A comprehensive review on Heat and fluid flow in Baffled Pipe/Channel

Maunshri Sahu[1], **Dilbag Singh Mondloe**[2], **Satish Upadhyay**[3]

[1]*M.Tech Researcher, Dept. of Mechanical Engineering, GEC Jagdalpur, Chhattisgarh, India*
[2]*Assistant professor, Dept. of Mechanical Engineering, GEC Jagdalpur, Chhattisgarh, India*
[3]*Lecturer, Dept. of Mechanical Engineering, GEC Jagdalpur, Chhattisgarh, India*

***

Abstract - *Baffles are the significant structural component, which is extensively been used in various industrial as well as energy conversion application for instance solar air heater, solar collector, heat exchanger (shell and tube), nuclear reactor, catalytic convertor, etc. In most of application the flow is turbulent, particularly in heat and mass transfer application, baffles plays a important role in enhancing mixing and heat transfer characteristics. Moreover, in case of laminar flow baffles helps in generation of turbulence in flow. Various researches have been carried out experimentally, computationally and numerically to examined the thermo as well as hydrodynamic characteristics which has been stated in this article.*

***Key Words*: Baffles, Heat transfer, Turbulence, CFD**

1.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.

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.

1.2. 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:

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

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

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

Governing equations of the flow of a compressible Newtonian fluid

Continuity

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

x-momentum

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

y-momentum

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

z-momentum

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

Energy

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

Using various correlation FEV results are been compared analytically

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

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:

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

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

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

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

Moody's Chart

R: radius of the pipe

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

$\text{Re} \to \infty$: Completely rough pipe.

2. LITERATURE REVIEW

Rafal et al. 2017 examined a thermodynamic performance of mixed convection heat transfer in the shell and coil tube heat exchanger with baffles. The influence of baffles configuration has been examined. The effect of water mass flow and heat flux on the heat transfer coefficient has been examined and experimentally developed a correlation for the same.

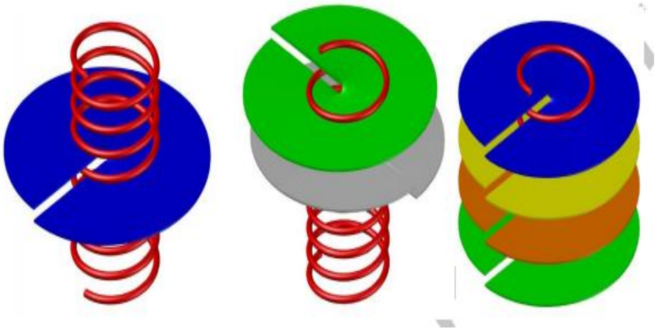


Fig -1 Baffle Configuration [1]

Wang et al. 2017 use multi-objective genetic algorithm in order to optimize the configuration of shell-and-tube heat exchangers with helical baffles. The used algorithm is based on fluid-structure interaction.

The result reveals that the heat transfer coefficient per unit pressure drop of shell-and-tube heat exchangers with helical baffles increases firstly and then decreases with the increase of helical angle, and decreases with the increase of overlapped degree under certain shell-inlet velocity.

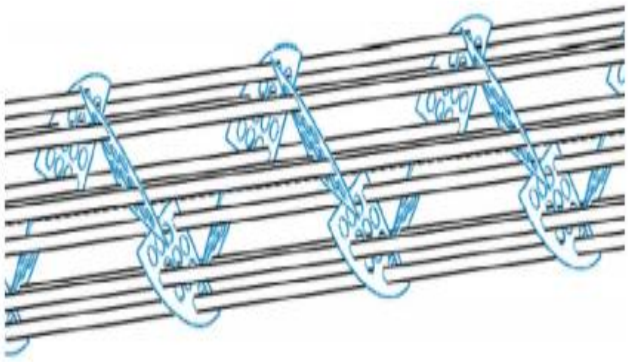
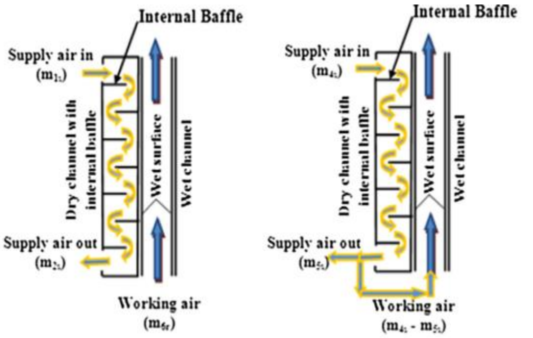


Fig -2 Tube bundle of shell-and-tube heat exchangers with helical baffles. [2]

Kabeel et al. 2017 applied indirect evaporative cooling system with internal baffles as a pre-cooling unit to improve the performance of hybrid air conditioning system. the results shows that on reducing supply air temperature by 21%, 71% improvement in coefficient of performance has been seen. They also recommended the optimal air working ratio in the indirect evaporative cooler with internal baffle should be 0.15.



