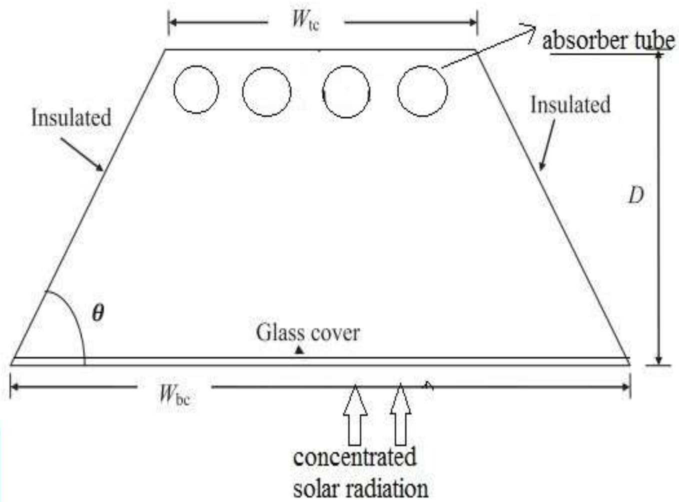

Figure: 7 Trapezoidal cavity receiver

iv. Air based linear Cavity Receiver

Air based linear cavity receiver which is the combination of two technologies linear Fresnel line type and solar tower point focus uses compressed air as HTF. This type of cavity receiver is used in the ongoing R & D project Cross linear concentrated solar power (CL-CSP) at RGPV, Bhopal India. It is installed with an Inclination of 22^0 from the ground to get maximum concentrated solar radiation [19]. Convective loss increases with mean receiver temperature and decreases with increase in receiver inclination. The thermal losses of a solar cavity receiver include convective and radiative losses to the air in the cavity and conductive heat loss through the insulation used behind the pipe surface.

VI. Heat Transfer Fluids

HTF is circulated to the absorber tube with help of pump or compressor, fluid should have high temperature dependent and measured in terms of mass flow rate kg/s or kg/hr. During circulation it gains heat in the absorber tube and comes back in the storage tank. The HTF is then recirculating again and again through the absorber tube throughout the whole day.

Selection criteria for heat transfer fluid [20]

- Temperature range, viscosity, density, thermal conductivity.
- High and low temperature applications, Cost, stability.
- Environmental impact, toxicity, corrosiveness.

On the basis of design parameters of CSP once temperature range criteria is known, then (HTF) fluid easily be chosen according to conditions .

i. **Air**

Generally used in volumetric receiver, operating at high temperature over 600^0C and compressed air having better heat transfer properties than uncompressed one because compressed air has better them physical properties. Eliminates cooling system requirement but receiver design becomes complex [21].Cavity receivers use air (compressed air) as heat transfer fluid. Generally, air cavity receiver configuration used in linear Fresnel systems. In linear air cavity with volumetric type CL-CSP (Cross linear concentrated solar power), RGPV, BHOPAL, 30 KW_{th} compressed air as heat transfer fluid [22].

ii. **Molten Salt**

Molten salt as heat transfer fluid ,in both receiver and heat storage used in solar tower rather than parabolic trough because gravity predominates to draining of molten salt prevents from freezing, use of heat exchanger for transfer of heat from molten salt to water to generate electricity[23]. Generally, are high temperature nitrate salts(60% sodium nitrate and 40% potassium nitrate, by weight) is desirable as a working fluid because its high density and specific heat make it attractive for thermal storage systems, and it is chemically stable at high temperatures. Molten salts used in SENER (Engineering, Consulting and Integration Company, Spain) and CIEMAT (Center for Energy, Environment and Techno logical Research, Spain) for 1.7MW_e Solar TRES plant [24].

iii. **Therminol 55**

Therminol 55 is a synthetic heat transfer fluid used in moderate temperature applications in parabolic dish type [25]. Therminol 55 fluid is designed for use in non-pressurized low-pressure, indirect heating systems. It delivers efficient, dependable, uniform process heat with no need for high pressures. Basically they replace mineral oil large due to their thermal properties [25].

