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Comparison of Double Tube Cavity Receiver with Single Tube Cavity Receiver for Heat Loss

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ABSTRACT

In the proposed research work the design of single tube cavity receiver is analysed and a new design of double tube cavity receiver is proposed to reduce heat losses computationally using CFD software. A heat transfer and flow simulation are proposed for Single & double tube solar thermal cavity receiver at receiver inclination of 0° without the wind & 0.02kg/s mass flow rate of water at Inlet temperature of 90°C & ambient temperature of 30°. The Numerical study of convection losses in single & double tube cavity receiver of solar parabolic dish collector is proposed. Measurements of energy losses, temperature drops, wind speed, working fluid flow rate, and inlet-outlet temperatures of the working fluid are proposed to analyse the performance of Double Tube Cavity Receiver.

Keyword: Single Tube Cavity Receiver, Double Tube Cavity Receiver, Convection Losses etc.

1. INTRODUCTION

Solar concentrators are used for many applications such as supplying process heat to industries, generating electricity, melting and processing of metals as in the case of solar furnaces, etc. Many varieties of concentrators are used in various parts of the world. Recently in India, Fresnel parabolic dish with a cavity receiver is being used for supplying low and medium temperature process heat. It consists of a mirror assembly in the form of a dish and a cavity receiver with a helical metallic coil. Such a system does not need any evacuated tube construction and uses simple float glass mirrors as reflectors. This makes the system cheaper in Indian scenario and durable in industrial environments.
Working fluids used in such systems are thermic oils, air or pressurized water. [4]

The cavity receiver has an aperture through which the reflected solar radiation passes. Once inside the cavity, internal reflections ensure that the majority of the radiation that has entered the cavity is absorbed on the internal absorbing surface. The cavity contains a suitable tube configuration through which the receiver fluid flows. The concentrated solar radiation entering the aperture of the cavity spreads inside and is absorbed on the internal walls where the heat is then transferred to a working fluid. Any radiation that is reflected or re-radiated from the walls of the cavity is also absorbed internally on the cavity walls resulting in a higher absorptance value of the receiver. This spreading of the solar radiation causes a reduction in the incident flux within the cavity, thus helping to prevent thermal cracking or smelting of the internal walls. Also, because of the design of the cavity receiver, it is easier to insulate to aid in avoiding radiant and convective heat loss to the environment. Cavities can be classified into two types namely closed cavity and open cavity (one side of the cavity called the aperture is open to the atmosphere). The open cavity heat transfer has been widely analyzed due to its applications in many fields of practical interest like solar concentrator systems, solar passive architecture, refrigeration, fire research and electronic equipment cooling. Among the heat transfer mechanisms from open cavities, the buoyancy-driven heat transfer plays a major role. The phenomenon is dependent on various factors such as the geometrical shape of the cavity, inclination angle, wall boundary conditions, the aspect ratio and the opening ratio thus making it difficult to estimate. [5]

Solar Cavity receiver designed by Clique Developments Pvt. Ltd, with the inputs from IIT Bombay under the name of Arun Solar Concentrator. System was run with water in place of milk. The system is delivering heat for milk pasteurization since Feb 2006. [3]

2. LITERATURE REVIEW

A central cavity receiver system is a concept for a high-temperature solar concentrator that aims at the collection of large amounts of highly concentrated solar energy without requiring a piping. In this concept, it is expected to achieve economy-of-scale benefits because systems with several 1,00,000 m^2 of reflector surface area can focus on a single receiver approaching several 100 MW of power and thus use conventional power plant technology for the power cycle. Fig.1 shows the Schematic diagram of the dish solar concentrator/cavity receiver system [6], [7].

