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Design and Analysis of CFD Simulation on Ceramic Heat Exchanger

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Abstract: **- There is a potential interest for warm exchangers equipped for supporting working temperatures well over 900°C. A wide range of concentrates in the writing consider these parts as basic for the usage of remotely let go gas turbines (EFGT) and remotely let go joined cycles (EFCC). It is sound judgment that earthenware production are the main option for the development of these warmth exchangers, however most piece of the writing about warmth exchangers more often than not thinks about just metallic materials for its development. Thusly, the plan of earthenware warm exchangers isn't minor and speaks to a genuine specialized test. Also, extraordinary warmth exchange modes are available all the while and as we as a whole realize that the geometry of warmth exchanger chooses the adequacy of warmth exchanger, two geometries are thought about and examined in this work. As a stage toward this path, the present work displays the plan of a clay warm exchanger utilizing CFD and limited component auxiliary reenactments. The warmth exchanger outlined shows little measurements so as to make it less demanding to build a model and test it later on.**

Keywords: **- Ceramic heat exchanger, EFGT, EFCC.**

I. INTRODUCTION

Heat exchangers are utilized as a part of numerous business applications and various sorts can be bought from an expansive number of makes. As of late, control age has been presented to the issues of the debilitates from petroleum derivatives and an unnatural weather change. Thusly, the utilization of sustainable power source and the improvement of atomic vitality have turned out to be more critical. Be that as it may, under existing conditions, they are not accessible, in light of the fact that the misuse of sustainable power source is little contrasted and the aggregate sum of vitality expended, and atomic vitality is related with security issues. Most importantly, it is critical to dispose of the reliance on oil fuel, and utilization of coal, which is then again copious everywhere throughout the world. Likewise, the productivity of energy age must be moved forward. High temperature warm exchanger innovation has turned out to be critical for enhancing the execution of energy age. Numerous in the field have been relying on the improvement of a warmth exchanger for producing high temperature gas. Be that as it may, it is troublesome for the ordinary metal warmth exchanger to be utilized at high temperatures or with destructive gasses. Metal warmth exchangers have restricts in their use. Artistic exchangers may meet these cutoff points. Under existing conditions, be that as it may, the trouble of assembling confused surfaces with pottery has kept the boundless utilization of such exchangers. As geometric requirements are especially vital for such a gas reactor to restrain the span of the essential vessels, minimized warmth exchangers working at high weight and high temperature are appealing potential answers for recuperator applications. Today, the dispersion fortified warmth exchangers with small scale channels appear to an all the more encouraging idea for recuperator application.

One of the promising applications for HTHEs is in the power business, since they would turn conceivable the execution of EFGT (remotely let go gas turbines) and EFCC (remotely let go consolidated cycles). The run of the mill course of action of the parts of one EFGT cycle is appeared in Fig. 1. As expressed by Kautz and Hansen (2007), the key segment in the cycle is the HTHE, on the grounds that alternate segments are standard parts. In both of these cycles the burning vent gasses don't go through the turbine so other fuel than gas can be utilized, similar to biomass or coal.

One artistic plate-blade HTHE was outlined by Fischedick et al (2007) for 50kWth and numerous essential plan contemplations were assessed, for example, the decision of the fired material; auxiliary uprightness of the warmth exchanger; warm outline; weight drop presented by the warmth exchanger, and others that will be tended to in the present investigation.

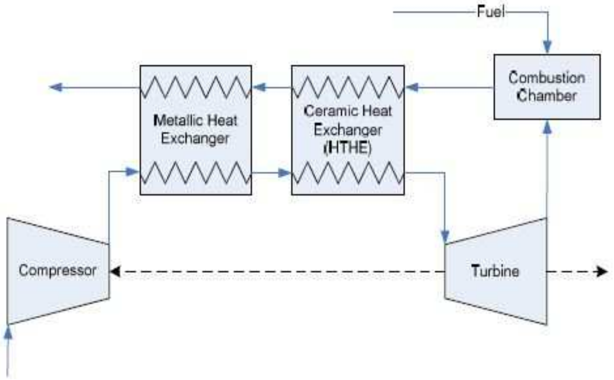


Fig.1. mill course of action of the parts of one EFGT cycle

Pressure drop produced by the heat exchanger deserves special attention during design stage because it reduces the thermal efficiency of the cycle (Kautz and Hansen, 2007). The challenge in the design of a ceramic HTHE for power applications is to achieve high effectiveness without producing high pressure drop. It is considered a difficult task since the same heat capacity rate is observed in both sides of the heat exchanger.