iv. **Carbon di oxide**

CO_2 as heat carrying fluid and storing high grade heat for extended periods of maximum storage temperatures above 600°C. The coupling of a solar central tower receiver with a thermal energy storing system using CO_2 instead of air as the heat transfer fluid supercritical CO_2 (sCO_2) solar central tower receivers [26].Which was constructed and operated at CSIRO's National Solar Energy Centre (NSEC) in Newcastle, Australia[26]. In the higher absorber metal temperatures and significantly reduced tube life, as CO_2 at high temperatures and pressures can also be very corrosive to metal alloys. Specialized high temperature steel, Haynes 230, which has comparably lower corrosion [27].

v. **NanoFluids**

Nanofluids are simply engineered dilute colloidal suspension of particle with sizes in the nano-scales (less than 100 nm) in a base fluid. Heat transfer performance obtainable with NanoFluids is known to surpass the performance of heat transfer liquid available today [28]. Investigated heat transfer enhancement in a parabolic trough collector tube using Al_2O_3/synthetic oil Nanofluid for nano particle concentration less than 5%, increase in heat transfer performance of receiver with use of Nanofluid [29].

VII. Discussion

The aim of the receiver is to accept the heat flux delivered by the heliostats and transmit it with minimal losses to the HTF. Modified cavity receiver for parabolic trough CSP low to medium range temperature and air cavity tubular type receiver for linear Fresnel are medium to high temperature. In order to increase the receiver efficiency is strongly dependent on the HTF used and its ability for effective heat transfer from the receiver surface to the HTF. It is also found in studies that change in dimension of cavity receiver there are variation in losses. Molten salt HTFs have high melting points (142–240^{0}C) and degrade above 900 ^{0}C, overall cost is very less as compared to other HTF. Storage technology with sCO_2 at high temperature is, however, impractical at the moment due to material limitations relating to containment wall thickness required and corrosion of candidate metals sensible thermo cline thermal energy storage (TES) test loop. Cavity design and its configuration plays vital role for reflection and emissivity of solar radiation.

VIII. Conclusion

During the last decades state-of-the-art of volumetric receivers is similar to tube receivers. This paper provides different cavities geometrical configurations and gives direction for relevant concentrated system. Receiver with cavity configuration development gives direction of further development new types of solar receiver is possible. Tubular receivers still appear to have a place in future CSP plants. Selection of an appropriate HTF is important for minimizing the cost of the solar receiver, thermal storage and heat exchangers, and for achieving high receiver and cycle efficiencies. Operating condition and receiver efficiency are both dependent on HTF used in concentrated solar system. Use of nanofluids as HTF helps to search new category of working fluid to increase temperature of existing CSP systems. But, studies of investigating the thermodynamic performance of receiver NanoFluids found exceptional. Replacement of HTF found from mineral oil to synthetic oil. Selection of receiver taking account of HTF for CSP system on different location is different, thus precisely be chosen. Combination of existing technologies to get new technology helps to eradicate limitations and challenges that facing yet now.

References

[1] Neber, M et.al (2012). Design of a high temperature cavity receiver for residential scale concentrated solar power. International Journal of Hydrogen Energy, 47, Issue: 1, 481-487.

[2] Ratzel, A. C.et.al (2012). Techniques for Reducing Thermal Conduction and Natural Convection Heat Losses in Annular Receiver Geometries. Journal of Heat Transfer, 101, Issue: 1, 108.

[3] Fang, J.B. et.al (2011). Thermal performance simulation of a solar cavity receiver under windy conditions. Solar energy, 85, Issue: 1, 126-138. U.S. Department of Energy (DOE). 2014. 2014: The Year of Concentrating Solar Power

[4] Uhlig, R, 2013. Strategies enhancing efficiency of cavity receivers. Energy Procedia, 49, 538-550.

[5] Le Roux, W.G. et.al (2014). The efficiency of an open-cavity tubular solar receiver for a small-scale solar thermal Brayton cycle. Energy Conversion and Management journal, 84, 457-470.

[6] Fricker, H.W. et.al (1983). Proposal for a novel type of solar gas receiver. In: Proceedings of the International Seminar on Solar Thermal Heat Production, Stuttgart, German Aerospace Center (DLR), Pfaffen-waldring 38-40, D-70569 Stuttgart.

[7] Chavez JM, et.al.(1991).Testing of a porous ceramic absorber for a volumetric air receiver. Solar Energy Materials 1991;24(1–4):172–81.

[8] Hoffschmidt, B. et.al (2001). Development of ceramic Romero, M., Stobbe, P., Te´llez, volumetric receiver technology. In: Proceedings of 5th Cologne Solar Symposium, Forschungsbericht 2001-10, DLR, Germany, pp. 51–61.