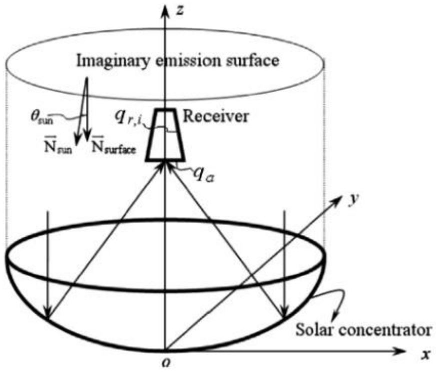


Fig.1. Schematic diagram of the dish solar concentrator/cavity receiver system [6]

M. Prakash, S.B. Kedare, J.K. Nayak [3], the effects of fluid inlet temperature, receiver inclination angle and external wind on the total thermal loss and the convective losses are studied experimentally as well as numerically for a downward facing cavity receiver made up of helical coil tube having cavity diameter less than the depth as well as the aperture diameter. The highest total and convective losses are obtained for the head-on wind condition at 0° inclination of the receiver. The losses are higher than the side-on wind convective loss. The no-wind convective loss at 0° inclination is greater than that due to 1 m/s and 3 m/s side-on wind as the side-on wind presumably prevents the hot air from flowing out of the cavity. At 3 m/s wind speed, the total and convective losses are independent of wind direction for all inclination except 0° receiver inclination. The effect of inclination on losses due to the side-on wind condition is very small when compared to the no-wind and head-on wind conditions. The experimental results are compared with the numerical values. They agree reasonably well, the maximum deviation being about 14%

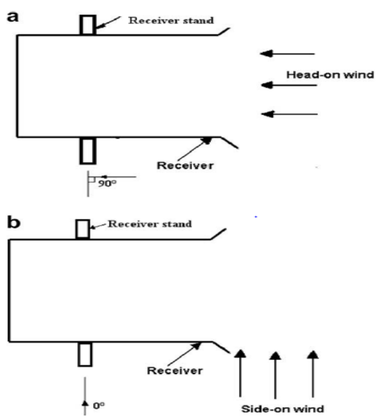


Fig.2. Head-on and side-on wind directions for the receiver at 0° inclination (top view); (a) head-on, (b) side-on [3]

The literature on convection heat transfer in open cavities mainly involved cubical, rectangular and square shaped cavities. Cylindrical, cylindrical with a conical frustum, spherical and hemispherical shaped cavities used for specific applications like solar thermal receivers were also studied. Studies on combined convection and radiation from hemispherical solar cavities have been reported by **Reddy and Sendhil Kumar [8]**. A 2D numerical analysis of combined laminar natural convection and surface radiation in the modified cavity receiver of a solar dish was presented. Two separate Nusselt numbers were proposed for both natural convection and surface radiation. The incorporation of the radiation in a modified cavity receiver completely alters the heat loss rate. It was found that the convective loss was significantly influenced by the orientation of the receiver. The convection heat loss was dominated by the radiation heat loss for higher receiver inclination angle (>45°). The radiation heat loss was considerably influenced by the area ratios. The receiver showed better performance at an area ratio of 8. The model was used to estimate the convection and radiation heat losses from the cavity receiver of solar parabolic dish collector system. The total heat loss from the receiver has been estimated for operating temperatures varying from 300˚C to 700˚C. The variation of total heat loss with operating temperature for different orientations of the receiver is shown in Fig.3.

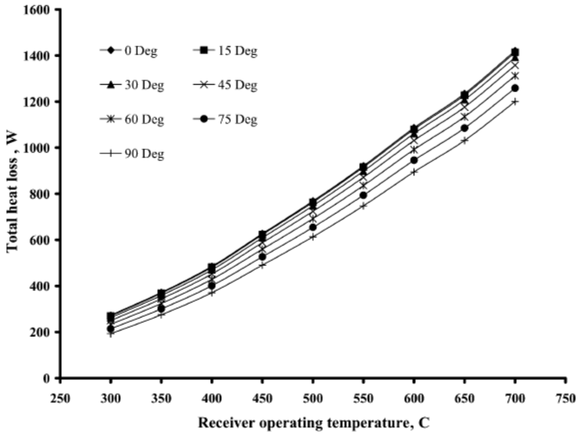


Fig.3. Effects of operating temperature on the total heat loss of the modified cavity receiver. [8]

An analytical model was presented for estimation of convective heat loss of a large cubical cavity receiver by **Clausing (1981) [9].** This model was developed based on two factors: (i) the ability to transfer mass and energy across the aperture (ii) the ability to heat the air inside the cavity and showed that latterly is of greatest importance for convective heat loss.

