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Review Article

IMPORTANCE OF BAFFLES IN FLUID FLOW AND HEAT TRANSFER- A COMPREHENSIVE REPORT

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ABSTRACT

This paper presents an exclusive review in the field of heat transfer and fluid flow where baffles has been implemented in order to enhance the thermo-hydraulic performance Some of the major factors affecting are well illustrated and discussed. Baffles are the major components which are especially been used for enhancing heat and mass transfer in various thermal application.

Mainly, the fully developed flow over a baffled channel, in either laminar or turbulent regime, is much further complex than that over a smooth surface or channel because of the additional parameters to be utilized and the correlated and turbulence flow phenomena to be deduced. Several researches perform numerical-computation simulations and experimentation in order to investigate the thermo-hydraulic characteristics for different baffled configuration is stated in this paper

INDEX TERMS— Baffles, Heat transfer, Turbulence, CFD

INTRODUCTION

Baffles are obstructing or flow-directing panel or vanes employed in some industrial process pipes, ducts and vessels (tanks), such as tube and shell heat exchangers, static mixers and chemical reactors. Baffles are an essential part of the shell and tube heat exchanger design. Baffles are designed to support tube bundles and direct the flow of fluids in order to maximize the thermal efficiency.

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Heat transfer technology has its significant relevance in various fields ranging from the functioning of refrigeration systems to nuclear reactors and everything in between [1]. Some of the other field where heat transfer must be regulated include fuel cells, heat engines, gas turbines, heat pumps, electronic packaging systems and food processing [2–5]. Conduction, Convection and Radiation are three basic modes of heat transfer. Conduction is practically involved in all operations in which heat interaction taking place. Transfer of heat through conduction take place through a solid surface that separates fluids having singular temperatures [6]. For transmitting heat by the process of conduction, baffles are the most common equipment used pipes, channels and ducts in process industries.

MATHEMATICAL MODELLING

For the fluid flow through pipe, duct and channel the conventional governing equations are the **Navier–Stokes equations** can be written in the most useful form for the development of the finite volume method:

$$\rho\frac{Du}{Dt} = -\frac{\partial p}{\partial x} + div(\mu\, grad u) + S_{Mx} \qquad (1)$$

$$\rho\frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + div(\mu\, grad v) + S_{My} \qquad (2)$$

$$\rho\frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + div(\mu\, grad w) + S_{Mz} \qquad (3)$$

Governing equations of the flow of a compressible Newtonian fluid

Continuity

$$\frac{\partial \rho}{\partial x} + div(\rho u) = 0$$

x-momentum $$\frac{\partial(\rho u)}{\partial x} + div(\rho u u) = -\frac{\partial p}{\partial x} + div(\mu\, grad u) + S_{Mx} \qquad (4)$$

y-momentum

$$\frac{\partial(\rho v)}{\partial y} + div(\rho v u) = -\frac{\partial p}{\partial y} + div(\mu\, grad v) + S_{My} \qquad (5)$$

z-momentum

$$\frac{\partial(\rho w)}{\partial z} + div(\rho w u) = -\frac{\partial p}{\partial z} + div(\mu\, grad w) + S_{Mz} \qquad (6)$$

Energy

$$\frac{\partial(\rho i)}{\partial t} + div(\rho i u) = -p\, div u + div(k\, grad T) + \Phi + S_i \qquad (7)$$

Using various correlation FEV results are been compared analytically

$$h_f = f\frac{LV^2}{D_h 2g}$$

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Where,

f is the friction factor for fully developed laminar flow

L: length of the pipe

V: mean velocity of the flow

d: diameter of the pipe

f is the friction factor for fully developed laminar flow:

$f = \frac{64}{Re}$ (For Re<2000) $Re = \frac{\rho u_{avg} d}{\mu}$

C_f is the skin friction coefficient or Fanning's friction factor.

