A CFD Analysis of the flow and thermal performance of Rectangular channel heat exchanger with and without baffle

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Abstract: *A heat exchanger is a piece of machinery that efficiently transfers energy from a hot fluid to a cold fluid with minimal initial and recurring costs. The main objective of this research is to simulate mathematically and using computational fluid dynamics to forecast how rectangular channels with and without baffles will affect the design and thermal performance. Different designs of solar collector rectangular channels employing without and with baffles were subjected to mathematical and computational fluid dynamics simulations in order to investigate the best design of a rectangular channel and maximize thermal performance.*

Keywords: heat exchanger, fluid streams, condensers, CAD, Solar energy

I. INTRODUCTION

A heat exchanger is a piece of machinery that efficiently transfers energy from a hot fluid to a cold fluid with minimal initial and recurring costs. As a result of the fact that each fluid in a heat exchanger passes through it at a different temperature, the wall separating the fluids also varies in temperature over the exchanger's length. The milk chillers in pasteurizing factories, condensers and boilers, condensers and evaporators, regenerators, automobile radiators, and heat engine oil coolers are a few examples of industrial applications for heat exchangers.

A. Type of flow path configuration through heat exchanger

1) Parallel flow: The two fluid streams enter contemporaneous or parallel flow units at the same end, move through them in the same direction, and exit with each other at the other end.

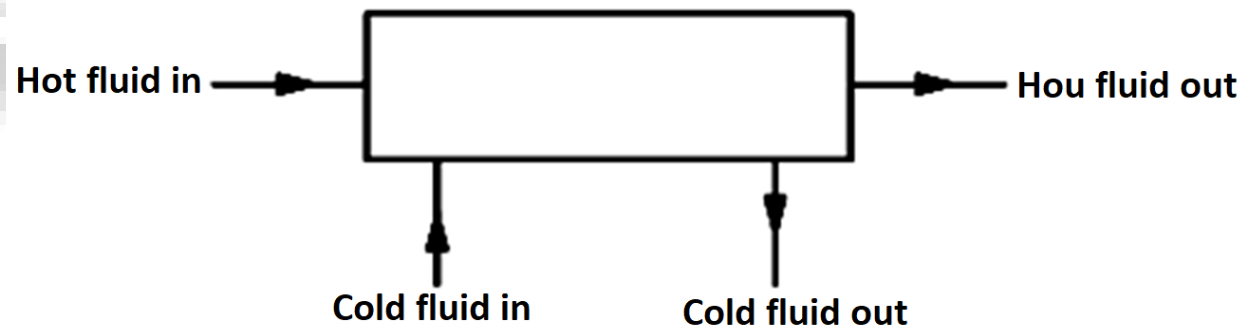

Figure 1 Parallel flow configuration

B. Effect of the direction of inclination

Hoary Amour et al. 2019 claim that the negative orientation of the baffle holds more promise for enhancing the heat transfer rates of these exchangers. This is so that there would be more kinetic energy generated during turbulent flow due to the secondary vortex that is present before the baffle. [11]