A 2-D-model is used by **N. Sendhil Kumar, K.S. Reddy [10]** to investigate 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 an increase in angle up to 90°. The effect of operating temperature on convection heat loss for different orientations of the receiver was studied.

A numerical investigation is performed by **N. Sendhil Kumar, K.S. Reddy [11]** to study the natural convective heat loss from three types of receivers for a fuzzy focal solar dish concentrator, namely cavity receiver, semi-cavity receiver and modified cavity receiver. The natural convection heat loss from the receivers is estimated by varying the inclination from 0° (cavity aperture facing sideways) to 90°(cavity aperture facing down). The orientation and geometry of the receiver strongly affect the natural convection heat loss. A comparative study is performed to predict the natural convection heat loss from the cavity, semi-cavity and modified cavity receivers. The convection heat loss is high at 0°and decreases monotonically with an increase in angle up to 90° in all three cases. The convection heat losses at 0° and 90° inclination of the modified cavity receiver are 26.03% and 25.42% of the convection heat loss of the cavity receiver, respectively. The influence of area ratio (A_w/A_1) on the convective heat loss is investigated for the modified cavity receiver, and an optimum A_w/A_1 of 8 is found for minimum natural convection heat loss. Among the three receivers, the modified cavity receiver is the preferred receiver for a fuzzy focal solar dish collector system.

A heat transfer and flow simulation was performed by **Dr. Umashankar and Ravi Kumar D S [6]** for four different solar cavity receiver’s viz.: cylindrical, conical, dome and spherical receivers at various receiver inclinations at a constant temperature. The receivers are designed such that they have same surface area and aperture. It was observed that convective heat loss decreases as the inclination changes from 0^0 to 90^0.Among these receivers, the convective heat loss is least for conical receiver followed by a dome, spherical and cylindrical receivers. Fig.4. shows Comparison of convective heat loss with different inclinations among cylindrical, conical, dome and spherical receivers at 450^0C.

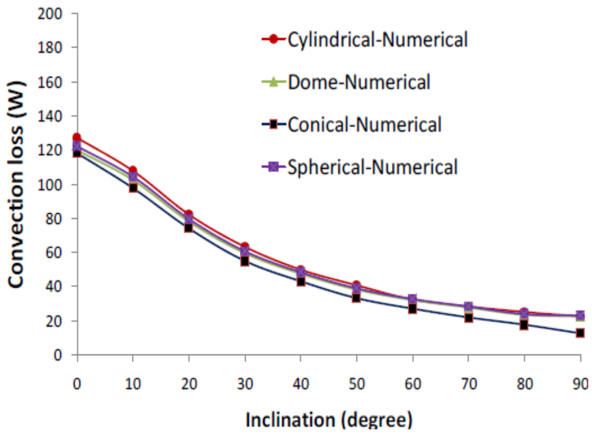


Fig.4. Convection heat loss comparison [6]