II. OBJECTIVES

The outline correlation of two distinct models of a fired warmth exchanger is exhibited and examined in the present work. The plan is led considering a little warmth exchanger that could be tried in a research center seat work, creating valuable information for the approval of the displayed outline procedure. The last model ought to have outer measurements littler than 100 mm.

The plan of the warmth exchanger is going for a specific application: the EFGT, however it doesn't consider noteworthy weight contrasts between the hot and chilly sides, which would present one additional trouble for the future test tests. In addition, different qualities of the application are kept up: air is the liquid in the two sides of the warmth exchanger and the stream rate is the same for the hot and chilly sides. This condition, as talked about later, will show confinements to the viability that can be gotten for the warmth exchanger.

2.1 Potential applications and requirements

The requirements for the design phase were drawn out following a detailed analysis of four different potential applications (Luzzatto [1997]) for a maximum temperature of 1500 °C, a maximum pressure of 2.5 MPa and a maximum differential pressure between gases of 0.6 MPa. The applications are:

- **Chemical**: a syngas production plant. Different syngas production processes have been considered leading to the choice of the scheme implemented in the Puertollano IGCC plant (Prenflo process).
- **Metallurgical**: an aluminum reheating furnace. Estimations from US sources show a very attractive market for this application, in which metallic recuperators suffer from very high corrosion.
- **Glass**: a typical production plant. The air preheating system can be changed from the regenerative type to the recuperative, and electric energy can be produced.

Waste: a waste incineration plant. Heat recovered from downstream of the incinerator is used in an indirect-fired

2.2General design considerations

- For high temperature heat exchangers, the thermal stresses during the startup, shutdown and load fluctuations can be significant. Heat exchanger must be designed accordingly for reliability and long life.
- The thermal capacitance (“thermal mass”) should be reduced for high temperature heat exchangers for shorter startup time.
- High temperature heat exchangers require costly materials contributing to the high cost of balance of power plant. Heat exchanger cost increases significantly with temperature above about 675°C.

III. SELECTION OF MATERIALS FOR HTHES

Three major classes of high-temperature materials are promising candidates for different applications:

High-temperature nickel-based alloys (e.g., Hastelloy). Good material compatibility potential for helium and molten salts up to temperatures in the range of 750°C. Also a candidate material for sulfuric acid thermal decomposition. Limited capability under fusion neutron irradiation.

High-temperature ferritic steels (particularly oxide-dispersion ferritic steels). Good performance under fusion and fission neutron irradiation, to temperatures around 750 °C Good potential for compatibility with lead/bismuth under appropriate chemistry control. Demonstrated compatibility with molten salts would have substantial value for the fusion application. Silica bearing steels provide a candidate material for sulfuric acid thermal decomposition.

Advanced carbon and silicon carbide composites. With excellent mechanical strength to temperatures exceeding 1000°C, these are now used for high temperature rocket nozzles to eliminate the need for nozzle cooling and for thermal protection of the space shuttle nose and wing leading edges. Many options are available that trade fabrication flexibility and cost, neutron irradiation performance, and coolant compatibility. These materials can potentially be used with helium and molten salt coolants. Silicon carbide is also compatible with sulfur-iodine thermochemical hydrogen production. Major opportunities and research challenges exist to apply these materials to high-temperature heat transport applications.

The best material available seems to be a SiCp/Al2O3, (particles reinforcing phase-based material), from a US manufacturer; no European manufacturer could supply Ceramic Matrix Composites (CMC) bayonet tubes.

IV. THERMAL DESIGN

In the work of Fischedick et al (2007), the thermal design of the HTHE was conducted by using correlations for theColburn and friction factors for offset strip fins. These correlations were obtained from experiments by Manglik andBergles (1995).

