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INLET GEOMETRY EFFECTS ON NUSSELT NUMBERS AND FRICTION FACTORS OF DEVELOPING FLOW IN A U-TUBE OF AN EVACUATED TUBE COLLECTOR WITH A COMPOUND PARABOLIC CONCENTRATOR

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KEY FINDINGS

Numerical investigation of the effect of the T-junction inlet geometry and non-uniform heat flux on the Nusselt numbers and friction factors of the developing flow in a single tube of an evacuated tube collector. The compound effects introduced by the tilt angle and non-uniform heat flux are investigated. A T-junction comprising of the inlet header and a single u-tube within the collector, is numerically modelled. To determine the non-uniform heat flux distribution along the circumference of the u-tube, the discrete ordinates model is employed in a 2D:3D phased approach which involves conducting a 2D optical study and 3D thermal study of the collector. The results provide insights into the effects of inlet geometries on the performance of various mechanical systems like solar thermal collectors and heat exchangers.

INTRODUCTION

Evacuated tube collectors (ETC) are a unique solar thermal collector system with domestic and industrial heating applications. The collector is made up of a series of compound parabolic concentrators and evacuated tubes that contain u-tubes, as shown in **Figure 1**. The selective absorber coating which lines the inner glass tube is made from aluminium nitride which enables high radiation absorption, **Figure 2**. Each u-tube forms a T-junction as shown in **Figure 3,** with the insulated inlet (and outlet) header. Water is used as the heat transfer fluid and the flow regime is characterised as laminar.

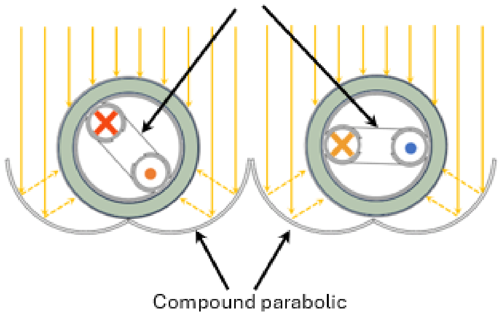

Figure 1: Transversal section of two evacuated tubes with CPCs where the orange lines represent the incoming solar radiation.

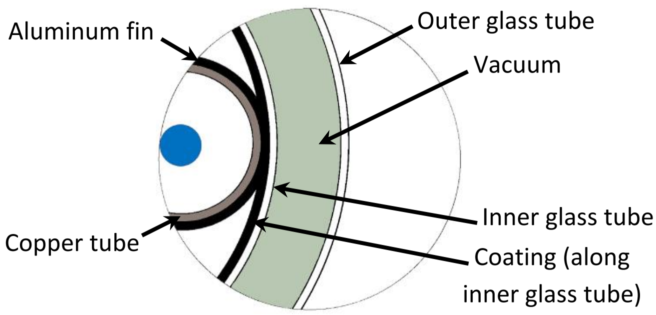

Figure 2: Annotated section of ETC with CPC

The effects of various inlet geometries have been investigated before [1-3] and shown to induce greater heat transfer rates in different flow regimes. In the context of solar thermal systems, higher heat transfer rates are desirable to enable better absorption of solar irradiation. However, there is limited literature available on 90° T-junctions and their effects on the development of laminar flow for non-isothermal cases, applicable to this study case. Additionally, the 30° system inclination introduces buoyancy forces that will also be considered. The solar heat flux is also a very important characteristic that has a significant influence on the fluid flow behaviour and heat transfer properties. Since the ETC is integrated with a compound parabolic concentrator positioned under each tube, the bottom portion of the ETC receives concentrated radiation from the concentrator and the top receives direct radiation from the sun which introduces a non-uniformity at the absorber located on the outer surface of the inner glass. Further, within the inner glass, there is a fin which almost encapsulates the u-tube which transports the heat transfer fluid. This fin and u-tube arrangement is located within an air cavity. The overall configuration of the system introduces non-uniform distribution of heat at the circumference of the u-tube. This non-uniformity will be considered and investigated in this study using numerical software and validated using existing experimental studies. The combined effects of these characteristics will also be discussed.

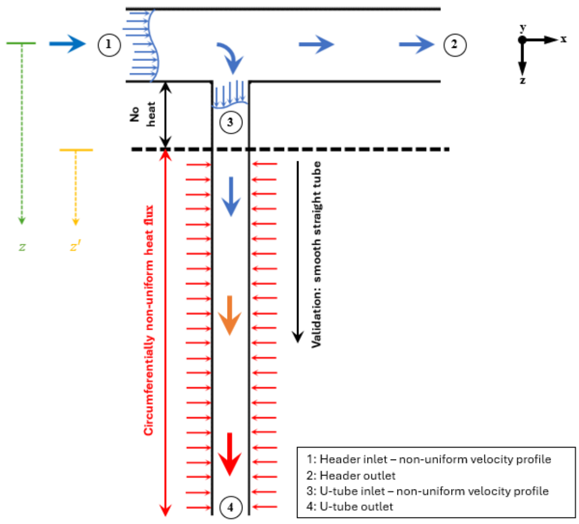

Figure 3: Geometric model – inlet header and u-tube T-junction connection.