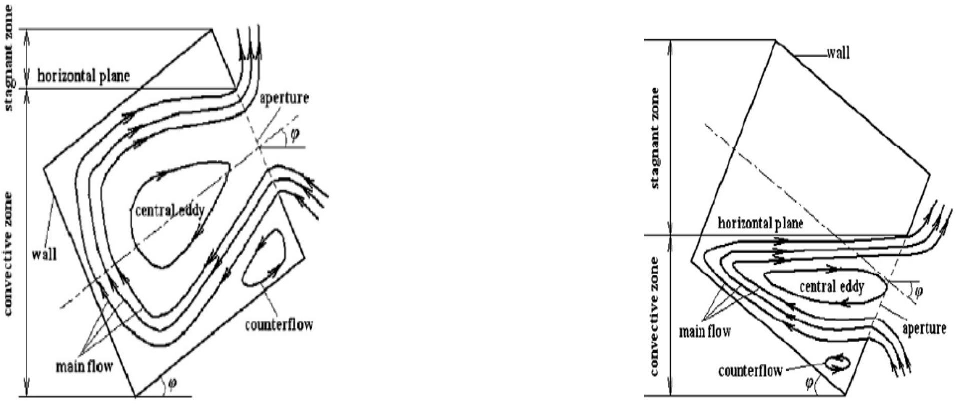
Solar cavity receiver plays a dominant role in the light-heat conversion process of the solar power system. Its performance can directly affect the efficiency of the whole power generation system. A computational model established by **J.B. Fang, N. Tu, and J.J. Wei [12]** for the start-up process was used to calculate the energy required by the aperture from heliostats during the whole start-up process. The thermal efficiency of the receiver has been gained as well, which is very low during the early start-up period due to severe convective heat loss. The velocity of air around the cavity can hardly be affected during the start-up process, but the temperature of air changes a lot with the start-up time.

Numerical three-dimensional studies of the natural convection and radiative heat loss from cavity receiver of different shapes with and without mouth-blockage have been investigated under isothermal wall condition by **R. D. Jilte, S. B. Kedare, and J. K. Nayak [13].** 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. The 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. The 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.

An experimental and numerical study of the steady state convective losses occurring from a downward facing cylindrical cavity receiver of length 0.5 m, the internal diameter of 0.3 m and a wind skirt diameter of 0.5 m was carried out by **M. Prakash et al (2008) [3].** The effects of fluid inlet temperature, receiver inclination angle and external wind on the total thermal loss and the convective losses were studied experimentally as well as numerically for a downward facing cavity receiver made up of helical coil tube having cavity diameter less than the depth as well as the aperture diameter. The highest total and convective losses were obtained for the head-on wind condition at 0^0 inclination of the receiver. The losses were higher than the side-on wind convective loss. The no-wind convective loss at 0^0 inclination is greater than that due to 1 m/s and 3 m/s side-on wind as the side-on wind presumably prevents the hot air from flowing out of the cavity. At 3 m/s wind speed, the total and convective losses are independent of wind direction for all inclination except 0^0 receiver inclination. The effect of inclination on losses due to the side-on wind condition was very small when compared to the no-wind and head-on wind conditions.

The natural convection occurring from open cavities was analyzed by **M. Prakash et al (2012) [5]**. Three different cavity shapes were studied namely cubical, spherical and hemispherical geometries having equal heat transfer area. The numerical analysis was performed on three-dimensional (3-D) cavity models using the Fluent CFD software. The highest convective loss was observed for the hemispherical open cavity and the lowest for the cubical open cavity for opening ratios of 0.25 and 0.5. The convective loss for all temperature and inclination cases is the least for the opening ratio of 0.25.There was a decrease in the convective loss as the cavity inclination angle increases. The highest loss is noticed for the 0^0 angle and the least for the 90^0. The stagnation zone area is found to increase with cavity inclination. This leads to the decrease in the convective loss with an increase in inclination. This was true for all cavity shapes.