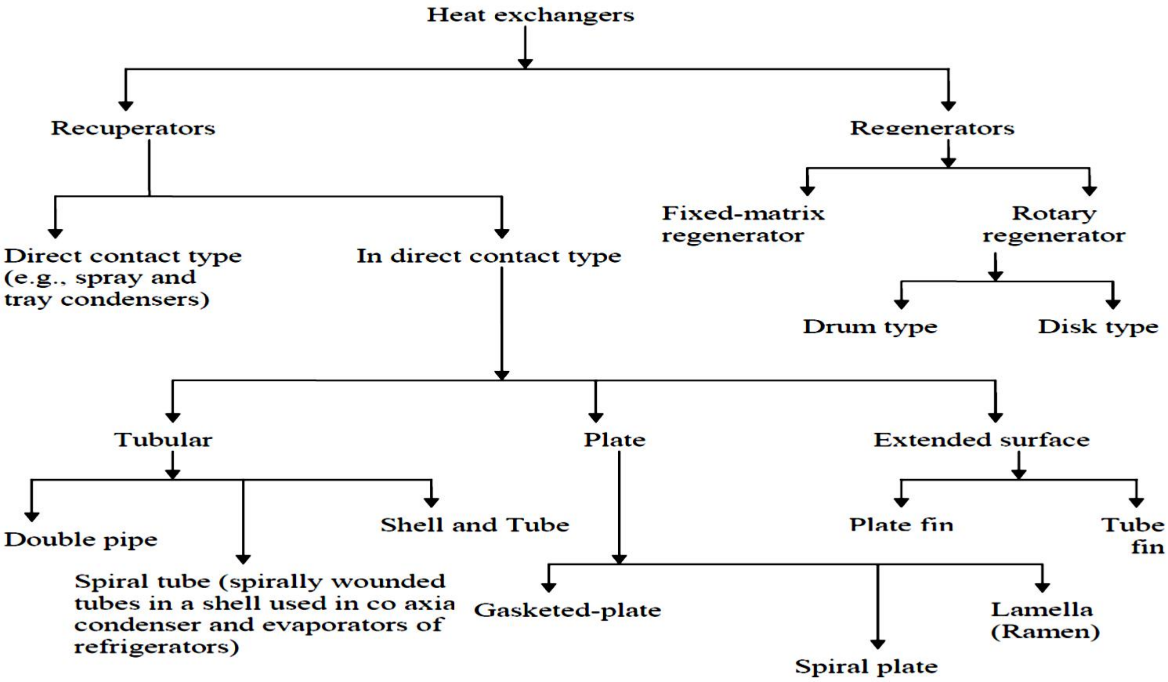

Figure 2 types of heat exchangers

II. LITERATURE REVIEW

Amnart Boonloi & Withada Jedsadaratanachai (2021) [1] Numerical studies of the heat exchanger tube (HXT) fitted with the dual-inclined baffle (DIB) are reported on fluid streams and heat transfer patterns. Three types of DIB setups are categorised: "Type I" refers to the DIB that is positioned in the centre of the HXT, "Type II" refers to the DIB that is positioned on the HXT wall, and "Type III" refers to the combination of the type I and II DIBs. Three different flow profiles were intended to be produced by the three DIB variantsThe effects of DIB height with a single pitch distance (P/D = 1) and 30° DIB attack angle on heat transfer characteristics and fluid streams are examined in a laminar flow zone at Re = 100–2000 (considered at). The numerical issue with the HXT that was added with the DIB is resolved using a commercial code (the finite volume method). The computing domain is validated in order to check the dependability and accuracy of the simulated outcomes. The simulated-result section suggests heat transfer behaviours and flow configurations for the HXT fitted with the DIB, including local Nusselt number contours (Nux) and streamlines in transverse planes (y-z planes) and temperature contours in these planes. In the HXT inserted with the DIB, the average Nusselt number ratio (Nu/Nu0), friction factor ratio (f/f0), and thermal enhancement factor (TEF) are displayed in proportion to the Reynolds numbers. Due to the development of vortex streams and impinging streams, the simulation results show that the DIB equipment in the HXT offers a greater heat transfer rate and thermal performance than the smooth tube.. Different flow patterns are found when the DIB types are changed, and these flow profiles have an effect on how the heat transfer profile changes. According to the DIB type, DIB blockage, and Reynolds number, the increased heat transfer rate in the HXT equipped with the DIB is seen to be approximately 1.03-17.46 times above the plain tube for the examined range. The type II DIB also has a maximum TEF of 3.70 at b/D = 0.25 and Re = 2000.