METHODOLOGY

The solar collector under investigation is the CPC1512 which is an evacuated tube collector technology with a CPC reflector manufactured by Linuo Paradigma, which is installed at an inclination angle of 30°. The geometric model of this study, as shown in **Figure 3,** consists of a u-tube located within the ETC, with an inner-tube diameter of 6.55 mm. The header and a short length of the u-tube is considered isothermal as it is well insulated. The heat from the solar heat flux (assumed as 1000 W/m^2 at an incident angle of 0° this study) is absorbed and then transferred to the u-tube via conduction and convection through the aluminium fin and air cavity. The magnitude of the velocity at the inlet header was obtained from experimental tests conducted by Keyser [8].

The discrete ordinates (DO) method in ANSYS Fluent was employed to obtain the non-uniform circumferential heat flux distribution at the u-tubes. The DO model is a numerical model that solves the radiative transfer equation, displayed in equation 1 [4], hence it accounts for scattering, semi-transparent media, specular surfaces, and wavelength-dependent transmission. It has been applied in various numerical studies of solar thermal collectors [4-7].

$$\frac{dI}{dx_i} + \underbrace{(a+\sigma_s)I(r,s)}_{\text{Absorption}} = \underbrace{an^2\frac{\sigma T^4}{\pi}}_{\text{Emission}} + \underbrace{\frac{\sigma_s}{4\pi}\int_0^{4\pi} I(r,s')\Phi(s'\cdot s')\,d\Omega'}_{\text{Scattering}} \qquad (1)$$

The 2D:3D approach proposed by Moghimi et al. [6] was applied to obtain the heat flux at the u-tubes. A 2D model (transversal section) of a single tube in the ETC was modelled in ANSYS to carry out the optical study. Spatial mesh count, angular discretisation, and discretisation scheme studies were conducted to account for ray effects and false scattering. The angular discretisation and pixelation in the two angular coordinates, θ and φ were determined as 3 x 100 and 3 x 3, respectively. The mesh count was set torv 180 000 cells and both first order and second-order discretisation schemes were applied. The resulting incident flux for both discretisation schemes were plotted and are shown in **Figure 4.** The second order discretisation scheme provides a more accurate representation of the non-uniformity of the heat flux whereas the first order discretisation shows a smoother profile. The Monte Carlo Ray Tracing Software, Tonatiuh [9] was employed to validate the 2D optical study and is also plotted in **Figure 4.** Discrepancy can be observed between the incident radiation flux obtained from Tonatiuh and the 2D DO radiation model in ANSYS Fluent. This is primarily due to the difference in the construction of the mirror in both cases. There is a 5 % difference in the average heat flux obtained in both cases, with the Tonatiuh model producing the higher heat flux. However, the peaks in both profiles occur at nearly the same locations.

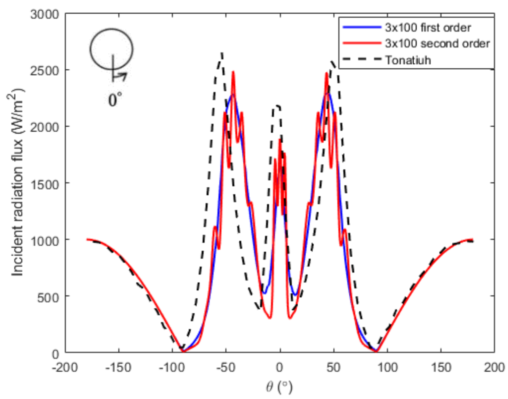

Figure 4: Incident radiation flux at absorber

The system will then be modelled as steady state in 3D on ANSYS Fluent to establish the heat flux at the boundary of the u-tube by applying conjugate heat transfer, to account for conduction and convection, and DO radiation to account for radiation. From the thermal model, the non-uniform and average heat flux conducted to the u-tube will be extracted.

To establish the velocity profile at the header inlet, the pipeline downstream of the header was modelled in a separate numerical study with a fully developed velocity profile prescribed at its inlet. The resulting outlet velocity profile is applied as the inlet velocity profile at the inlet header of the study case.

MAIN RESULTS/EXPECTED OUTCOMES

The non-uniform heat flux at the wall of the u-tube is expected to assume the radial profile depicted in **Figure 5**, owing to the u-tube being exposed to the air cavity along a portion of its circumference and the fin (with a very small airspace) along the rest of its circumference. Given the higher thermal conductivity of the aluminium fin, the portion exposed to the aluminium fin is expected to experience a higher heat flux compared to the portion exposed to the cavity.

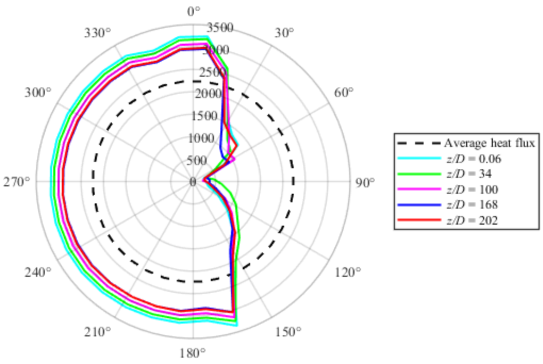

Figure 5: Radial plot of heat flux at u-tube leg

The Nusselt number and friction factor results are expected to show that the T-junction induces disturbances which are dominant in the entrance region and reduce in intensity along the tube length. Further, the disturbances are expected to be characterized by recirculating flow, which will occur within the inlet region of the u-tube and as the fluid approaches the u-bend. Disturbances are also expected within the u-bend and after the u-bend, the disturbances are expected to reduce in intensity. The average heat flux will also be applied to investigate the effect of the non-uniform nature of the actual heat flux on heat transfer and fluid flow.

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