The important energy loss for the receiver originates from convection and radiation heat transfer to the surroundings. These losses depend on the design of the receiver, whether it is a cavity or external receiver, it's heated (or aperture) area, and its operating temperature. Additional factors include the local wind velocity, ambient temperature, and the orientation of the receiver. Studies had been made on the combined radiation, free and forced convection losses from large surfaces, and tilted cavities. The Fig.5 show the streamlines in downward and upward facing tilted cavity receiver. [6], [15]



(a) **(b)**

Fig.5. Stream Lines in (a) Downward Facing Tilted Cavity Receiver & (b) Upward Facing Tilted Cavity Receiver [6]

3. OVERVIEW

3.1. Gaps Identified

Literature review shows that most of the researcher's study has been carried out for determination of conduction, convection & radiation losses from solar cavity receiver with

i) Different cavity shapes,
ii) Different inclination angles,
iii) With or without wind conditions,
iv) With or without mouth blockage,
v) Absorbers inside cavity receiver,
vi) With or without Insulation.

But the investigation for utilization of convective losses is not carried out by doing the modifications in the number of tubes or geometry of tubes inside cavity receiver. So to utilize hot air inside the cavity receiver proposed work is to be done by use of additional tube in cavity receiver with different inclination angle at a constant temperature.

3.2. Problem Statement

Thermal losses affect the performance of a solar parabolic dish-cavity receiver system. 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 helical tube surface. Convective and radiative heat losses from the major constituents of the thermal losses. The radiative loss is dependent on the cavity wall temperature, the shape factors and emissivity/absorptivity of the receiver walls while conduction is dependent on the receiver temperature and the insulation material. The radiative and conductive losses are independent of the cavity inclination.

The convective heat loss depends on the air temperature within the cavity, the inclination of the cavity and the external wind conditions, thus making the phenomenon complex. To utilize convective losses additional tube is used inside the cavity receiver which will gain the heat lost by first tube & also heat carried by hot air inside the cavity receiver. The receiver in proposed work done with cylindrical shape double tube cavity receiver having skirt is similar to the receiver used in a parabolic dish-receiver system installed at Mahananda Dairy, Latur, Maharashtra, India for supplying process heat and the receiver used for investigation of heat losses from solar cavity receiver, (M. Prakash, S.B. Kedare, J.K. Nayak)[3].

3.3. Objectives

1. To evaluate the thermal performance of Double tube cavity Receiver over Single tube cavity receiver.
2. To utilize the convective heat losses in the cavity.

3. To study the effect of inclination of the cavity.
4. To achieve high temperatures.
5. Measurements of Temperature drops.

4. NUMERICAL ANALYSIS

Solar Cavity Receiver model is divided into three parts for CFD modeling a) Solar Cavity Receiver, b) Insulation, c) Enclosure. Solar Cavity Receiver model consisting cylindrical tube along with inlet and outlet tube is modeled in Pro-E. Insulation and Enclosure are been modeled in the workbench. All the three parts are taken in ICEM CFD /ANSA for meshing.

The boundary conditions used for the numerical analysis are as follows:

1. The fluid inlet temperature (at the receiver outlet) and the fluid velocity as specified.
2. Enclosure walls are maintained at ambient temperature.
3. The adiabatic condition is assumed for the cavity external wall.

4.1. Cylindrical Single Tube Solar Cavity Receiver

4.1.1. Meshing

The meshing consist elements of around 2 million tetra cells for without the wind.