Bahiraei, M., et al. (2021) [2] This study's goal is to examine the thermohydraulic characteristics and performance index for the flow of nanofluids with a variety of particle forms, including cylinder, blade, brick, platelet, and oblate spheroid (OS) (STHX). A spiral stream forms inside the shell side of the STHX thanks to innovative unilateral ladder-type helical baffles. The nanofluid is thought to be the heated fluid that flows inside the tube wall. Water is selected as the cold fluid that moves at Reynolds numbers between 5000 and 20,000 inside the shell side. The performance of STHX is significantly impacted by the flow pattern that the baffles produce. As the shell side's Reynolds number rises, the effectiveness, pressure drop, Number of Transfer Unit (NTU), and heat transfer rate all increase but the performance index falls. Additionally, the heat transfer rate, overall coefficient, and pressure loss are all highest in the nanofluid with platelet additives, but the effectiveness, NTU, and performance index are highest in the nanofluid containing OS additives. The severe cross and secondary flows are completely apparent on the shell side thanks to the additional baffles, especially at high Reynolds numbers.

Ameur, H. (2019) [11] Results on the flow fields and thermal distribution in a rectangular channel heat exchanger are presented in this work. One method for enhancing the performance of such systems is bafflement. Investigated are the impacts of baffle inclination angle and inclination direction.

Chang, S. W., et al. (2019) [12] A novel study was done to create a heat transfer enhancement element employing a plate insert with periodic oblique bafes and perforated slots to enhance a heat exchanger's hydrothermal performance. The endwall Nusselt number distributions of a square channel that had been improved by freshly created bafe inserts were found using the infrared thermography technique, and the Fanning friction coefficients and thermal performance factors were assessed. The core fluid was tripped toward the channel walls by the current bafe inserts, causing near-wall separated and accelerated flows that promoted heat convection. The thermal performance factors were in the ranges of 1.6-3.2 and 2-3.4 for forward and backward flows, exceeding many previous types of bafe inserts, with Nusselt numbers and Fanning friction coefficients elevated to 9-5 times the Dittus-Boelter references and 5-85 times the Blasius correlation levels for Reynolds numbers between 10,000 and 50,000. To assess average Nusselt numbers and Fanning friction coefficients with forward and backward flows, empirical correlations were created. In order to attain higher hydrothermal efficiency, the oblique slots were placed downstream of the neighbouring oblique ribs based on thermal performance data.

Ary, B. K. P., et al. (2012) [22] In a rectangular channel with various types of baffles, the impact of a number of inclined perforated baffles on flow patterns and heat transfer is examined numerically and experimentally. Reynolds has a population between 23,000 and 57,000. Using the SST k turbulence model, the approach forecasts turbulent flow. The baffles are 19.8 cm wide, have a 2.55 cm long square diamond-shaped opening on one side, and are inclined at a 5° angle. The findings demonstrate that the number of holes has a substantial impact on the flow patterns around the holes, with two baffles outperforming one baffle in terms of local heat transfer.

III.OBJECTIVE

The main objective of this research is to simulate mathematically and using computational fluid dynamics to forecast how rectangular channels with and without baffles will affect the design and thermal performance.
The goals of the current work are as follows:
• To perform mathematical analysis to determine the properties of Cu + water nano fluid and the mass flow rate, Reynolds number, nusselt number, heat transfer rate, and heat transfer coefficients for all designs of rectangular channel.
• To create a two-dimensional CAD model of a rectangular channel without and with a baffle installed in the bottom wall at different angles, such as 30o, 60o, and 90o.
• Use simulations of computational fluid dynamics to determine how the placement of a baffle will affect the thermal performance and design of a rectangular channel in terms of temperature distribution and velocity stream function.
• To assess how each rectangle channel heat design performed.

IV.METHODOLOGY

Plates and finned chambers are used in a rectangular channel with baffle heat exchanger to transfer heat between fluids. It is widely employed in a variety of industries, such as aerospace because of its small size and light weight, and cryogenics because of its capacity to promote heat transfer at low temperature differences. The interruption of hydrothermal layers brought on by the installation of baffles in channel walls raises the heat transmission ratio. [HouariAmeur et al. (2019)].