For Hagen-Poiseuille flow: $C_f = \tau_{wall} l \frac{1}{2} \rho u_{avg}^2 = \frac{16}{Re}$

For turbulent flow: $\frac{1}{\sqrt{f}} = 1.74 - 2.0 \log_{10} \left[\frac{\varepsilon_p}{R} + \frac{18.7}{Re\sqrt{f}} \right]$ Moody's Chart

R: radius of the pipe

ε_p: degree of roughness (for smooth pipe, $\varepsilon_{p=0}$)

$Re \to \infty$: Completely rough pipe.

LITERATURE REVIEW

Usman et al. [7] Presents review report on the helical baffles in order to improve the performance of shell and tube heat exchangers. Factors affecting thermal performance of tube and shell heat exchanger are illustrated. . A comparison between helical and segmental baffles was also presented to show that helical baffles are more advantageous than segmental baffles. In most cases, sextant helical baffles, discontinuous, folded, 40° baffle inclination angle as well as low baffle spacing will offers the best results when integrated in some combination, while continuous helical baffles reduce dead regions. Additionally, sealing strips are more likely to improve the performance of shell and tube heat exchangers with continuous helical baffles.

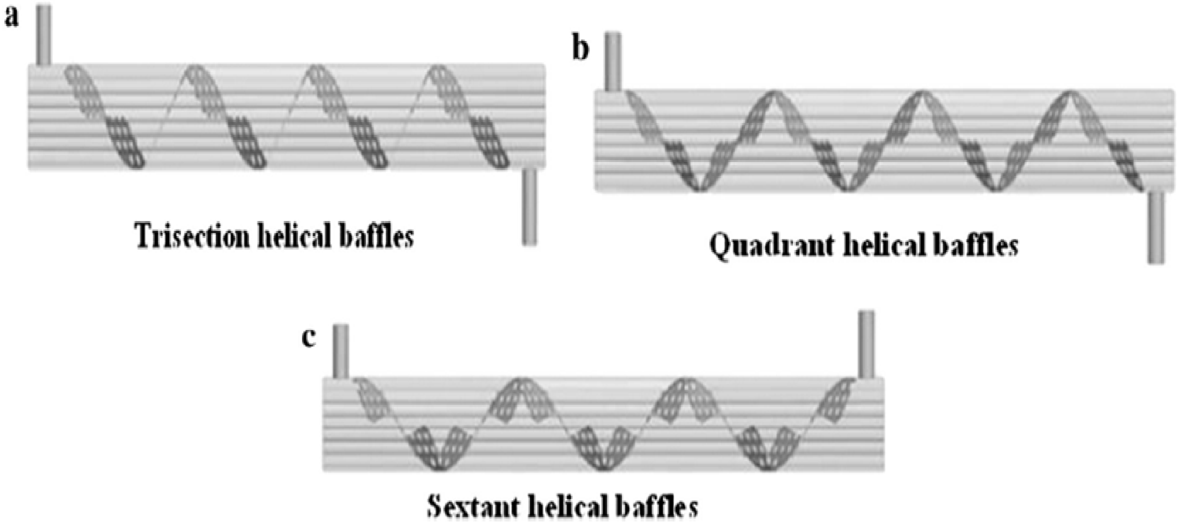

Fig. 1. Different shapes of helical baffles [7]

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Gaddis and Gnielinski [8] presented a novel procedure for calculating the shell side pressure drop in shell-and-tube heat exchangers with segmental baffles. The method was based on correlations for calculating the pressure drop in an ideal tube bank coupled with correction factors, which take into consideration where the influence of bypass streams and leakages, and on equations for calculating the pressure drop in a window section from the Delaware method. The proposed equations were validated by comparing experimental data available in the literature with the theoretical calculations. The obtained result has been compared with experimentation and are within acceptable range i.e. ± 35%.

