

Thermal and Fluid Systems: Analysis, Design, and Optimization

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Abstract--- Heat transfer is an important and inevitable process that pertains to every activity of our day-to-day life including household heating and cooling equipment, electric power generation, thermal management of electronic equipment and many more. Compound heat transfer augmentation is of particular interest currently that involves several techniques being employed simultaneously, to get an augmentation that is superior to the individual techniques working separately. The heat transfer rate could be improved if the stagnant fluid layer within the laminar sub-layer is set into motion. Transverse vortices or primary recirculation region induced by sudden expansion and longitudinal vortices, or secondary flow imparted by winglet vortex generators are the key factors employed here in this current investigation to demolish the laminar sub-layer. Rectangular winglet vortex generator has been considered along with sudden expansion channel and water being working fluid, as its ability to augment heat transfer rate is substantially large when compared to other winglet vortex generators like trapezoidal and delta winglet vortex generators.

Keywords--- AAG, Bi-LSTM, Convolution Encoder, Machine Learning, Extraction, Selection, Scoring.

Received: 04 - 01 - 2024; Revised: 21 - 01 - 2024; Accepted: 05 - 02 - 2024; Published: 29 - 03 - 2024

I. Introduction

By the late 17th century, people had imagined that something flowed between hot and cold objects. It was known as caloric fluid and perceived to be an invisible one. Because it was a time when the evolution of electricity that was also assumed to be invisible fluid, was all the rage. However, the definition of heat as caloric fluid was inconsistent with the characteristic that it had weight and could not be created. Though heat was not defined properly it was all-pervasive (Assad & Rosen, 2021). Heat is transferred from every living organism to the surrounding air. This is so evident from the fact that room air becomes warm when people are there. This phenomenon emphasis that heat should have been transferred from bloodstream to body and from body to ambient air (Dincer et al., 2017). These discussions accelerated the process of defining the heat more clearly. One of the important characteristics of caloric which was very useful to define heat transfer in future, was that it flowed from hot body to cold body (Dbouk, 2017). So, no heat flow would take place if a body were isolated or completely at isothermal condition having no heat interaction is technically known to be at dead state. So, the overall driving potential for all heat flow processes in this globe is reaching dead state or levelling the imbalance (Akinlabi & Solyali, 2020). All the activities on this earth right from birth to death have necessarily progressed to meet out these energy flow. In summer, ordinary people are naturally in balance with the ambience. However, engineers try to make it levelled by developing air-conditioning system. So, our voracious appetite in manipulating the energy flow or heat flow on this earth needs efficient means to have a sustainable future (Kundu et al., 2023). In the end, heat is described as a type of energy in transit due to the caution of temperature differentiation. The intensity moves rate increases with the size of the temperature difference. In particular, there are three types of heat movement: intensity conduction, heat convection, and intensity radiation (Merchán et al., 2020).

II. Literature Review

Forced convection mode of heat transfer seeks its role in every engineering device and machinery. Many heats transfer equipment has been employed for conversion and recovery of heat in most of the domestic and industrial applications. Energy conservation is one of the primary factors to be considered in the current scenario and near future. By channelizing the heat flow properly through heat transfer enhancement

techniques, energy conversion, conservation and recovery could be accomplished in heat transfer devices. Increasing the overall thermal conductivity and inducing the turbulence in the fluid are the main factors to improve the performance of all the heat transfer equipment. The aim of doing all these is to reduce the thermal resistance for the heat flow (Lee et al., 2019). Heat transfer enhancement does not only improve the performance of the thermal equipment and also saves the material and cost involved. Heat move improvement might be characterized comprehensively into dynamic, latent and mix of both the strategies as per Bergles (1998) and Bergles (2001). Dynamic strategies in all actuality do require an outside drive to actuate the stream or to diminish generally speaking warm obstruction. However, inactive techniques needn't bother with any outside drive or energy to upgrade the intensity move rate (Wang et al., 2023). All things being equal, aloof strategies utilize auxiliary intensity move surfaces like plain, louvered, cut, wavy, annular, longitudinal, and serrated blades or even liquid added substances to increment compelling warm conductivity of liquid is talked about. It also includes porous media, surface coating, phase change devices, and vortex generators. Passive methods not only improve the heat transfer rate all the time, but it may also accompany some pressure drop in the fluid flow. To evaluate the effectiveness of passive methods an overall performance factor has been defined. It is the ratio of relative heat transfer enhancement to relative change in friction factor.

