Reduction of heat losses in parabolic trough collector using vacuum seal

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Abstract: Solar energy is primary source of all type of energy which is present in nature i.e. all the energy derived from it. So, direct utilization of solar energy into useful energy is important. There are so many solar thermal equipments in which concentrating type collector heated the fluid up to 100 to 400 degree celsius. It is employed for a variety of applications such as power generation, industrial steam generation and hot water production. Parabolic trough collector is preferred for steam generation because high temperatures can be achieved. The trough collect energy using a heat transfer fluid (HTF) that is pumped through the receiver tube in the focal line of parabolic trough. The inlet and outlet water temperature, mass flow rate, useful heat gain and the thermal efficiency of the collector are calculated. Theoretical values of heat loss with vacuum as the annulus gas was found out and these values were compared with those heat loss values of air as annulus gas. A new glass metal seal was developed which help in maintaining the vacuum inside the annulus gap. The seal helped in reducing the heat loss and thus improving the overall efficiency of the collector.

Index Terms— Heat loss, increase efficiency, parabolic trough, vacuum seal.

INTRODUCTION

Humanity has a near total dependence on fossil fuels and other unsustainable sources for its energy needs. The known sources of energy including oil, gas, coal and nuclear fuel are exhaustible. Energy consumption is increasing at an alarming rate exacerbating the social and environmental impacts and accelerating depletion. Thus we are forced to rely mostly upon the renewable sources of energy in the coming future. There are several reasons for why the world should be looking forward to Renewable sources of energy for its power production. The principal reason among them can be cited as

- The rapid depletion of conventional fuels such as oil, coal etc.
- Pollution caused by other energy sources.
- Increased usage of energy in all the countries.
- Environmental damage through problems like Acid rain, Ozone depletion, Greenhouse effect.

Solar energy has greatest potential of all the sources of renewable energy. The solar power where sun hits atmosphere is $10^{17}$ watts. Total world-wide power demand of all needs of human civilization is only $10^{13}$ watts. Solar energy is a diffuse source. To harness it, we must concentrate it into an amount and form that we can use, such as heat and electricity. This can be solved by approaching the problem through:

1) Collection, 2) conversion, 3) storage.

For the above said approach use of Parabolic trough solar collector is the most matured technology. Parabolic trough technology is one of the most advanced solar thermal technologies. This method employs the use of a mechanism to concentrate the solar radiation in a relatively small area. Thus it increases the working temperature of the heat transfer fluid. Parabolic trough technology can effectively produce heat in a temperature range of 50 deg. Celsius to 400 deg.celsius. This is done by the positioning of an optical device (parabolic shaped mirror) between the source and energy absorbing surface and so concentrating the entire radiation received to a small area. It is usually made with a mirrored surfaces curved in a parabolic shape extended into a trough shape and this focuses the solar radiation on to the absorber tube running through the focus of the trough. Collector is usually aligned on a north-south horizontal axis. Heat collecting element or receiver is made of a material of high absorbitivity. Normally absorber pipe are made of stainless steel surrounded by an evacuated gas pipe in order to minimize convective and radiative heat losses. Heat transfer fluid that is flowing through the receiver tube absorbs the heat from the solar radiation.

Heat loss reduction of the parabolic trough solar collector is very important as this will increase the efficiency of the solar collector. Heat loss in a solar collector is of 3 types

1. Convection
2. Conduction
3. Radiation

Conduction loss is negligible when comparing to convection and radiation. Reduction of convective and radiative heat losses is the main objective of the heat loss reduction of parabolic trough technology.

![Fig. 1 Parabolic trough and Receiver tube](image)

**Thermal Energy Capture and Loss Mechanism**

The energy balance on a solar collector receiver is

\[ Q_{\text{useful}} = E_{\text{opt}} - Q_{\text{loss}} \]

- \( Q_{\text{useful}} \) = rate of 'useful' energy leaving the absorber (W)
- \( E_{\text{opt}} \) = rate of optical (short wavelength) radiation incident on absorber (W)
- \( Q_{\text{loss}} \) = rate of thermal energy loss from the absorber (W)

The useful energy for a solar thermal collector is the rate of thermal energy leaving the collector

\[ Q_{\text{useful}} = \dot{m}C_p(T_{\text{out}} - T_{\text{in}}) \]

- \( \dot{m} \) = mass flow rate of heat transfer fluid (kg/s)
- \( C_p \) = specific heat of heat transfer fluid (J/kg.K)
- \( T_{\text{out}} \) = temperature of heat transfer fluid leaving the absorber (K)
- \( T_{\text{in}} \) = temperature of heat transfer fluid entering the absorber (K)

The area of the collector on which the solar irradiance falls is called the(opening) area of the collector. The incident solar resource then is:

\[ E_{\text{ins}} = I_A A_a \]

- \( I_A \) = solar irradiance entering the collector aperture (global (total) or direct (beam)) (W/m2)
- \( A_a \) = aperture area of the collector (m2)

This solar resource is reduced by a number of losses as it passes from the aperture of the collector to the absorber. The rate of optical (short wavelength) energy reaching the absorber or receiver is the product of the incoming solar resource multiplied by a number of factors, all less than 1.0 describing this reduction:

\[ E = \Gamma \rho \alpha T I_A A_a \]

- \( \Gamma \) = capture fraction (fraction of reflected energy entering or impinging on receiver).
- \( \rho \) = reflectance of any intermediate reflecting surfaces
- \( \alpha \) = absorptance of absorber or receiver surface
- \( T \) = transmittance of any glass or plastic cover sheets or windows

