Heat Exchange Rates of Solar Refrigeration Systems Using Vacuum Tube Collector

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***Abstract*: A detailed literature review was presented to know the heat transfer rates for both cooling and heating sources from radiation exchange. Different authors have given and presented the solar refrigeration system using evacuated tube collector both experimentally and analytical models to know the heat transfer rates in vacuum tube and make comparisons with flat plat solar refrigeration system.**

***Keywords*: heat transfer, vacuum tube and solar energy etc.**

Introduction:
H U Helvaci and Z AKhan [1] presented in their technical paper a detailed numerical model of a flat plate collector was developed to investigate the fluid mean temperature, useful heat gain and heat transfer coefficient along the collector tube. The refrigerant HFC-134a was used in the simulation as the working fluid of the collector. The model can both predict the location where the fluid undergoes a phase change in the tube and the state at the exit under given inlet conditions. The effect of boiling on the heat transfer coefficient of the fluid is also investigated. Simulations were performed at three different mass flow rates (0.001, 0.005 and 0.01 kg/s) and three different operating pressures (4, 6 and 8 bar) to be able to see the effect of mass flow rate and pressure on plate temperature, heat loss coefficient, efficiency of the collector and the heat transfer coefficient of the fluid. The simulation results indicate that the heat transfer coefficient of the fluid increases from 153.54 W/m^2 K to 610.27 W/m^2 K in multiphase flow region. In the liquid single phase region, the collector efficiency rises from 60.2% to 68.8% and the heat transfer coefficient of the fluid increases from 39.24 W/m^2 K to 392.31 W/m^2 K with an increased flow rate whereas the collector efficiency decreases from 72.5% to 62.3% as the operating pressure increases from 4 bar to 8 bar. In order to validate the simulation model an experimental test rig was built and the experiments were performed with HFE 7000 as working thermo-fluid. A new simulation model utilizing HFE 7000 has been developed and the outlet temperature of the fluid was compared with the measured outlet temperature. Both measured and simulated results have shown close conformity.

A W badar R Buchloz F Ziegler [2] presented in their technical paper an analytical steady state model was developed to study the thermal performance of an individual vacuum tube solar collector with coaxial piping (direct flow type) incorporating both single and two-phase flows. A system of equations which describe the different heat transfer mechanisms and flow conditions was established, discretised, and solved in an iterative manner.
For the case of good vacuum condition (10^{-5} mb) the calculated efficiency curve for single phase flow deviates significantly from the experiments with increasing collector temperature, but agrees well for the case of gas conduction inside the glass envelope at very low pressure ($\ll$1 mb) due to the corresponding increase in overall heat loss coefficient (*U*-value).
For two-phase flow, the occurrence and propagation of flow boiling and condensation inside the collector piping under saturated condition is hypothesized. The modeling results indicate that for all-liquid-single-phase fluid flow, the collector efficiency decreases with decreasing mass flow rate. Once the fluid reaches the boiling point at a certain mass flow rate, no significant reduction in efficiency is observed anymore, which is in accordance with the experimental study.

A W badar R Buchloz F Ziegler [3] presented in their technical paper the overall heat loss coefficient (*U*-value) of a vacuum tube solar collector was investigated experimentally and theoretically with regard to the pressure of the remaining gas inside the evacuated glass envelope. A number of collector tubes of same geometry are randomly selected from an installation of a solar based air-conditioning system and tested individually in the laboratory for the determination of the *U*-value. Measurement results indicate that most of the examined collector tubes have higher overall heat loss coefficients than expected corresponding to a significant amount of gas inside the glass envelope. For the same conditions, an approximate theoretical model is developed for the evaluation of the *U*-value.

Zhiyong Li et al [4] presented in their technical paper the heat transfer model of all-glass vacuum tube collector used in forced-circulation solar water heating system. In this model, the simplified heat transfer of collector is composed of the natural convection in single glass tube and forced flow in manifold header. Thus the heat balance equation of water in single tube and the heat balance equation of water in manifold header have been established. The flow equation is also built by analyzing the friction and buoyancy in tube. Through solved these equations the relationship between the collector average temperature, the outlet temperature and natural convection flow rate have been obtained. From this relationship and energy balance equation of collector, the collector outlet temperature can be calculated. The validated experiments of this model were carried out in winter of Beijing K Chen et al[5] presented in their technical paper tubular solar collector was fabricated from acrylics for improved resistance to shattering. A plasma on was employed to apply a thin gas-barrier coating to the surfaces of the plastic tube to prevent/alleviate gas infiltration. Experiments were conducted to investigate the effect of vacuum level on the performance of the non-glass vacuum-tube solar collector. Inserted in the evacuated tube was a finned heat pipe for solar energy collection and heat transfer to a water tank. Time variations of temperatures on the heat pipe surface and in the water tank were recorded and analyzed for different degrees of vacuum in the collector. The steady-state temperature of the non-glass collector was compared to that of a commercial glass vacuum-tube collector to assess the feasibility of the use of evacuated plastic tubes for solar energy collection. A simple analytical model was also developed to assist in understanding and analyzing the transient behavior and heat losses of the vacuum-tube solar collector.