[9] Antonio, L. et.al (2011). Volumetric receivers in Solar Thermal Power Plants with Central Receiver System technology: A review. solar energy, 85, Issue:5, 891-910.

[10] Pritzkow, W. et.al (1989). The Pressure Loaded Volumetric Ceramic Receiver (5kW Version). DLR-Mitteilung 89-17.

[11] Pritzkow, W. et.al (1993). The Pressure Loaded Volumetric Ceramic Receiver 500 kW Version Design and Construction. DLR-Mitteilung 93-02.

[12] N.D. Kaushika, K.S. Reddy Performance of a low cost solar paraboloidal dish steam generating system Energy Converse. Manage. J., 41 (2000), pp. 713-726.

[13] Bello-Ochende, T et.al (2014). The efficiency of an open-cavity tubular solar receiver for a small-scale solar thermal Brayton cycle. Energy Conversion and Management, 84, 457-470.

[14] Bader ,R .Experimental and numerical heat transfer analysis of an air-based cavity-receiver for solar trough concentrators. J Sol Energy Eng 2012;134(2):021002–021002-8.

[15] Shuai, Yong et.al (2011). Radiative properties of a solar cavity receiver/reactor with quartz window. International Journal of Hydrogen Energy, 36, Issue: 19, 12148-12158.

[16] Bader, R et.al (2015). An air-based corrugated cavity-receiver for solar parabolic trough concentrators. applied energy, 138, 337-345.

[17] Reddy, K. S. et.al (2009). Convection and surface radiation heat losses from modified cavity receiver of solar parabolic dish collector with two-stage concentration. Heat and Mass Transfer/Wärme und Stoffübertragung, 45,Issue:3, 363-373.

[18] Sendhil Kumar N. et.al (2008) Comparison of receiver for solar dish collector system. Energy Convers Manage 49:812–819.

[19] Tiwari, Ravi Kumar. (2016). Analytical Design for Heliostats System and Review of Its Working for A 30 Kw CL-CSP System at RGPV Bhopal. International Journal for Scientific Research & Development, 4; issue 03, 2021-2027.

[20] Panchal Ramchandra, H et.al (2016). The CFD Analysis of Solar Parabolic Trough System with Reflectors. International Journal of Current Engineering and Technology, Issue: 5, 431-435.

[21] Tobergte, David R. et.al (2014). Global Review of Solar Tower Technology. Journal of Chemical Information and Modeling, 53, Issue: 9, 1689-1699.

[22] Singh, Rohit. et.al (2016). Analytical Analysis for Receiver and Its Processing for A 30 Kw CL-CSP System at RGPV Bhopal. International Journal for Scientific Research & Development, 04; Issue 03, 1859-1864.

[23] Saxena, Harshit.et.al (2013). Computational Study on Estimating the Surface Heat Transfer Coefficient of Absorber Tube in Solar Parabolic Trough Collector. Applied Mechanics and Materials, 446-447, 1546-1551.

[24] Ortega, J.et.al (2008). Central receiver system solar power plant using molten salt as heat transfer fluid. Journal of Solar Energy Engineering, Transactions of the ASME, 130; Issue 3, 245011-245016.

[25] THERMINOL Heat Transfer Fluid.(2017). THERMINOL® 55 HEAT TRANSFER FLUID. [ONLINE] Available at: https://www.therminol.com/products/Therminol-55. [Accessed 30 August 2017].

[26] Soo Too, Y.C. et.al (2017). Thermal Performance and Operation of a Solar Tubular Receiver With CO 2 as the Heat Transfer Fluid. Journal of Solar Energy Engineering, 139; Issue 4, 041004.

[27] Klarstrom, D. L. et.al (2001), "The Development of Haynes 230 Alloy," Materials Design Approaches and Experiences, J.C. Zhao, et al. editors, TMS, Warren dale, PA, pp. 297- 307.

[28] Godson, L. et.al (2010). Enhancement of heat transfer using nanofluid-An Overview. Renewable and Sustainable Energy Reviews, 14, 629-641.

[29] Mwesigye, A. et.al (2015). Thermal and Thermodynamic Performance of a Parabolic Trough Receiver with Syltherm 800-Al2O3 Nanofluid as the Heat Transfer Fluid.75, 394-402.