The present work uses CFD simulations for the thermal design task. This choice can be justified by the possibility of considering the heat conduction in the ceramic material coupled with the convective heat transfer, technique known as conjugate heat transfer. This type of simulation is particularly important since it can provide the temperature distribution in the ceramic material as a result that can be used as input to the structural design.

The number of transfer units (NTU) method is used for the present analysis and design. The theory related to NTU can be found in many texts from literature. It states that the effectiveness ε depends on the number of heat transfer units NTU and the heat capacity rates of the hot and cold flows Cr. This dependence is summarized by Eq. (1).

$$\varepsilon = \varepsilon\,(NTU, Cr) \qquad (1)$$

The number of transfer units (NTU) and the ratio between heat capacity rates are given by Eq. (2) and (3), respectively.

$$NTU = UA/C_{min} \qquad (2)$$

$$Cr = C_{min}/C_{max} \qquad (3)$$

Here, U is the overall heat transfer coefficient, A is the heat transfer area, and Cmin and Cmax are the minimum and maximum capacity rates.

The heat exchanger designed in the present work is very similar to the one presented by Fischedick et al (2007), but its dimensions are much reduced, for the reasons already commented in the design objectives section. The heat exchanger is formed by ceramic plates that are stacked. The geometry of the ceramic plates can be seen in Fig. 3 and its dimensions were a result of the following criteria: the thickness of any plate region should not be less than 5 mm; the external dimensions of the mounted heat exchanger should be smaller than 100 mm.

All the CFD simulations were conducted using ANSYS FLUENT 15.0 and modeling of plates has been done in CREO 3.0 The convergence criteria was set to RMS of the residuals lower than 5×10-5. The high order interpolation scheme was used. The Reynolds number, based on the 5.0 mm channels shown in Fig. 3, is between 200 and 1000, depending on the flow rate. Therefore, no turbulence model was needed. The density variation with temperature is very significant for the application considered herein and it was considered in the simulations with ideal gas model. considering only the air flow through the channels (without conjugate heat transfer).