III. Increasing the Overall Thermal Conductivity

- **Porous Media Heat Transfer**

Porous media resembles a sieve or a mesh in shape. Porous media may be defined as a solid matrix with pores or voids or holes which are interconnected throughout. Limestone, soil, sand, and wood are some of the examples available for natural porous materials. Fluid can flow through the voids created by solid matrix all the way from one part to another part. Porous material is a special type of extended surface that provides a larger heat transfer area between fluids which are flowing through these voids. Liquids are generally having a very low thermal conductivity. Selecting a base metal with a high warm conductivity for the robust network could result in a heat move upgrade. Since the framework's successful warm conductivity will be built by the strong network's high warm conductivity and the extended contact region between the strong and fluid stages, its intensity move rate will follow. Porosity and penetrability are characteristics of permeable materials.

- **Surface Coating**

Surface coating method of heat transfer enhancement is especially used in boiling and condensation applications. Surface structure of the heating surface is modified using a porous coating or smooth coating to increase the effective surface area for heat transfer or thermal conductivity of the system. Chemical vapour deposition, so-gel and thermal spray coating are some of the surface coating techniques. Graphene, carbon nanotubes, micro/nanoparticles of copper, silver and gold are preferred for surface coating. Other than heat transfer enhancement, some non-metallic coating of Teflon and hydrophilic materials are used to promote drop wise condensation and condensate drainage on evaporator surface, respectively.

- **Nano Fluid**

Due to the poor thermal conductivity of liquid, the heat transfer rate associated with those liquid in all heat transfer equipment is very low. A classic way of enhancing the thermal conductivity of liquid is mixing small sized solid particles of metals and non-metals, and polymeric particles having high thermal conductivity. These suspended solid particle increases surface area and fluid heat capacity, effective fluid thermal conductivity and turbulence of the fluid. However, the problem involved in dispersing solid particles in fluid is agglomeration due to very strong Van-der-Waal's force between those particles. Nanoparticles should be evenly distributed, and this distribution should be stable for a very long time. So that this nanofluid could be employed in heat transfer enhancement. Even and stable suspension of nanoparticles in base fluid is really a matter of concern and could be obtained by one of the following methods: by changing the pH value of the particle, using surface activators, and imparting ultrasonic vibrations to the nanofluid. Surface activators and dispersants are used to impart charges to the particle. So that they repel each other and stay dispersed and suspended in the base fluid. Thiols, oleic acid, and laurate salts are normally used dispersants. Water, oil, acetone, and glycol are the conventional heat transfer base fluid for preparing nanofluid. The common nanoparticles used for preparing nanofluid are grouped into carbon nanoparticles (multi-walled carbon nanoparticle, single-walled carbon nanoparticle, graphite, diamond, graphene, and fullerene), metal nanoparticles (silver, aluminium, gold, copper, and iron) and metal oxides of aluminium, copper, iron, titanium, and zinc.

3.1. Design Framework

ICEM-CFD module of the ANSYS 16.2 is preferred over other modeling and drafting software to have a compatibility between modeling and meshing platforms and to avoid loss of data upon transferring the file. Because it does not require any export and import processes between modeling and meshing platforms. The mesh generation process of computational domain was executed in ICEM-CFD. To accommodate the flow physics precisely in the solution of governing equation, fine grids using hexahedral volume elements were created near the corners and the walls of the sudden expansion channel. Once the meshing process is over, the computational domain is exported to the solver called FLUENT 16.2. Pressure and velocity terms in governing equations were coupled through SIMPLE algorithm using mass conservation equation. In order to arrive at an asymptotic arrangement, the second request upwind design was modified to discretise the energy and force circumstances (Von Spakovsky & Evans, 1990). The solver then handles the limit states of the mathematical problem. Recreations were conducted until the mathematical technique's scaled residuals were less than 10^{-5} for the energy condition and under OK for the progression and energy conditions. An insignificant portion of the overall energy and mass transition via the computational space is considered to be the unevenness of the mobility of energy and mass throughout the computational area (Balaji & Balaji 2021).