Table 4.1Thermo physical properties of water and Cu particles

Properties	Water	Cu Particles
Density (Kg/m^3)	996.5	8300
Specific heat (J/Kg K)	4183	420
Thermal conductivity (Wm K)	0.5981	401
Viscosity (Kg/m Sec)	0.0008514	-

Table 4.2:Geometrical parameters of rectangular channel with baffles[*N. M. Phu et al 2021*

Geometrical parameters	**Value with units**
Length of rectangular channel (L)	500 mm
Height of rectangular channel (h)	20 mm
The baffle height (e)	8 mm, 10 mm & 12.5 mm
Baffles Pitch (p)	80 mm
First baffle is placed at a distance	15 mm from the inlet section
Working fluid	Cu +water nano-fluid
Temperature of fluid at the inlet section is taken	300 K
Heat flux at the absorber plate of the rectangular channel	1000 Watt
Lower wall of channel and the baffles	Adiabatic

A.CAD Geometry of Rectangular channel without baffles

The current study develops a two-dimensional CAD model of a rectangular channel without a baffle using the design module of ANSYS workbench.

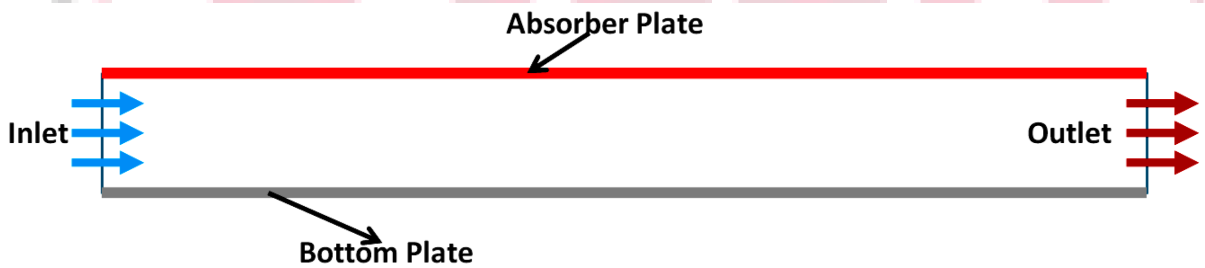

Figure 3 CAD geometry of rectangular channel without baffles

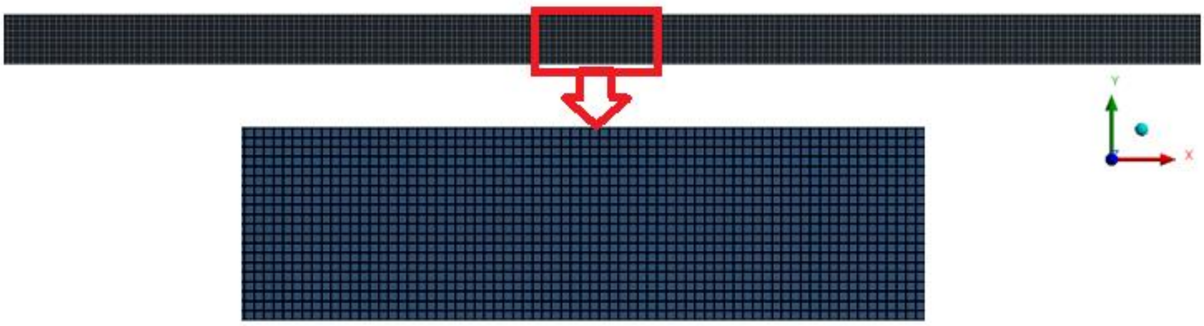

Figure 4 Meshing of rectangular channel without baffles

B.CAD geometry of rectangular channel with baffles inclined at 30o on bottom wall at different baffle height:

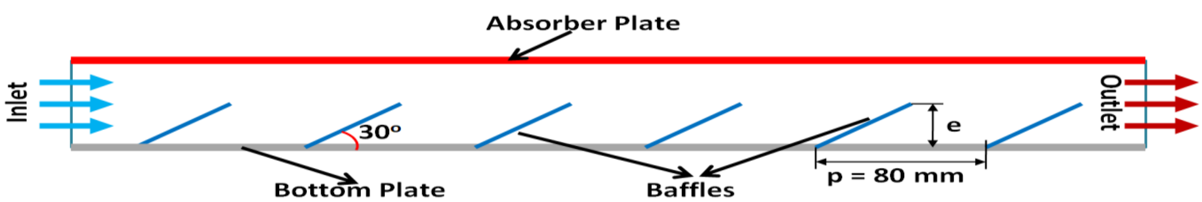

Figure 5 CAD geometry of rectangular channel with baffles inclined at 30o on bottom wall at different baffle height