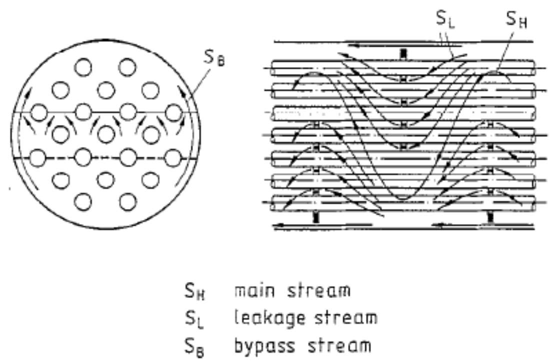

Figure 2 Flow through the shell of a shell and tube heat exchanger with segmental baffles.[8]

Howes et al. [9] numercially investigates the flow of an incompressible Newtonian fluid within a two-dimensional channel with periodic baffles. For *uneven* flows in this geometry a regime of chaotic advection was observed when baffles are used. The unsteadiness obtains one of two forms: a "natural" unsteadiness caused by a symmetry breaking instability of the flow, or a "forced" unsteadiness caused by concerning an oscillatory component to the flow. This chaotic advection is illustrated to provide an proficient mixing mechanism and has a several applications in the process industry. Enhanced transverse mixing was examined which results in enhanced transfer properties, reduced fouling rates and, in some circumstances, a reduction in axial dispersion, as recently experimentally reported in the available literature.

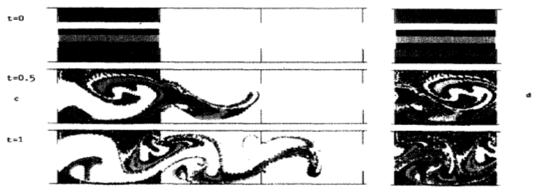

Fig. 3 Results for a baffled channel with no oscillatory component in the flow at Re, = 300. [9]

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Sun and Emery [10] examine the Conjugate natural convection heat transfer in a two-dimensional, air-filled enclosure containing discrete internal heat sources with internal baffle. The governing equation is solved by using Finite volume approach for wide range of Rayleigh numbers, and for other parameters such as internal-extemal heat source ratios, solid-fluid conductivity ratios and baffle heights has also been examined in terms of heat transfer and the flow characteristics resulting from the internal heat sources as well as the conductive baffles. To support the obtained result comparison has made between numerical calculations and experimental data of temperature distributions in the window calorimeter.

Riccardo et. al [11] presented modeling of break-up in an inhomogeneous flow which develops in concentric restriction in a pipe. Euler-Lagrange is used for simulations of the drop motion of interface deformation model. Turbulent flow downstream is solved by direct numerical simulation firstly then single drop trajectories are calculated. Simultaneously, the interface deformation is computed by Rayleigh–Lamb type oscillator forced. The flow conditions and fluid properties is taken to match with the experimental studies. Turbulent flow statistics and break-up probability calculations are in decent covenant with experimental data.

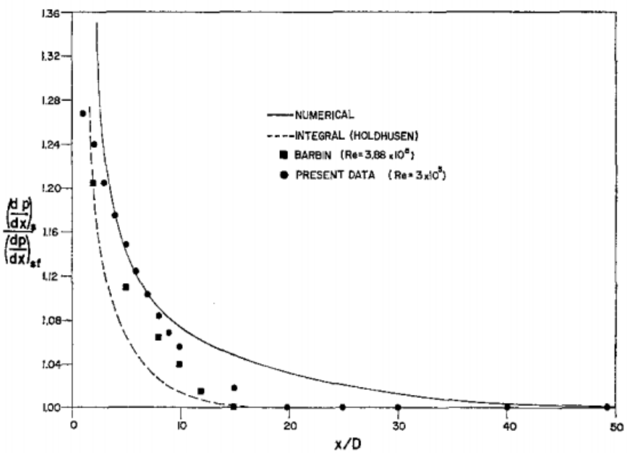

Fig. 4 Pressure gradient ratios in developing flow, Re = 3 × 10^5 [11]

Kang and yang [12] investigates the flow instability in presence of baffles in channel. The simple geometry of baffles is adopted from heat exchanger for analyses. In investigation parametric analyses has been done to verify the effect of baffles aspect ratio, however the effect of baffle interval and variable Reynolds number has also carried out. The main aim for stability analysis in order to study the secondary instability through which time-periodic two-dimensional flow bifurcates into three-dimensional flow The obtained results are compared with computational result and showing good agreement.