It is now insufficient to support a practical or functional framework that carries out the ideal project while staying within the constraints imposed by material, financial, ecological, security, and other considerations. Improving the cycle to increase or limit a chosen variable or rule has become essential due to the growing overall competition and the necessity to increase production. The Architecture of the Proposed Framework shown in Figure 1.

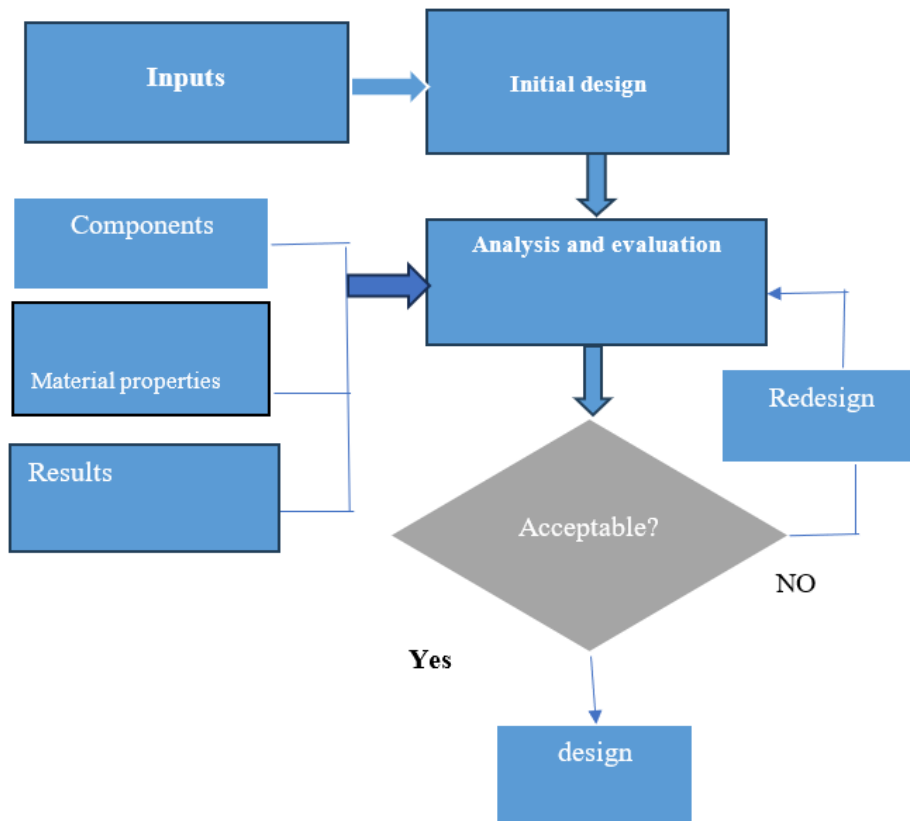


Figure 1: The Architecture of the Proposed Framework

This variable, which is commonly referred to as the objective capability, may be associated with quantities such as benefit, cost, item quality, and outcome. Especially in the consumer sector, the days when a company could corner a few things are long gone. Many value reaches and execution details are available from different manufacturers for anything, such as a small sound system, a computerised camera, or a clothes drier. A specific item's durability is typically a component of its cost per unit presentation. However, following transactions are also influenced by commercial and technological advancements as well as various elements such as durability,