(a) Indirect evaporative cooler with internal baffles, is employed to pre- cool the outdoor air before entering the desiccant wheel

(b) Indirect evaporative cooler with internal baffles, is employed to pre- cool the supply air before entering the room

Fig -3 Schematic of the hybrid air conditioner with two indirect evaporative coolers with internal baffles [3]

Bachmann et al. 2017 experimentally investigates and developed a correlation of the Bondenstein number in horizontal fluidized beds through baffles. In their work two configuration of baffles i.e. over and under flow are considered. The developed correlation has been validated with the experimental work of literature data.

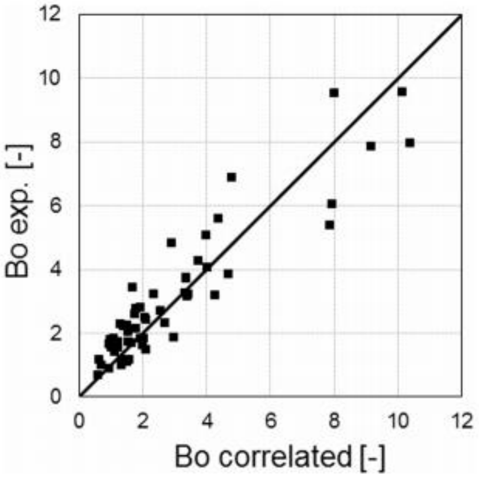


Fig -4 The experimental Bodenstein number versus the correlated Bo for underflow configuration [4]

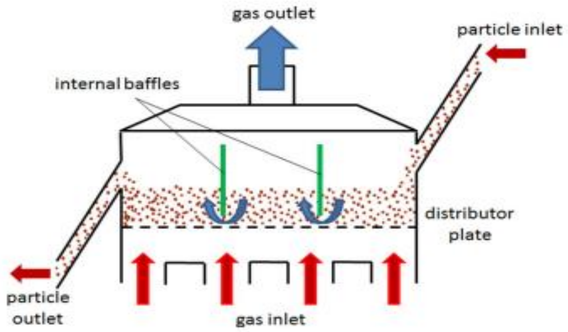


Fig -5 Sketch of a common horizontal fluidized bed. The green lines represent the internal vertical baffles

Anas et al. 2017 used annulus with continuous helical baffles in a double-pipe heat exchanger to enhance the the thermal performance. Using CFD the pressure drop and heat transfer characteristics has been studied and the performance of heat exchanger has been compared in both turbulent and laminar flow regimes.

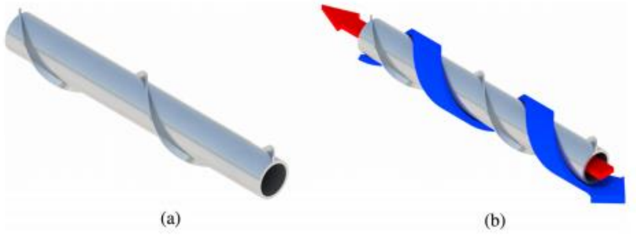


Fig -6 (a) Double pipe heat exchangers with helically baffled annulus side. (b) Flow pattern.[5]

Xue et al. 2017 experimentally examined the influence of vertical baffles o f different configurations in suppressing sloshing pressure. On changing the frequency of vertical baffles the suppressing sloshing pressure was studied. The dynamic impact pressure on tank wall and vertical baffle were measured simultaneously and the found that the maximum dynamic pressure response to frequencies for tank is different with different vertical baffles.