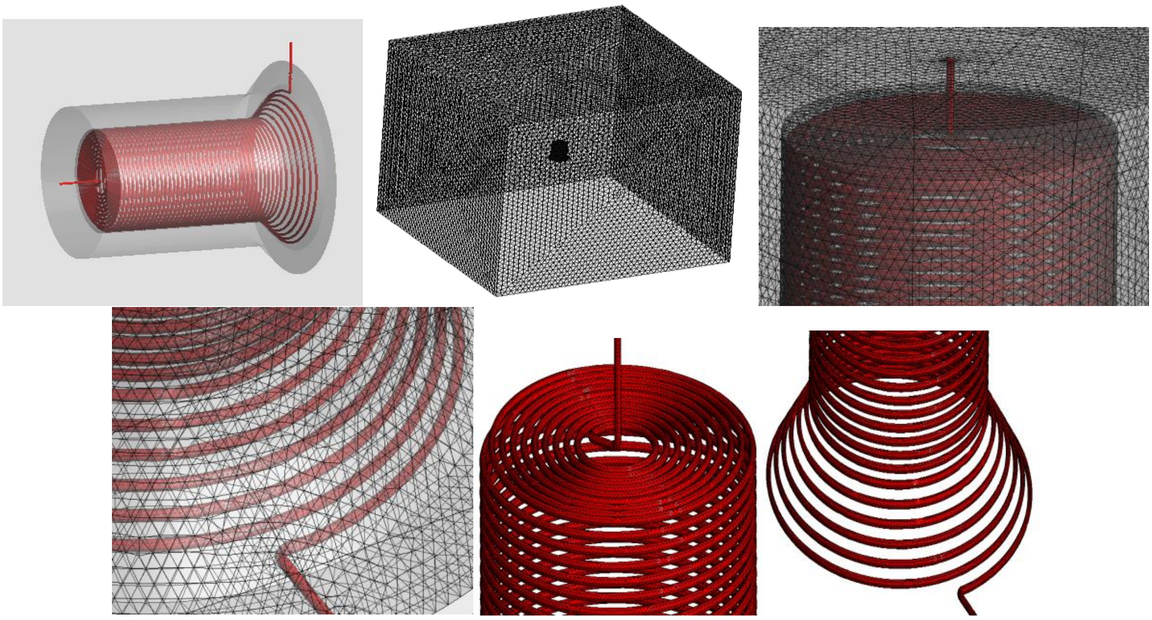


Fig.6. Single Tube Solar Cavity Receiver full model meshing

4.1.2. Post Processing

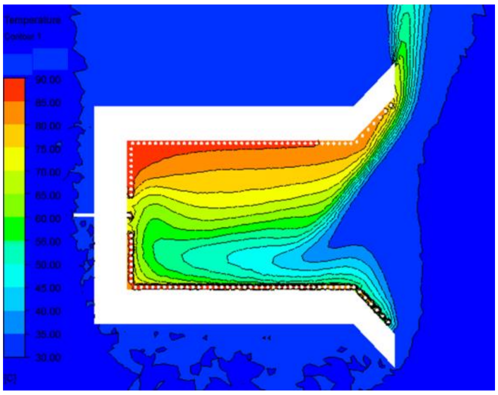


Fig.7. Air Temperature Contour for Single tube cavity receiver

4.1.3. Report

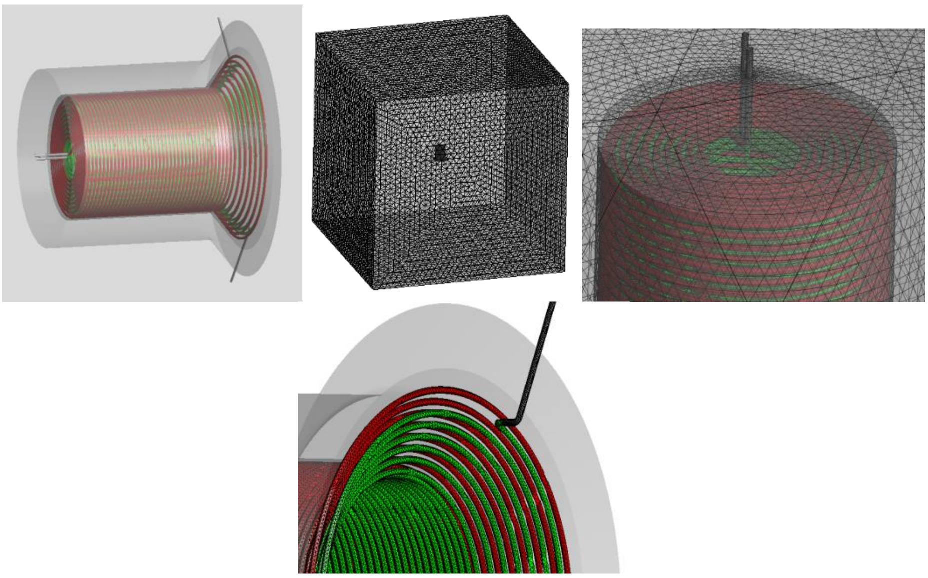
Table 1. Total Heat Loss at Single Tube Cavity Receiver