J Glembin et al [6] presented in their technical paper the impact of low flow rates on the efficiency of coaxial vacuum tube collectors. Measurements show an efficiency reduction of 10% if reducing the flow rate from 78 kg/m^2 h to 31 kg/m^2 h for a collector group with 60 parallel vacuum tubes with a coaxial flow conduit at one-sided connection. For a more profound understanding a model of the coaxial tube was developed which defines the main energy fluxes including the internal thermal coupling. The tube simulations show a non-linear temperature profile along the tube with the maximum temperature in the outer pipe. Due to heat transfer to the entering flow this maximum is not located at the fluid outlet. The non-linearity increases with decreasing flow rates. The experimentally determined flow distribution allows simulating the measured collector array. The simulation results confirm the efficiency decrease at low flow rates. The flow distribution has a further impact on efficiency reduction, but even at an ideal uniform flow, a considerable efficiency reduction at low flow rates is to be expected. As a consequence, low flow rates should be prevented for coaxial tube collectors, thus restricting the possible operation conditions. The effect of constructional modifications like diameter or material variations is presented. Finally the additional impact of a coaxial manifold design is discussed.

Ma Liangdong et al [7] presented in their technical paper the energy balance for the glass evacuated tube solar collector with U-tube, the thermal performance of the individual glass evacuated tube solar collector was investigated by analytical method. The solar collector considered in this study was a two-layered glass evacuated tube, and the absorber film is deposited in the outer surface of the absorber tube. The heat loss coefficient and heat efficiency factor are analyzed using one-dimensional analytical solution. And the influence of air layer between the absorber tube and the copper fin on the heat efficiency is also studied. The results show that the function relation of the heat loss coefficient of the glass evacuated tube solar collector with temperature difference between the absorbing coating surface and the ambient air is nonlinear. In the different ambient temperatures, the heat loss coefficient of the solar collector should be calculated by different expressions. The heat efficiency factor will be subject to influence of air layer between absorber tube and the copper fin. Specially, the influence is remarkable when the heat loss coefficient of the collector is large. When the synthetical conductance amounts to 5 W/m K, the solar collector efficiency decreases 10%, and the outlet fluid temperature decreases 16% compared with the case which the air thermal resistance is neglected. And the surface temperature of the absorbing coating increases 30 °C due to the effect of air thermal resistance. So the surface temperature of the absorbing coating is an important parameter to evaluate the thermal performance of the glass evacuated tube solar collector.

L Ruobing et al [8] presented in their technical paper energy absorbed by the working fluid flowing in the U-tube, was proposed to eliminate the influence of thermal resistance between the absorber tube and the copper fin of the conventional evacuated solar collector. In this paper, the thermal performance of the filled-type evacuated tube with U-tube was researched by means of theoretical analysis and experimental study. The temperature of the working fluid in the flow direction was obtained, and the efficiency of the evacuated tube was also calculated, based on the energy balance equations for the working fluid in the U-tube. The effects of the heat loss coefficient and the thermal conductivity of the filled layer on the thermal performance of the evacuated tube were studied. In addition, the test setup of the thermal performance of the filled-type evacuated tube with U-tube was established. The evacuated tube considered in this study was a two-layered glass evacuated tube, and the absorber film was deposited in the outer surface of the absorber tube. The results show that the filled-type evacuated tube with U-tube has a favourable thermal performance. When the thermal conductivity of the heat transmission component is $\lambda_c = 100$, the efficiency of the filled-type evacuated tube with U-tube is 12% higher than that of the U-tube evacuated tube with a copper fin. The modelling predictions were validated using experimental data which show that there is a good concurrence between the measured and predicted results.

Louise Jivan Shah, Simon Furbo [9] presented in their technical paper heat transfer and flow structures inside all glass evacuated tubular collectors for different operating conditions are investigated by means of computational fluid dynamics. The investigations are based on a collector design with horizontal tubes connected to a vertical manifold channel. Three different tube lengths varying from 0.59 m to 1.47 m have been modelled with five different inlet mass flow rates varying from 0.05 kg/min to 10 kg/min with a constant inlet temperature of 333 K. Under these operating conditions the results showed that: the collector with the shortest tube length achieved the highest efficiency, the optimal inlet flow rate was around 0.4–1 kg/min, and the flow structures in the glass tubes were relatively uninfluenced by the inlet flow rate, generally, the results showed only small variations in the efficiencies. This indicates that the collector design is well working for most operating conditions. L.M. Ayompe, A. Duffy, S.J. McCormack, M. Conlon [10] presented in their technical paper a validated TRNSYS model for forced circulation solar water heating systems used in temperate climates. The systems consist of two flat plate collectors (FPC) and a heat pipe evacuated tube collector (ETC) as well as identical auxiliary components. The systems were fitted with an automated unit that controlled the immersion heaters and hot water demand profile to mimic hot water usage in a typical European domestic dwelling. The main component of the TRNSYS model was the Type 73 FPC or Type 538 ETC. A comparison of modelled and measured data resulted in percentage mean absolute errors for collector outlet temperature, heat collected by the collectors and heat delivered to the load of 16.9%, 14.1% and 6.9% for the FPC system and 18.4%, 16.8% and 7.6% for the ETC system respectively. The model underestimated the collector outlet fluid temperature by −9.6% and overestimated the heat collected and heat delivered to load by 7.6% and 6.9% for the FPC system. The model overestimated all three parameters by 13.7%, 12.4% and 7.6% for the ETC system.

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