C. CAD Geometry ofrectangular channel with baffles inclined at 60o on bottom wall at different baffle height:

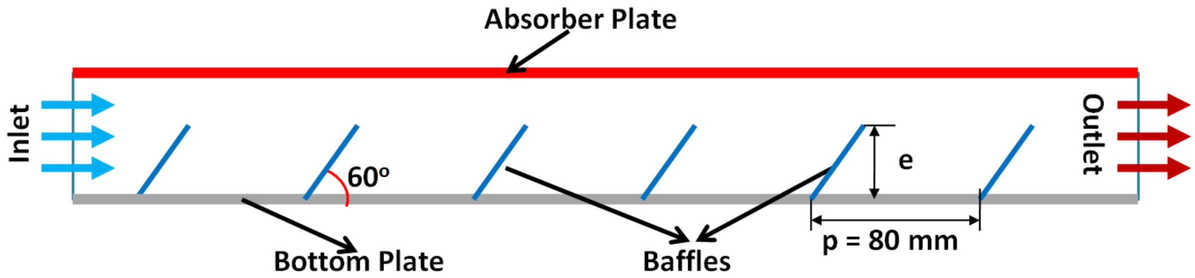

Figure 6CAD geometry of rectangular channel with baffles inclined at 60o on bottom wall at different baffle height

D.CAD Geometry ofrectangular channel with baffles inclined at 90o on bottom wall at different baffle height:

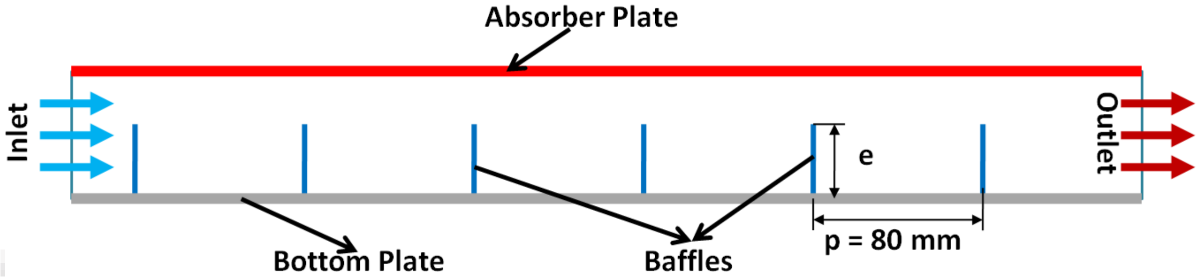

Figure 7 CAD geometry of rectangular channel with baffles inclined at 90o on bottom wall at different baffle height

E.CAD Geometry ofrectangular channel with baffles inclined at 30o installed inside absorber plate (Top wall) & on the bottom wallet different baffle height:

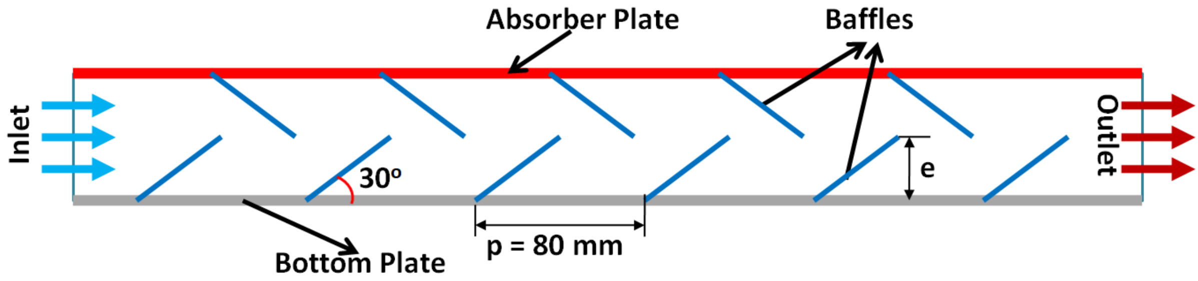

Figure 8 CAD geometry of rectangular channel with baffles inclined at 30o installed inside absorber plate (Top wall) & on the bottom wall at different baffle height