Once the solar energy resource (short wavelength radiation) has made its way down to the surface of the absorber or receiver of a collector, it raises the temperature of the absorber above ambient temperature. This in turn starts a process of heat loss from the absorber as with any surface heated above the temperature of the surroundings. These loss mechanisms are convection, radiation and conduction, and all are dependent on, among other things, the difference in temperature between the absorber and the surroundings.

\[ Q_{\text{loss}} = Q_{\text{loss,convection}} + Q_{\text{loss,radiation}} + Q_{\text{loss,conduction}} \]

\[ Q_{\text{loss,convection}} = h_A(T_r - T_s) \]

- \( h_A \) = average overall convective heat transfer coefficient (W/m2.K)
- \( A \) = surface area of receiver or absorber (m2)
- \( T_r \) = average temperature of receiver (K)
- \( T_s \) = ambient air temperature (K)

Radiation heat loss is important for collectors operating at temperatures only slightly above ambient, and becomes dominant for collectors operating at higher temperatures.

\[ Q_{\text{loss,radiation}} = \varepsilon\sigma A_a(T_r^4 - T_{\text{sky}}^4) \]

- \( \varepsilon \) = emittance of the absorber surface (or cavity in the case of a cavity receiver)
- \( \sigma \) = the Stefan-Boltzmann constant \((5.670 \times 10^{-8} \text{ W/m}^2 \text{K}^4)\)
- \( T_{\text{sky}} \) = the equivalent black body temperature of the sky (K)

This is generally described in terms of a material constant, the thickness of the material and its cross section area:

\[ Q_{\text{loss,conduction}} = kA_x(T_r - T_s) \]

- \( k \) = equivalent average conductance (W/m.K)
- \( A_x \) = the average thickness of insulating material

**DESIGN AND DEVELOPMENT OF END SEAL FOR EFFECTIVE VACUUMIZATION**

Vacuumization of the annulus gap instead of air increases efficiency as the convection between annulus gap reduces. Current techniques such as use of vacuum tube is not cost effective hence industrially not
applicable. Adding to this, maintenance of vacuum is another challenge. Development of low cost vaccumization method and seal is essential. The type of seal we use is the aluminium cap which is very effective and also giving due importance to thermal expansion during high temperature operations.

MODEL OF SEAL

Assembly of reciver tube

Glass meatl seal

This seal is attached to the both end of the glass envelope. This is attached to the glass envelope with the help of Vaseal and Silicon sealing which is used as an adhesive between cap and glass envelope or receiver tube.

COST OF SEALING

Aluminium cap and its manu facturing = Rs 30
Vaseal = Rs 2100 for 14ml pack (can be used for 30 to 35 caps)
Silicon seal = Rs 145 (can be used for 30 to 35 caps)
Total cost for employing a single cap = 30 + 70 + 5 + vacuumization process charges = Rs 105 + vacuumization charges

RESULTS AND DISCUSSIONS

Heat loss vs temperature difference

5.1 Calculation of Heat loss by Theoretical method

When vacuum is maintained in the annulus gap
Convection heat transfer becomes negligible between annulus gap
Reynolds number of air flow when wind speed is 4m/s
\[ \text{Re} = \frac{\rho v D}{\mu} \]
\[ = 1.127 \times 4 \times 0.05 \times (16.97 \times 10^{-6}) = 1328.2 \]
\[ \text{Nu} = 0.30 \text{Re}^{0.6} = 0.30 \times 1328.2^{0.6} = 89.34 \]
\[ h = \frac{h_\text{r}}{h_\text{r}} = \frac{89.34 \times 0.027}{0.050} = 48.24 \text{ W/m}^2\text{c.} \]
Substituting \( h \) in \( Q_{\text{loss}} \)
\[ Q_{\text{loss}} = \pi D_c L h_c L_h (T_{\text{co}} - T_0) + \varepsilon \pi D_c L \sigma (T_{\text{co}}^4 - T_{\text{sky}}^4) \]
\[ = \pi \times 0.5 \times 0.1 \times 48.24(323 - 303) + 0.88 \times 3.14 \times 3.07 \times 0.05 \times 10^{-6} \times (323^4 - 300^4) \]
\[ = 312.07 \text{ W} \]

When vacuum is not employed in annulus gap
Convection heat transfer in the annulus gap
\[ Q_{\text{loss}} = h A (T_r - T_{\text{co}}) = 16.55 \times 2.159(423 - 385) = 135.77 \text{ W} \]
\[ h = 0.30 \text{Re}^{0.6} = 16.55 \]
\[ A = \text{area between annulus gap} \]
Decrease in percentage of heat loss when vacuum is used=(Q_{\text{loss}}/(Q_{\text{loss,1}}+Q_{\text{loss}}))*100=30.3% \]
Hence it has been found out that when vacuum is used a significant amount of convective heat loss can be reduced. Thus the use of vacuum in parabolic trough receiver is found out to be very effective.

CONCLUSION

Design and development of an vacuum seal for the reduction of the heat loss is done. The idea of vacuumizing the annulus gap and designing a low cost seal for the maintenance of this vacuum is found out to
be a suitable method. Cost estimation of the manufacturing and employment of seal is conducted and it has been found out that this method is cheaper. Calculations are done considering the annulus gas type (both air and vacuum). Using vacuum is found out to increase the efficiency by 30.3 percentage than using air in the annulus gap. Seal with Vacseal and silicon sealant is expected to give a good life expectancy with improved efficiency.

The new glass metal seal proved to be an effective way to reduce the heat loss.

REFERENCES