Water Inlet Temperature	363.15 K
Water Outlet Temperature	354.95 K
Temperature Drop	8.2 K
Total Heat Loss	Q = Mass x Specific Heat x Temperature Drop
	Q = 0.02 x 4182 x 8.2
	Q = 685.85 Watt

4.2. Cylindrical Double Tube Solar Cavity Receiver

4.2.1. Meshing

The meshing consist elements of around 4.5 million tetra cells for without the wind.



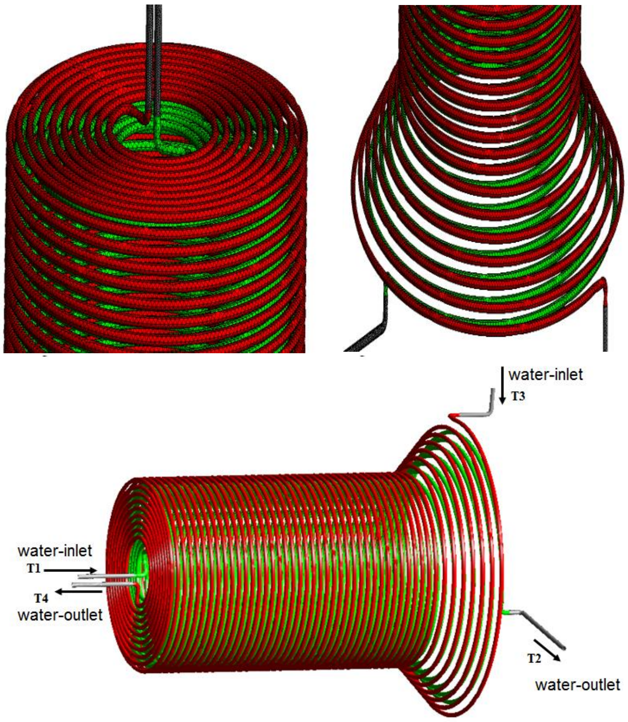


Fig.8. Double Tube Solar Cavity Receiver full model meshing

4.2.2. Post Processing

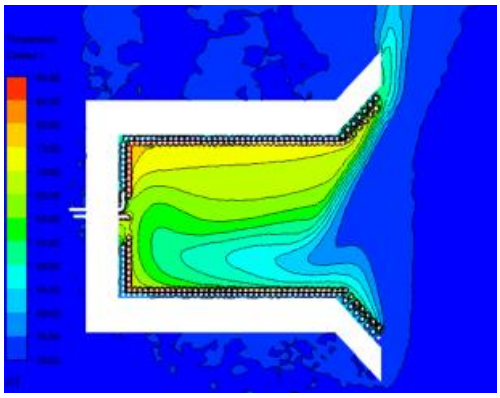


Fig.9. Air Temperature Contour for Double Tube Solar Cavity Receiver

4.2.3. Report

Table 2. Total Heat Loss at Double Tube Cavity Receiver

Inner Tube	Water Inlet Temperature	T1	363.15 K
	Water Outlet Temperature	T2	353.86 K
	Temperature Drop		9.29 K
Total Heat Loss at Inner Tube	Q = Mass x Specific Heat x Temperature Drop		
	Q = 0.02 x 4182 x 9.29		
	Q = 777.02 Watt		
Outer Tube	Water Inlet Temperature	T3	303.15 K
	Water Outlet Temperature	T4	308.62 K
	Temperature Drop		
Total Heat Loss at Outer Tube	Q = Mass x Specific Heat x Temperature Drop		
	Q = 0.02 x 4182 x 5.47		
	Q = 457.51 Watt		