V. RESULT AND DISCUSSION

Mathematical and computational fluid dynamics calculations were carried out on several designs of rectangular channels employing without and with baffles in order to investigate the best design of a rectangular channel and maximise thermal performance.

A. Computational fluid dynamic of rectangular channel without baffle

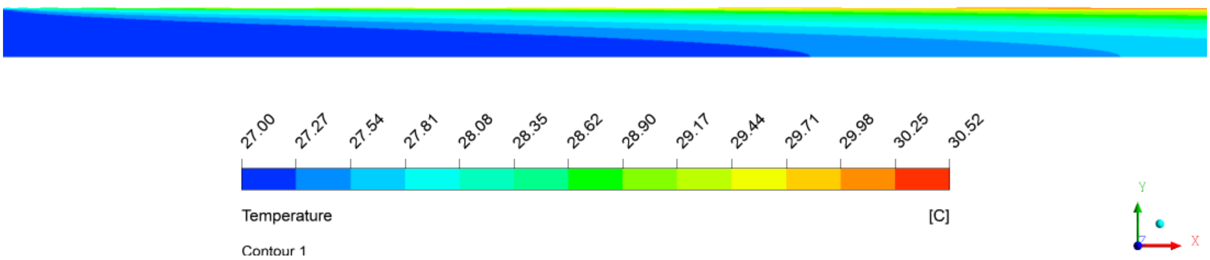

Figure 9Temperature distribution for rectangular channel without baffles

B.Computational fluid dynamic of rectangular channel with baffles inclined at 30o on bottom wall

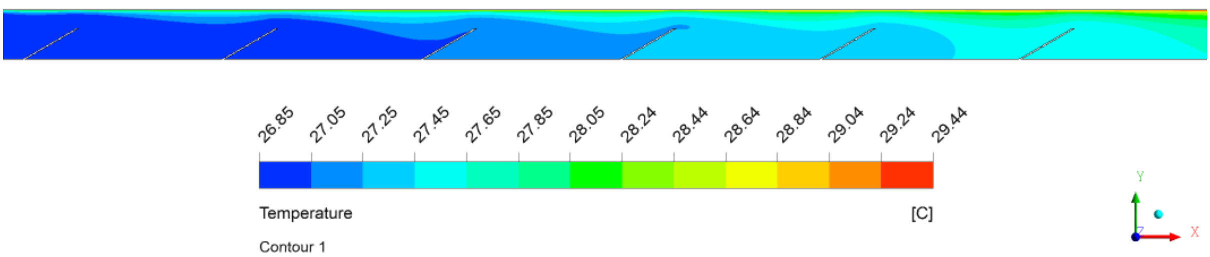

Figure 10 streamline flow for rectangular channel with baffles inclined at 30o installed in the bottom wall with baffles height of 12.5 mm

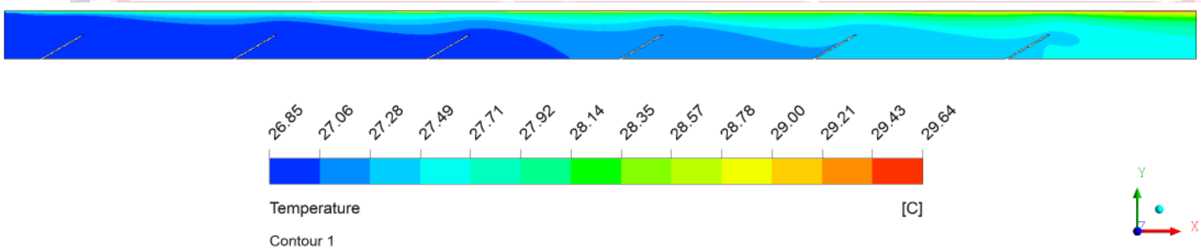

Figure 11 Temperature distribution for rectangular channel with baffles inclined at 30o installed in the bottom wall with baffles height of 10 mm