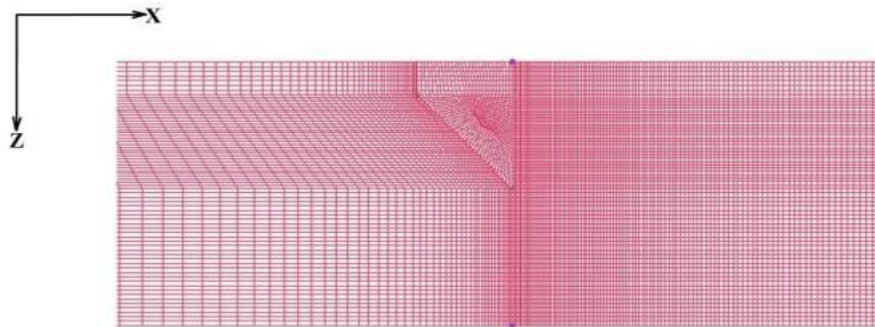
management, and repair. Improving the assembly method to obtain the best quality per unit cost is essential to the product's longevity and performance. Most of the time, a framework is improved based on its cost or benefit, but depending on the application, many other factors, such as weight, size, efficacy, dependability, and result, may also be simplified. For instance, a refrigerator may be designed to expel air at a specific rate, and an interior regulator control may be used to adjust the cooler's temperature. Anyway, a variety of cooler frameworks, such as fume pressure and fume assimilation frameworks, are possible.

Heat Pipe

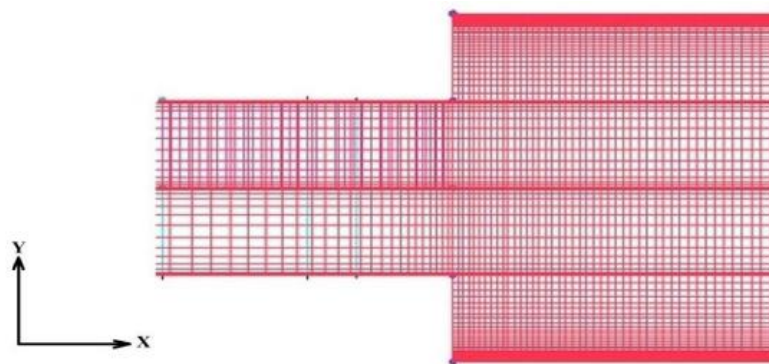
Heat pipe is a passive heat transfer enhancement device with unfathomable effective thermal conductivity of 10 to 10,000 times larger than that of copper. It is very effective in heat transfer enhancement, as it is working at vacuum pressure and using latent heat to transfer heat. Lower is the vacuum pressure, larger is the heat transfer rate. Normally copper is used to construct the heat pipe. For cryogenic applications, helium and nitrogen gases are used in heat pipes. Metals like sodium and potassium in liquid form are used in heat pipe when the heat dissipation rate must occur at higher temperature. For electronic cooling applications, ammonia, water, acetone, and methanol are normally used as the working fluid in heat pipe. To improve the thermal performance of heat pipe, design modifications in wick structure, surface treatment and use of nanofluid can be incorporated. A heat pipe has three sections namely evaporator, adiabatic section, and a condenser. It has working fluid at a low vacuum pressure corresponding the operating temperature of the applications. Working fluid observes heat at evaporator end and becomes vapour.

IV. Performance Analysis

Temperature and streamwise speed of the stream at $x/s=64$ and $z/L=0.5$ of the ongoing review at Reynolds number equivalent to 600 are in great concurrence with that of the mathematical assessment by (Balaji & Balaji 2021). The deviation in the arrangements is under 1.4% as displayed in Figure 2(a) and Figure 2(b) separately. Two-layered y-z plane along x and x-y plane along z bearings and lines along z course as depicted in Figure 2 have been taken ready for deciphering the mathematical outcomes.



(a)



(b)

Figure 2: Mesh Details

Planes and lines are created in the FLUENT 16.2 for postprocessing purpose once the simulation is over. Flow and heat transfer properties are evaluated on those planes and lines based on the context of the flow physics. Temperature Comparison and Velocity Comparison shown in Figure 3 and Figure 4.