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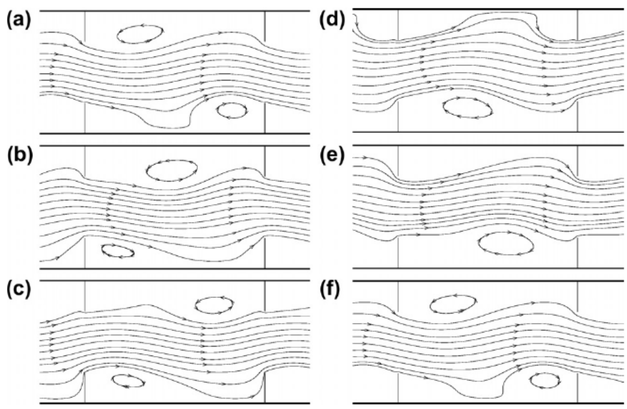
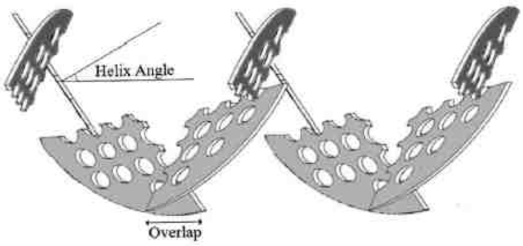
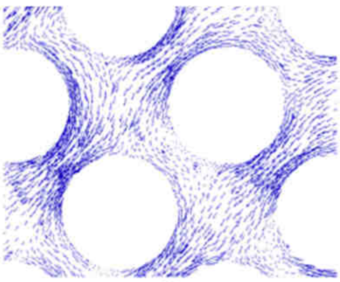


Figure 4 Streamlines of the unsteady flow during one period for RB = 1.456 and Re = 130; (a) t = 0T, (b) t = 1/5T, (c) t = 2/5T, (d) t = 3/5T, (e) t = 4/5T and (f) t = 5/5T. [12]

Mehdi et al.[13] present s a novel application for energy efficiency improvement using nanofluid in shell and tube heat exchanger equipped with helical baffles using two-phase mixture model. It has been observed that increasing nanoparticle concentration and baffle overlapping, and decreasing helix angle the Heat transfer rate and pressure drop increases. for the convective heat transfer coefficient and the pressure drop smaller helix angles and change the overlapping is more efficient . The obtained result for convective heat transfer coefficient and the pressure drop is done by using Neural network and optimization has also been carried out and found that single-objective optimization specifies that when a low pressure drop is significantly important for designer, nanofluids with high concentrations can be used. For the meantime, when both high heat transfer and low pressure drop are significant, a small helix angle can be employed.





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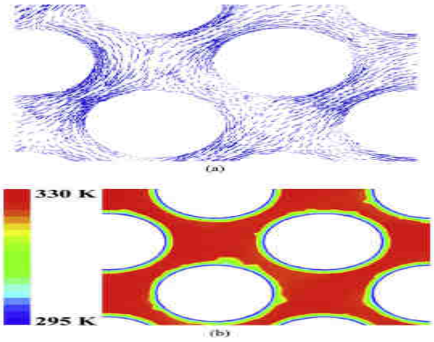

Fig. 5. Schematic view of helical baffles. a) Velocity vectors of the flow, b) Temperature contour; in a part of the transverse cross section of the Shell tube heat exchanger [13]

Bin et al [14] conducts experimental investigation to examine the effects of baffle helix angle on shell-side performance of shell-and-tube heat exchangers with discontinuous helical baffles with wide range of helix angles. Apart from this second-law based thermodynamic analysis was also analyzed for the effects of baffle helix angle on the irreversible loss of heat exchangers. The results shows that the shell-side pressure drop and heat transfer coefficient of the heat exchanger with smaller helix angle are higher than those with larger helix angle at a given shell-side volume flow rate.