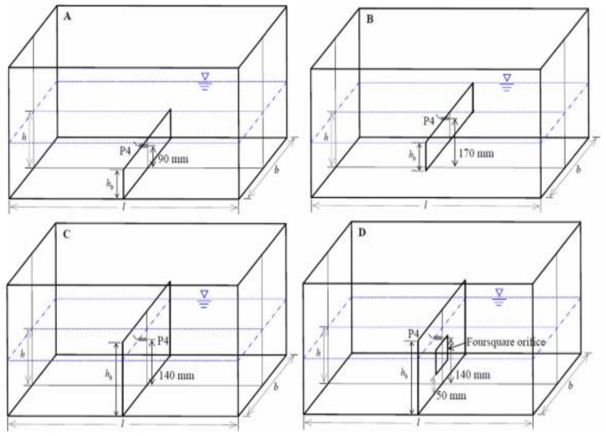


Fig -7 Various of vertical baffle configurations in rectangular tanks.[6]

Wen et al. 2017 examined the flow patterns of shell-side flow field in heat exchanger with helical baffle are investigated by particle image velocimetry. According to field synergy principle a series of velocity vector graphs is analyzed and found that the shell-side flow field of heat exchangers has a periodic behavior and conclude that the performance of heat exchanger can be improved by using improved fold baffles.

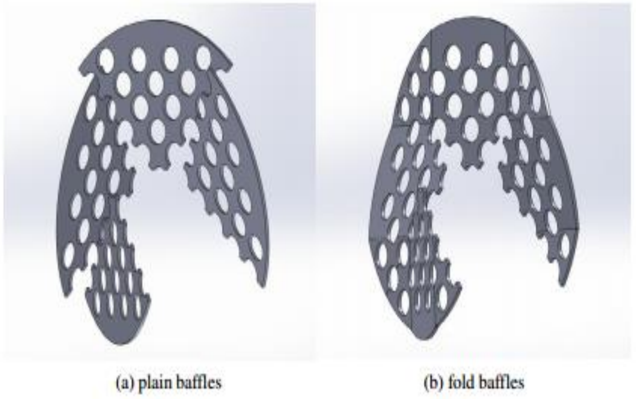
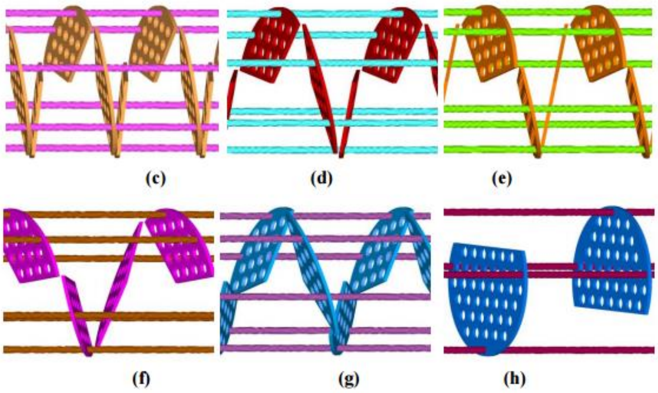

(a) plain baffles (b) fold baffles

Fig -8 Configuration of different baffles [7]

Dong et al. 2017 studied the mechanisms of resistance characteristic and thermal performance of trisection helical baffles heat exchangers with diverse inclination angles and baffle structures. The effect of different inclination angles, baffle shapes and connection patterns are examined. They conclude that the sector baffle is better than ellipse baffle and axial overlap is not a good structure and the performances of helical baffle heat exchangers are higher than segmental one.



.

Fig -9 Calculation model of circumferential overlap trisection helical baffle heat exchanger: (a) common shell, and (b) tube bundle core for 20°S scheme, (c) 10°S scheme, (d) 15°S scheme, (e) 15°E scheme, (f) 20°S scheme, (g) 20°D scheme, (h) SEG scheme. [8]

Cho et al. 2016 analyzed the effect of dual vertical porous baffles on sloshing reduction in a swaying rectangular tank analytically. To validate the analytical solution a series of experiments were conducted in the 2D rectangular tank with dual vertical porous baffles. The effects of the porosity and the position/submergence depth of baffles on sloshing motions were systematically investigated and the prediction tool will be used to find the optimal design of baffles through an extensive parametric study.

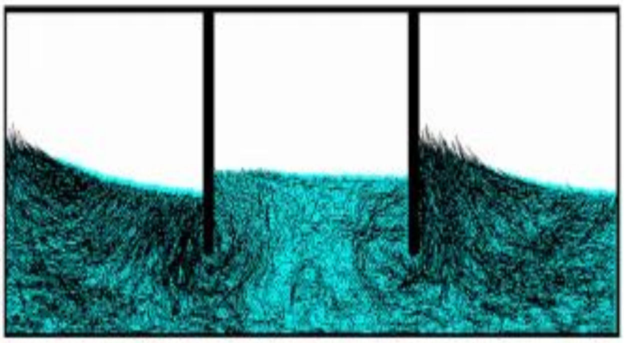


Fig -10 Velocity vector snapshot for the case of Fig. 7 at 0.47 s by MPS method.[9]

Yang et al. 2016 experimentally examined the performance of combined multiple shell-pass shell-and-tube heat exchanger with continuous helical baffles. On comparing performance it has been found that CSTSP-STHX has better performance than that of SG-STHX and concludes that with proper design annulus separator can obviously reduce leakage.