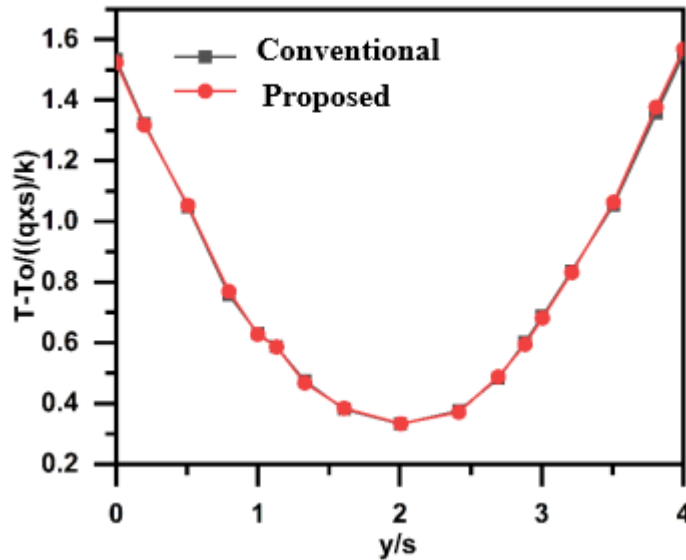


Figure 3: Temperature Comparison

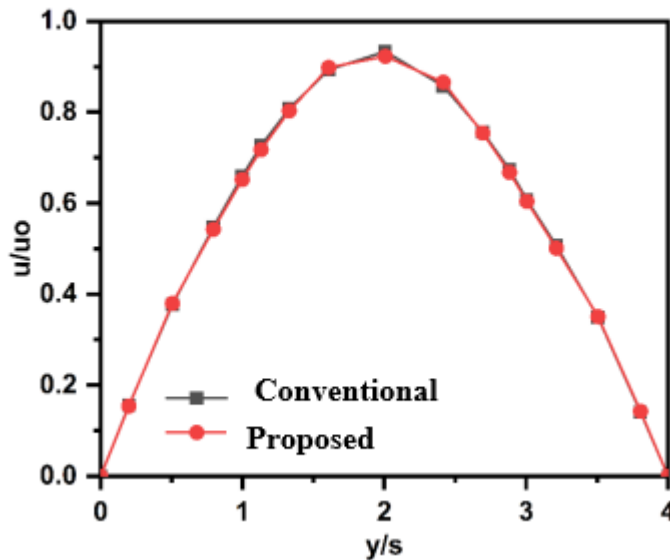


Figure 4: Velocity Comparison

For plotting the velocity streamlines, temperature, and velocity contours of fluid flow at various locations in the computational domain for interpreting results, the simulation file is exported to CFD-Post 16.2. Planes and lines are created in CFD-Post 16.2 within the computational domain to get the required flow property contour. Temperature and streamwise speed of the stream at $x/s=64$ and $z/L=0.5$ of the ongoing review at Reynolds number equivalent to 600 are in great concurrence with that of the mathematical assessment by (Balaji & Balaji 2021). The deviation in the arrangements is under 1.4% as displayed in Figure 2(a) and Figure 2(b) separately. Two-layered $y-z$ plane along x and $x-y$ plane along z bearings and lines along z course as depicted in Figure 2 have been taken ready for deciphering the mathematical outcomes.

V. Conclusion

This vapour gets transported to the condenser end where heat is removed from the vapour. Vapour gets condensed upon losing heat in the condenser to the atmosphere. The condensate is moved to evaporator through wick structure due to capillary action where once again it becomes vapour. Using nanofluid in the pipe is one of most prominent way of enhancing heat transfer. The elevation of heat transfer rate in recirculation zone has been the primary motivation for the continuous research in sudden expansion by research community for decades. The local heat transfer augmentation in separated and reattached flow region was found to be nine times greater than that of the fully developed flow in the pipe of the same diameter. A volume of research has been carried out to investigate heat transfer enhancement for various values of Reynolds number, aspect ratio, expansion ratio. Even, water and air have been replaced by nanofluid to enhance heat transfer rate along with transverse vortex in sudden expansion duct.

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