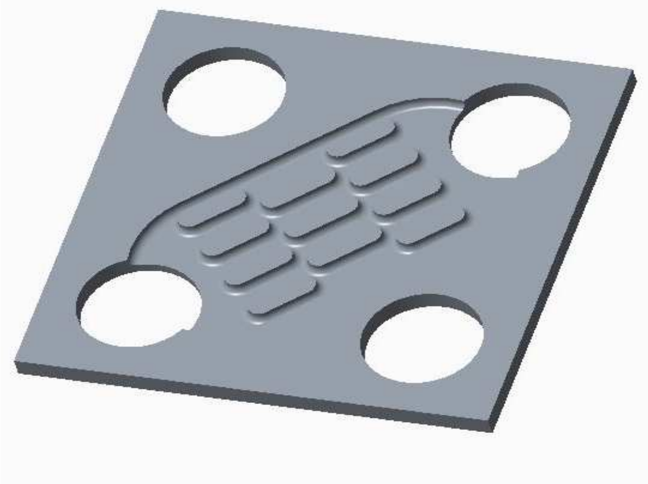
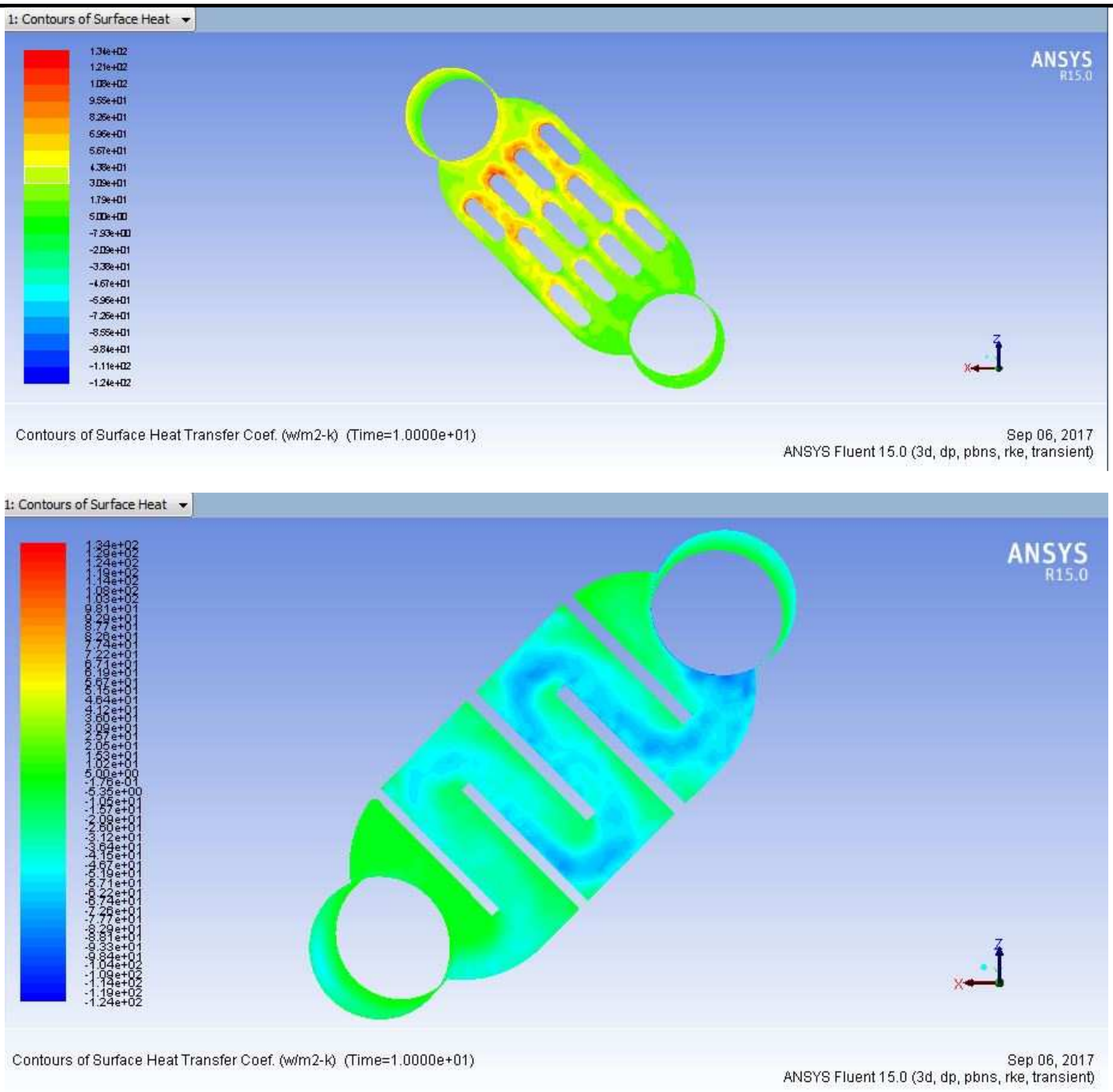


Fig.2 Rectangular duct with elliptical pins

Fig.3 Rectangular duct with pins arranged in serial pattern

4.1. CFD Simulations

The number of elements in the grids varied from 1.8 to 2.7 millions. The results have not shown asymptotic behavior, but the difference observed between the highest and lowest heat transfer rate was smaller than 30% (120.58 W and 176.576 W respectively) in case of elliptical pins rectangular duct and in case of serial pins rectangular ducts followed the same trend but heat transfer rates are slightly low. It produced differences over the effectiveness of almost 1% considered satisfactory but effectiveness is just more with 0.97 in case of serial pins rectangular duct against 0.96 in case of pins rectangular duct.



Contours of Surface Heat Transfer Coef. (w/m2-k) (Time=1.0000e+01)

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ANSYS Fluent 15.0 (3d, dp, pbns, rke, transient)

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Fig.4 Contour of local heat transfer coefficient (air is flowing from left to right)

The results obtained with a typical simulation, are presented in table 2. For this ideal condition the overall heat transfer coefficient is equal to the average heat transfer by conduction

	ELLIPTICAL MODEL			ELLIPTICAL AND SERIAL BAFFELE ARRANGEMENT		
mass flow rate (kg/s)	HEAT TRANSFERRED TO COLD FLUID	EFFECTIVENESS	COLD FLUID OUTLET TEMPERATURE (K)	HEAT TRANSFERRED TO COLD FLUID	EFFECTIVENESS	COLD FLUID OUTLET TEMPERATURE
3.00E-04	120.57307	0.9644	568.76331	116.73681	0.9073	554.98486
4.00E-04	150.20998	0.9659	557.23462	142.80825	0.9383	544.35583

5.00E-04	176.58465	0.9659	544.76093	165.75339	0.9713	538.02991

Under real conditions, where Cr is close to unity, the effectiveness should be significantly lower. It suggests that the effect of the flow rate over the effectiveness could be evaluated with the ideal model before dealing with the much demanding model, using conjugate heat transfer.

