STUDY ON THERMAL PERFORMANCE OF DIFFERENT HEAT TRANSFER FLUIDS USED IN ABSORBER TUBES OF A CLFR POWER PLANT

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ABSTRACT

In the present numerical investigation, a three-dimensional trapezoidal cavity is studied for different heat transfer fluids at various inlet temperature conditions. Operating parameter i.e. inlet temperature is varied from 80°C to 200°C keeping absorber wall temperature 573 K and mass flow rate 0.2 kg/s as constant. It can be concluded that for lower inlet temperature i.e. 80°C, the temperature rise is higher as compared to higher inlet temperature. The temperature rise is reduced from 39.72°C, 29.65°C, 26.77°C and 16.48°C for Marlotherm X, Syltherm XLT, Therminol D12 and Santotherm 59 to 18.22°C, 15.43°C, 14.81°C and 15.19°C respectively. The temperature rise is maximum for Marlotherm X at all values of inlet temperature followed by Syltherm XLT, Therminol D12 and Santotherm 59. There is 49.87% reduction in temperature rise for Marlotherm X as inlet temperature is increased from 80°C to 200°C. However, heat transfer is higher for Therminol D12 followed by Marlotherm X, Santotherm 59 and Syltherm XLT. There is 35.53% increase in heat transfer from Therminol D12 with increasing inlet temperature. Further, for an inlet temperature of 200°C least heat transfer is shown by Syltherm XLT which is 24.5% lesser than Therminol D12 at the same temperature.

Key words: CLFR, Numerical Analysis, Trapezoidal Cavity, Heat Transfer Fluid, Heat Transfer.

http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=7
1. INTRODUCTION
World energy balance is facing a serious issue of energy shortage and pollution. Renewable energy being sustainable and pollution free is a chief element of world energy balance. Concentrating Solar Power (CSP) i.e. central tower, parabolic dish, linear Fresnel reflector and parabolic trough are prominent among renewable energy sources\[1\], \[2\]. This type of technology works by converting solar irradiation into heat (trigger chemical reaction or generate electricity). The efficiency of any plant depends on the components it is made of. Since, Compact Linear Fresnel Reflector (CLFR) plant (advantageous as the stationary absorber, lower mirror heights, separate reflector and receiver system) consist of concentrating system, thermodynamic cycle (coupled with generator), receiver and Heat Transfer Fluid (HTF)/Thermal Energy Storage (TES) as its main components. There had been evidence in literature exploring the effect of HTF as optimizing parameter. Various prototypes\[3\] had been presented in for gas and fluid HTFs with a challenge of heat transfer between walls and the fluid. Supercritical CO$_2$ as HTF is increasing interest with Brayton cycle in CSP\[4\]. Particle suspension system receivers were used in central tower system with various concepts\[5\], dense particle suspension receiver consists of fluidized particles in suspension and behaves like HTF\[6\], \[7\]. For all types of receivers, the heat transfer is an indirect method i.e. HTF receives heat only after absorber walls gets heated. Hence, a temperature limit is introduced and thermal energy exchange limitation gets imposed on HTF flowing. Thus, the heat carrying capacity (inherent property) of HTF impacts thermal efficiency. For these reasons, HTF is a primary component that justifies development and strong research efforts so that performance can be increased.

The key features for selection of HTF\[8\], \[9\] are higher thermal stability with the higher working temperature range, low melting point (to avoid solidification in tubes), high thermal conductivity as well as heat capacity, lower viscosity, less corrosion. Therminol VP-1 or Dowtherm A (temperature range as high as 400 °C) were initially used as synthetic oils for CSP plants avoiding phase change and high-pressure requirements for water application as HTF. These fluids when heated above 400 °C produces hydrogen due to molecular breakdown leading to increased makeup fluid requirements. It reduces fluid lifetime produces sludge or byproducts resulting in the reduction of thermal exchange efficiency and increased maintenance. The commercial oils Marlotherm X (Sasol data), Santotherm 59 (Monsanto data), Syltherm XLT (Dow Corning Corporation) and Therminol D12 (Solutia Inc.) were chosen for this study. In order to facilitate the study, computational software package ANSYS WorkBench (WB) was employed\[10\]. Heat transfer is calculated by varying different parameters like the mass flow rate and inlet temperature. Further, different fluid flow patterns are determined.

1.1. Receiver Details
In the present study, 1m long receiver cavity is modeled containing eight tubes with symmetry wall as shown in Figure 1 (a). The absorber pipes are SS 304 material with NPS1 as diameter. For thermal expansion, space has been provided between absorber tubes. The HTF is flowing in absorber tubes. Numerical investigations are performed and results are presented for fluid flow behavior.
2. NUMERICAL STUDY

2.1. Model Specifications
The present model is symmetrical and three dimensional with the insulated side as well as the top wall. Mesh function of ANSYS WorkBench package is employed to further divide computational domain into different elements. A total of 1,14,240 elements are generated to obtain the result. The generated grid is validated according to criteria present[11]. The mesh model is shown in Figure 1 (b). The continuity, momentum and energy equations are solved for the analysis:

Continuity equation
\[
\frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0
\] (1)

Momentum equation
\[
\left( u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = -\frac{1}{\rho} \frac{\partial P}{\partial x} + \partial \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) + g\beta (T - T_h)
\] (2)

Energy equation
\[
\left( u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} \right) = \alpha \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right)
\] (3)

The air present in the cavity is chosen with ideal gas assumption. Since the product of temperature difference and average temperature gives the result that is greater than that for Boussinesq approximation to be applicable. Since cavity is subjected to both radiation as well as convection heat transfer. Therefore, Surface to surface (S2S) model is selected for calculating radiation heat loss. S2S includes buoyancy as well as natural convection model is coupled. It assumes fluid to be non-participating medium besides Grey and diffuse surface. View factors are calculated for orientation, size and distance influence on thermal losses.