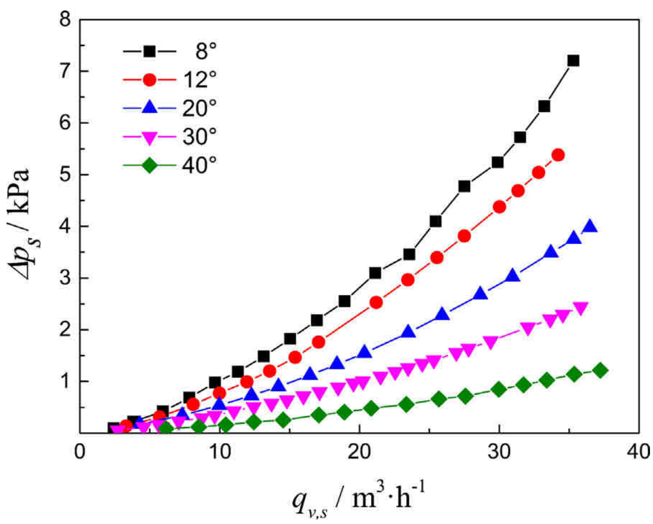

Fig. 6. Pressure drop in shell-side tube bundle zone versus volume flow rate. [14]

Sayem et al. [15] investigates the Effects of baffles on flow distribution in an electrostatic precipitator (ESP) of a coal based power plant. It has been observed that Baffles increases the residence time of flue gas which assists to collect more particles into the collector plates, and hence enhance the collection efficiency of an ESP. moreover, parametric analysis has also been carried out in terms of effects of position, shape and thickness of the baffles on collection efficiency and the flow distribution was visualized using CFD tool ANSYS Fluent.

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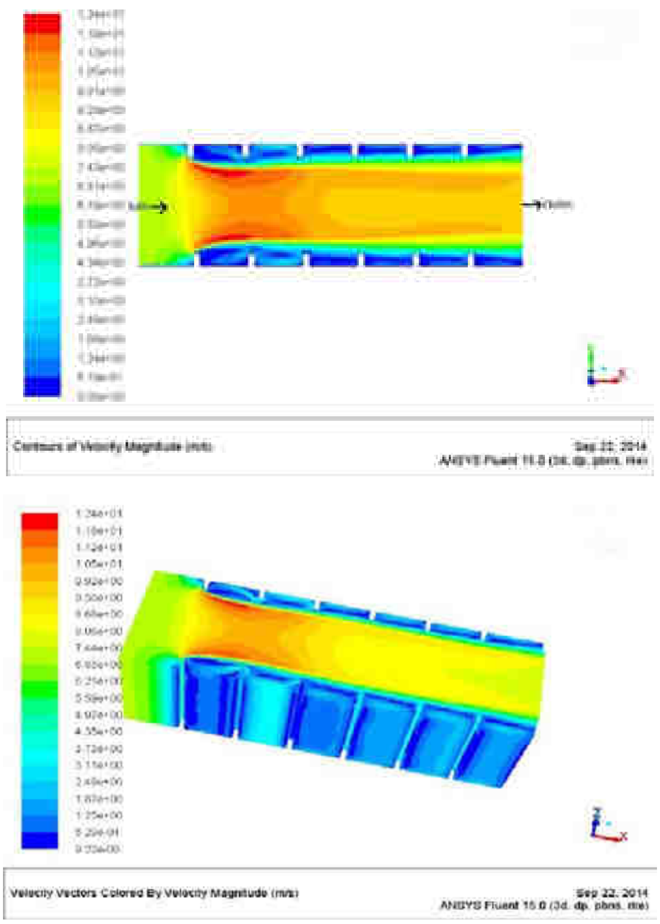

Fig. 7. Contour of velocity magnitude at section x= 150, y= 55 and z= 25 [15]

CONCLUSION

- Implementing Baffles the rate of heat transfer can be increased.
- The turbulence intensity of baffle equipped channel or duct increases as Reynolds number increases.
- Increasing baffles height the heat transfer significantly increases.
- Increasing baffle space, pressure gradient decreases remarkably.
- Increasing the baffle space at the same mass flow rate reduces heat transfer coefficient, while increasing the baffle spacing at the same pressure drop increases heat transfer coefficient.
- helical baffles are more advantageous than segmental baffles.
- Higher pressure drop enhances the heat transfer rate but it leads to an increase in the power consumption.
- Heat transfer and pressure drop increase by increasing nanoparticle concentration and baffle overlapping, and decreasing helix angle.

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