Following this approach, a series of simulations with different flow rates was conducted. When the flow rate is reduced, the overall heat transfer coefficient U and the heat capacity rate Cmin decrease. Due to this behavior, it is not obvious the effect of the flow rate over NTU. But the graph of Fig. 5, which summarizes the results, shows clearly that NTU increases when flow rate is reduced. In other words, Cmin decreases faster than U when the flow rate is reduced, at least for the heat exchanger considered here.

Of course, another option to increase NTU would be to increase heat transfer area, but it is not in agreement with the objectives of the present work, considering the limitations imposed to the size of the heat exchanger. The effectiveness, varied from 0.9644 to 0.9659 for elliptical pins rectangular duct and the same varied from 0.9073 to 0.9713 for serial pins rectangular ducts when the flow rate is increased from 3×10-4 kg/s to 5.0×10-4 kg/s

Conjugate heat transfer simulations were conducted including the effect of heat conduction in the ceramic walls. The steady state simulations considered the heat conductivity of alumina k = 11.4 W/m K, according to data from NIST (2010). Figure 6 shows the stacked arrangement of the plates. The geometry of each plate was already shown in Fig. 3. Only one pair of plates was simulated and periodicity boundary conditions were used in order to approximate the stacked plate arrangement. Periodic boundary condition means that, for calculation purposes, the bottom side of the pair of plates is in contact with the top side of an adjacent pair. This boundary condition is used only for the solid domain.

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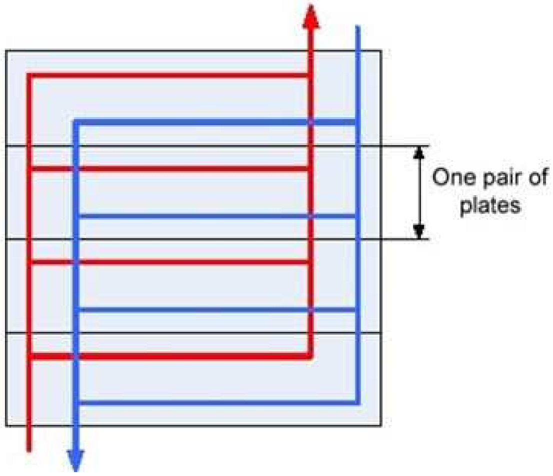

Fig.5 Scheme of the stacked ceramic plates. Only one pair of plates is considered in the simulation

For the fluid domains, temperatures and flow rates are imposed in the inlets of the heat exchanger. Different flowrate conditions were simulated, but maintaining equal flow rates on cold and hot sides for each condition. Temperatures imposed to the inlet flows of the cold and hot sides are respectively 30°C and 1000°C.

The most important result of each simulation is the temperature of the air leaving the heat exchanger, in hot and cold sides. These results allow the calculation of a series of derived results: effectiveness, NTU, among others.