2.2. Boundary Conditions and Numerical Procedure
The cavity is subjected to different boundary conditions. Walls are assumed with no slip conditions as well as insulated. The absorber tube walls are subjected to isothermal temperature (573 K) as assumed in the previous literature[12]–[15]. Since radiation losses are dominant for high-temperature walls hence cavity walls (\(\varepsilon=0.1\), absorber wall with \(\varepsilon=0.8\)) are considered[16]. Moreover, glass bottom is assumed to confine the heat from outside wind effects (h=5 W/m²K) and emissivity (\(\varepsilon=0.9\)), since convection is dominant with glass bottom wall. The Fluent software package is employed to obtain results of numerical analysis. Pressure-velocity coupling equation is discretized using Second Order Upwind Scheme with momentum and energy is monitored with \(10^{-3}\) and \(10^{-6}\) for residuals. The convergence is concluded monitoring heat transfer as well as residual levels. Solutions are obtained once convergence criteria are met.

2.3. Grid Independence Test
The cavity grid is shown in Figure 1 (c). The independence of grid with respect to the solution obtained is calculated. The percent deviation of solution from initial value is determined. Therefore, Nusselt Number is studied for various mesh sizes having element numbers in the range of 70,644 to 2,36,680. A total of 1,14,240 elements were sufficient to model the cavity and obtain satisfactory results.
3. RESULTS AND DISCUSSIONS

3.1.Isotherms and Flow Patterns

Sample isotherm contours and velocity profile (inlet temperature 80°C) can be seen in Figure 2. It can be clearly seen that higher temperature at the outlet is for Marlotherm X. The region that is at higher temperature is similar for Syltherm XLT and Therminol D12. The changes in velocity contours are easily visible. Therminol D12 is at flowing at a higher flow rate followed by Marlotherm X, Syltherm XLT and Santotherm 59.
3.2. Cavity Heat Exchange

Figure 3 shows temperature rise as a function of inlet temperature and heat transfer associated with varying inlet temperature from 80°C to 200°C. It can be seen that for lower inlet temperature i.e. 80°C the temperature rise is higher as compared to 200°C of inlet temperature for each fluid keeping mass flow rate 0.2 kg/s and absorber wall temperature 573 K as constant. The outlet temperature obtained at 80°C of inlet temperature are 119.72°C, 109.65°C, 106.77°C and 96.48°C for Marlotherm X, Syltherm XLT, Therminol D12 and Santotherm 59 respectively. However, at 200°C inlet temperature, outlet temperature for Marlotherm X, Syltherm XLT, Therminol D12 and Santotherm 59 is 218.22°C, 215.43°C, 214.81°C and 215.19°C respectively. The temperature rise is reduced from 39.72°C, 29.65°C, 26.77°C and 16.48°C for Marlotherm X, Syltherm XLT, Therminol D12 and Santotherm 59 to 18.22°C, 15.43°C, 14.81°C and 15.19°C respectively keeping absorber wall temperature (573 K) and mass flow rate (0.2 kg/s) as constant by varying inlet temperature from 80°C to 200°C. The temperature rise is maximum for Marlotherm X at all values of inlet temperature followed by Syltherm XLT, Therminol D12 and Santotherm 59. There is 49.87% reduction in temperature rise for Marlotherm X as inlet temperature in increased from 80°C to 200°C. However, heat transfer is highest for Therminol D12 followed by Marlotherm X, Santotherm 59 and Syltherm XLT. There is 35.53% increase in heat transfer from Therminol D12 with increasing inlet temperature. Further, for the inlet temperature of 200°C least heat transfer is shown by Syltherm XLT which is 24.5% lesser than Therminol D12 at the same temperature.

![Figure 3](image_url)  
**Figure 3** Cavity heat exchange with varying inlet temperature.

4. CONCLUSION

In the present numerical investigation, the three-dimensional trapezoidal cavity is studied for different heat transfer fluids at various inlet temperature conditions. It can be concluded that for lower inlet temperature i.e. 80°C the temperature rise is higher as compared to 200°C of inlet temperature for each fluid keeping mass flow rate 0.2 kg/s and absorber wall temperature 573 K as constant. The temperature rise is reduced from 39.72°C, 29.65°C, 26.77°C and 16.48°C for Marlotherm X, Syltherm XLT, Therminol D12 and Santotherm 59 to 18.22°C, 15.43°C, 14.81°C and 15.19°C respectively. The temperature rise is maximum for Marlotherm X at all values of inlet temperature followed by Syltherm XLT, Therminol D12 and Santotherm 59. There is 49.87% reduction in temperature rise for Marlotherm X as inlet temperature is increased from 80°C to 200°C. However, heat transfer is highest for Therminol D12 followed by Marlotherm X, Santotherm 59 and Syltherm XLT. There is 35.53% increase in heat transfer from Therminol D12 with increasing inlet temperature. Further, for the inlet temperature of 200°C least heat transfer is shown by Syltherm XLT which is 24.5% lesser than Therminol D12 at the same temperature.
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