5. CONCLUSION

Numerical analysis has been carried out for 0° inclination and without the wind, condition to identify the convective heat utilization by improved Double Tube Solar cavity receiver over the Single tube solar cavity receiver. The effect of inlet water at an ambient temperature of the outer tube over the temperature of the inner tube is also investigated. The study shows that the convective losses in case of single tube cavity receiver are utilized by an outer tube with the increase in inlet water temperature (T3) by 5.47°C supplied at an ambient temperature which is measured at water outlet (T4) with a gain in heat of about 457.51watt. Further, we can take the benefit by preheating same working fluid using the double tube to obtain higher temperatures. And also the heat gain by the second tube can be used for other process heating applications using different working fluids.

6. REFERENCES

1. Soteris A. Kalogirou, Solar thermal collectors and applications, *Progress in Energy and Combustion Science*, 2004, 30, pp.231-295.
2. J.B. Fang, J.J. Wei, X.W. Dong, Y.S. Wang, Thermal performance simulation of a solar cavity receiver under windy conditions, *Solar Energy*, 2011, 85, pp.126-138.
3. M. Prakash, S.B. Kedare, J.K. Nayak, Investigations on heat losses from a solar cavity receiver, *Solar Energy*, 2009, 83, pp.157-170.
4. M. Prakash, S.B. Kedare, J.K.Nayak, Determination of stagnation and convective zones in a solar cavity receiver, *International Journal of Thermal Sciences*, 2010, 49, pp.680-691.
5. M. Prakash, S.B. Kedare, J.K. Nayak, Numerical study of natural convection loss from open cavities, *International Journal of Thermal Sciences*, 2012, 51, pp.23-30.
6. Dr.Umashankar, Ravi Kumar D.S, *Numerical Simulation of Solar Receiver*, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 1 Issue 5, July – 2012, pp.1-7.
7. Yong Shuai, Xin-Lin Xi, He-Ping Tan, Radiation performance of dish solar concentrator/cavity receiver systems, *Solar Energy*, 2008, 82, pp.13-21.
8. K.S. Reddy, N. Sendhil Kumar, Combined laminar natural convection and surface radiation heat transfer in a modified cavity receiver of the solar parabolic dish, *International Journal of Thermal Sciences*, 2008, 47, pp.1647-1657.
9. A.M.Clausing, an Analysis of Convective Losses from Cavity Solar Central Receivers, *Solar Energy*, 1981, Vol. 27. No. 4, pp. 295-300.
10. N. Sendhil Kumar, K.S. Reddy, Numerical investigation of natural convection heat loss in modified cavity receiver for fuzzy focal solar dish concentrator, *Solar Energy*, 2007, 81, pp.846–855.
11. N. Sendhil Kumar, K.S. Reddy, Comparison of receivers for solar dish collector system, *Energy Conversion, and Management*,2008, 49, pp.812–819.
12. J.B. Fang, N. Tu, J.J. Wei, Numerical investigation of start-up performance of a solar cavity receiver, *Renewable Energy*, 2013,53, pp.35-42.
13. R. D. Jilte, S. B. Kedare, and J. K. Nayak, Comparison of Cavity Receivers with and without Mouth-Blockage of Different Shapes and Sizes Used in Paraboloid Dish Applications, *Journal of Fundamentals of Renewable Energy and Applications*, 2012, Vol. 2, Ashdin Publishing, Article ID R120306,pp.1-6.
14. Shuang-Ying Wu, Lan Xiao, Yiding Cao, You-Rong Li, Convection heat loss from cavity receiver in a parabolic dish solar thermal power system: A review, *Solar Energy*, 2010, 84, pp.1342-1355.