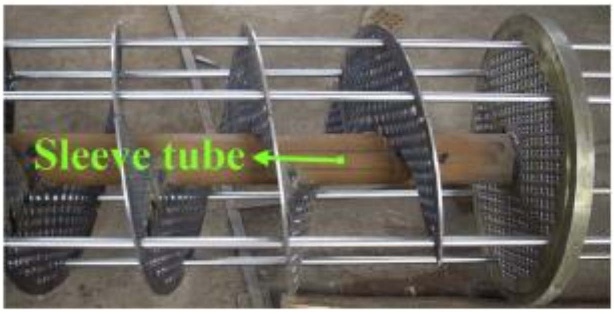


Fig -11 Central sleeve tube of a continuous helical baffled STHX [10]

3. CONCLUSIONS

- 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.

REFERENCES

[1] Rafal Andrzejczyk, Tomasz Muszynski, Thermodynamic and geometrical characteristics of mixed convection heat transfer in the shell and coil tube heat exchanger with baffles , Applied Thermal Engineering, Volume 121, 5 July 2017, Pages 115-125

[2] Simin Wang, Juan Xiao, Jiarui Wang, Guanping Jian, Jian Wen, Zaoxiao Zhang, Configuration optimization of shell-and-tube heat exchangers with helical baffles using multi-objective genetic algorithm based on fluid-structure interaction , International Communications in Heat and Mass Transfer, Volume 85, July 2017, Pages 62-69

[3] A.E. Kabeel, Mohamed Abdelgaied, Ravishankar Sathyamurthy, T. Arunkumar, Performance improvement of a hybrid air conditioning system using the indirect evaporative cooler with internal baffles as a pre-cooling unit, Alexandria Engineering Journal, In Press, Corrected Proof, Available online 26 April 2017

[4] P. Bachmann, A. Bück, E. Tsotsas, Experimental investigation and correlation of the Bodenstein number in horizontal fluidized beds with internal baffles, Powder Technology, Volume 308, 15 February 2017, Pages 378-387

[5] Anas El Maakoul, Azzeddine Laknizi, Said Saadeddine, Abdellatif Ben Abdellah, Mohamed Meziane, Mustapha El Metoui, Numerical design and investigation of heat transfer enhancement and performance for an annulus with continuous helical baffles in a double-pipe heat exchanger, Energy Conversion and Management, Volume 133, 1 February 2017, Pages 76-86

[6] Mi-An Xue, Jinhai Zheng, Pengzhi Lin, Xiaoli Yuan, Experimental study on vertical baffles of different configurations in suppressing sloshing pressure, Ocean Engineering, Volume 136, 15 May 2017, Pages 178-189

[7] Jian Wen, Huizhu Yang, Simin Wang, Xin Gu, PIV experimental investigation on shell-side flow patterns of shell and tube heat exchanger with different helical baffles, International Journal of Heat and Mass Transfer, Volume 104, January 2017, Pages 247-259

[8] Cong Dong, Xin-Fa Zhou, Rui Dong, You-Qu Zheng, Ya-Ping Chen, Gui-Lin Hu, You-Sheng Xu, Zhi-Guo Zhang, Wen-Wen Guo, An analysis of performance on trisection helical baffles heat exchangers with diverse inclination angles and baffle structures, Chemical Engineering Research and Design, Volume 121, May 2017, Pages 421-430

[9] I.H. Cho, M.H. Kim, Effect of dual vertical porous baffles on sloshing reduction in a swaying rectangular tank, Ocean Engineering, Volume 126, 1 November 2016, Pages 364-373

[10]Jian-Feng Yang, Yuan-Sheng Lin, Han-Bing Ke, Min Zeng, Qiu-Wang Wang, Investigation on combined multiple shell-pass shell-and-tube heat exchanger with continuous helical baffles, Energy, Volume 115, Part 3, 15 November 2016, Pages 1572-1579)F. Cheung, Limiting factors for external reactor vessel cooling, Nucl. Technol. 152 (2) (2005) 145–161