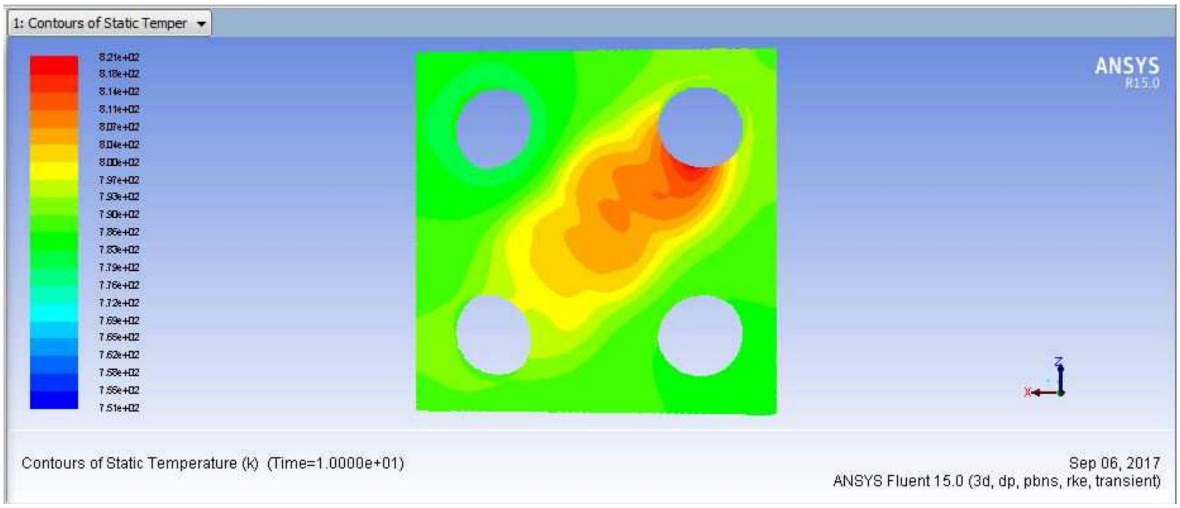

Fig.6 Temperature distribution in the ceramic plates (°C).

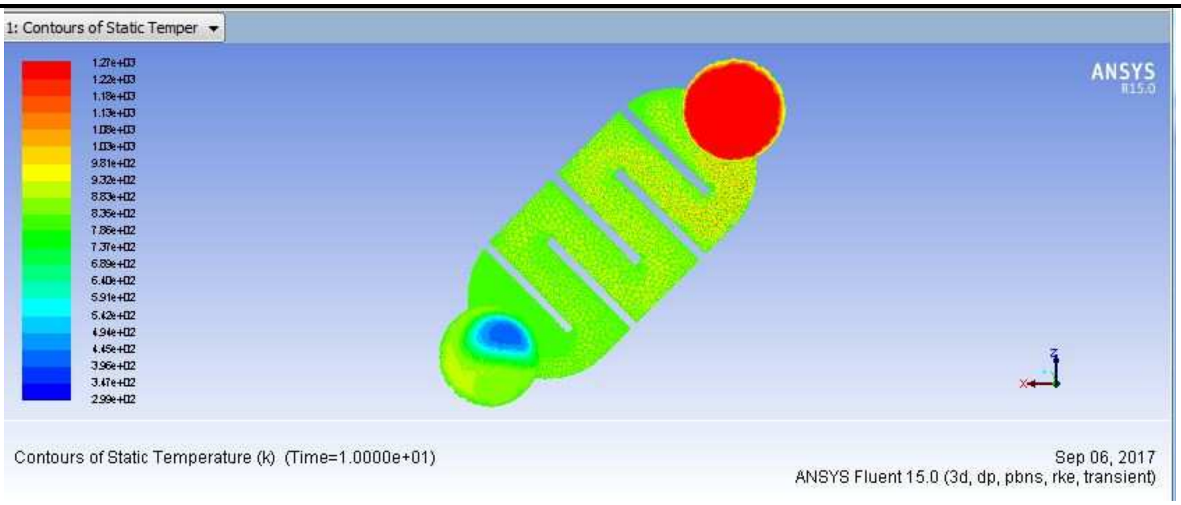

Fig.7 Temperature contour of hot side fluid in serial pins rectangular ducts

V. CONCLUSIONS

This work exhibited a method for the plan of an earthenware warm exchanger of little measurements. Later on, the development and trial of the warmth exchanger is proposed, keeping in mind the end goal to approve the outline system and increase advance knowledge to extend it to commonsense applications.

The low adequacy acquired with the plan can be credited to the cross stream arrangement and nearly high convective warmth exchange coefficients resultant from k-ε turbulent model. The warm protection by conduction in the clay dividers isn't huge for the plan reproduced.

Measure of warmth moved is less if there should be an occurrence of serial pins rectangular pipes when contrasted with curved pins rectangular conduit because of distinction in channel width. be that as it may, the viability is more because of the time slack in stream. likewise weight drop is less if there should be an occurrence of serial pins with rectangular conduit when contrasted with curved pins with rectangular channel.

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