Table 5.1 Comparative results for rectangular channel without & with baffles inclined at 30° on bottom wall

Design	Minimum Temperature [°C]	Maximum Temperature [°C]	Difference ΔT	Velocity Stream Function [mm/Sec]
Rectangular channel without baffles	27	30.52	3.52	9.08
Rectangular channel with baffles inclined at 30°& e= 12.5	26.85	29.44	2.59	21.45
Rectangular channel with baffles inclined at 30°& e= 10	26.85	29.64	2.79	16.72
Rectangular channel with baffles inclined at 30°& e= 8	26.85	29.78	2.93	14.43

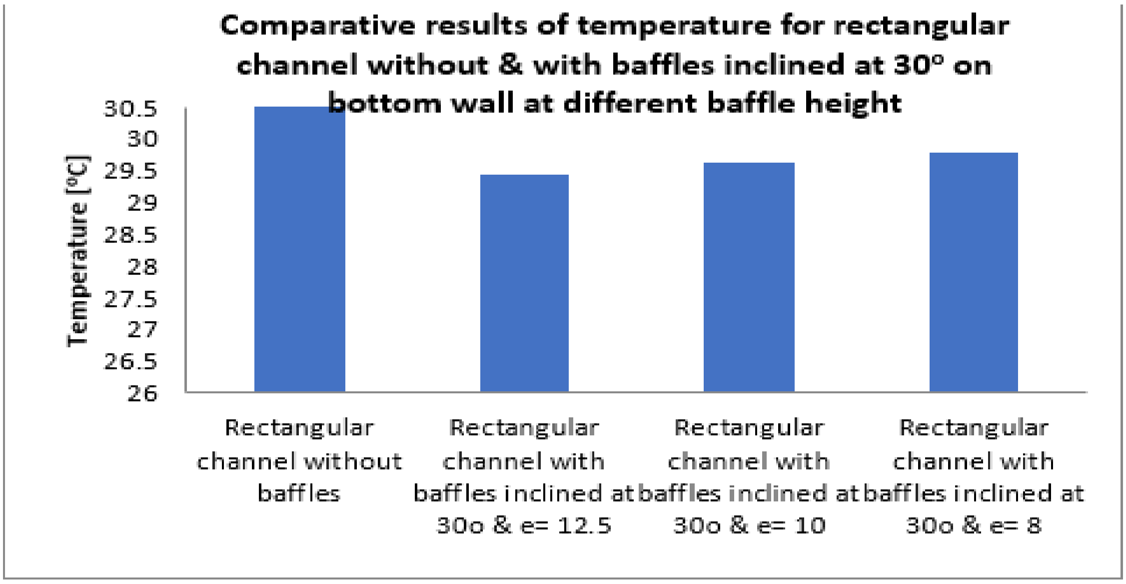

Figure 12 Comparative results of temperature for rectangular channel without & with baffles inclined at 30o on bottom wall at different baffle height

C. 5.10 Computational fluid dynamic of rectangular channel with corrugated baffles inclined at 60o installed inside absorber plate (Top wall) & on the bottom wall

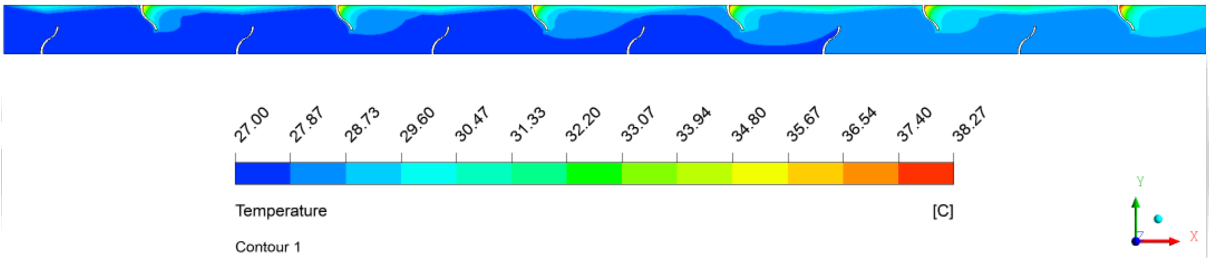

Figure 13 Temperature distribution for rectangular channel with corrugated baffles

VI. CONCLUSION

A. Conclusion

Different designs of solar collector rectangular channels employing without and with baffles were subjected to mathematical and computational fluid dynamics simulations in order to investigate the best design of a rectangular channel and maximise thermal performance. Utilizing sun radiation, water is heated in this rectangular tube. There were employed a total of 28 different designs of rectangular channels, both with and without baffles, with various heights and constant pitches. rectangular channel without baffles, rectangular channel with baffles inclined at 30 degrees in the bottom wall, rectangular channel with baffles inclined at 60 degrees in the bottom wall, and rectangular channel with baffles inclined at 90 degrees in the bottom wall, rectangular channel with baffles inclined at 90 degrees installed in the bottom wall, rectangular channel with baffles inclined at 30 degrees installed in the bottom wall, rectangular channel with baffles inclined at 30 degrees installed in both the absorber plate and the bottom wall, and rectangular channel with baffles inclined at 60 degrees installed in both the absorber plate and the bottom wall. At different baffle heights, including 12.5 mm, 10 mm, and 8 mm, computational fluid dynamics analyses were performed Investigations have been made on the thermal hydraulic performance of a Cu-water nanofluid with constant flow rate and concentration.

The following conclusions can be drawn from the above analysis.

❖ A maximum temperature of 30.52 oC with a temperature difference of 3.52 oC from the intake at a maximum velocity of 9.08 mm/sec was discovered at the outlet after running a computational fluid dynamic analysis on a rectangular channel without baffles. The heat transfer coefficient was 103.93 W/m2C, and the heat transfer rate was 0.8 KW.

❖ After conducting a computational fluid dynamic analysis on a rectangular channel with baffles angled at 30 degrees on the bottom wall, maximum temperatures of 29.44 oC at e = 12.5 mm, 29.64 oC at e = 10 mm, and 29.78 oC at e = 8 mm were found at the outlet with temperature differences of 2.59 oC, 2.79 oC, and 2.93 oC, respectively, and a maximum velocity of 21.45 With heat transfer coefficients of 206.73 W/m2C, 169.37 W/m2C, and 150.55 W/m2C, respectively, the heat transfer rates are 1.39 KW, 1.16 KW, and 1.06 KW.

❖ After performing computational fluid dynamic analysis on a rectangular channel with baffles inclined at 60 degrees on the bottom wall, the maximum temperatures of 30.09 degrees Celsius at e = 12.5 millimetres, 30.26 degrees Celsius at e = 10 millimetres, and 30.42 degrees Celsius at e = 8 millimetres were noted at the outlet with temperature differences of 30.9 degrees Celsius, 3.26 degrees Celsius, and 3.42 degrees Celsius, respectively, and the maximum velocity of 21.95 millimetres With heat transfer coefficients of 210.57 W/m2C, 173.66 W/m2C, and 152.88 W/m2C, the heat transfer rates are 1.69 KW, 1.40 KW, and 1.26 KW, respectively.

B. Future scope

Mathematical and computational fluid dynamics evaluations of several designs of solar collector rectangular channels employing without and with baffles were carried out in order to investigate the best design of a rectangular channel and maximise thermal performance. Despite the seriousness and dedication with which this job was completed, some additional work is still possible as explained below.

Heat transfer rate, heat transfer coefficient, and temperature difference were used in this study to assess the thermal performance of a rectangular channel; however, future studies may also examine other parameters, such as LMTD.

To test the thermal performance of a rectangular channel in the current work, Cu-water nan fluid with constant flow rate and concentration was employed; however, in the future, another nan fluid may be used.

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