AUGMENTING HEAT TRANSFER OF SHELL AND TUBE HEAT EXCHANGER – A CFD ANALYSIS APPROACH

Jagadeesh Duraisamy [1*], Vivekanandan Mahendran [2], Kawin Nallsivam[3] , Ashok Manivasagan[4]

[1*] *Professor, Department of Mechanical Engineering, Kongunadu College of Engineering andTechnology, Trichy, Tamilnadu-621215, India.*

[2] *Adjunct Faculty,Department of Mechanical Engineering, Kongunadu College of Engineering and Technology, Trichy, Tamilnadu-621215, India.*

[3] *Assistant Professor, Department of Mechanical Engineering, Kongunadu College of Engineering and Technology, Trichy, Tamilnadu-621215, India.*

[4] *UG Scholar, Department of Mechanical Engineering, Kongunadu College of Engineering and Technology, Trichy, Tamilnadu-621215, India.*

Abstract— A shell and tube heat exchanger journal that has undergone experimental analysis is used as a guide. There are four different segmental baffle layouts employed in the referred journal. The four types of baffle layouts are flower segmental baffle (FSB), hybrid segmental baffle (HSB), staggered single segmental baffle (SSSB), and conventional single segmental baffle (CSSB). STHX using CSSB by itself was examined in this paper. Since heat transmission is the foundation for the shell and tube heat exchanger's (STHX) performance. We added twisted tape inside the tube and used helical baffles in place of the traditional baffles to improve it. In this research, four varieties of STHX have been constructed and simulated. The STHX with helical baffle, STHX with helical baffle and twisted tape, and STHX with CSSB and twisted tape are the four variants. For the chosen shell and tube heat exchanger, theoretical calculations are performed, and the outcomes are compared with the experimental journal. The STHX was created and simulated in the HTRI Xchanger suite using the theoretically derived value. The STHXs are created and put together in SolidWorks, and then the file is exported to FLO EFD for CFD analysis.Four STHX configurations' simulation results were compared, and it was found that the new configurations—STHX with helical baffle, STHX with twisted tape, and STHX with CSSB and twisted tape—had a noticeably better heat transfer enhancement. For every test situation, STHX with a helical baffle and twisted tape arrangement had a greater impact on improving heat exchanger performance than the other configurations.

Keywords: Shell and tube heat exchanger, STHX, Twisted tape, Helical Baffle, Segmental baffle, FLO EFD, HTRI.

1. INTRODUCTION

A heat exchanger is a device designed to facilitate the transfer of heat between two or multiple process fluids. Heat exchangers have widespread industrial applications. Many types of heat exchangers have been developed for use in steam power plants, chemical processing plants, building heat and air conditioning systems, transportation power systems, and refrigeration units. The shell and tube heat exchanger is widely utilized in various process industries, making it the prevailing type of heat exchanger in use. Shell and tube heat exchanger (STHX) are suitable for high pressure operating conditions. The baffles are introduced in the shell side of the STHX to provide improved flow in the shell side and prolonged resident time of the shell side fluid than that of conventional shell and tube heat exchangers.

The comparative experimental study to improve the thermal, hydraulic, and thermodynamic performance of shell and tube heat exchangers using new segmental baffle arrangements. With regard to shell side mass flow rates, they examined four distinct segmental baffle configurations ranging from 0.14 kg/s to 0.216 kg/s. The overall heat transfer coefficient is increased by changing the baffle layout. (M.M. Abou Al-Sood et al. 2019)

In this study, simulation was used to perform a reliability-based sensitivity analysis of shell and tube heat exchangers. Among the different plans, they chose four optimal heat exchanger layouts. The sensitivity analysis is used to find the suitable ranges for variation of operational circumstances. (Hassan Azarkish et al. 2019)

The experimentally investigated the mini-channel shell and tube heat exchanger's shell side heat transfer and pressure drop. They have examined relationships between shell side convective heat transfer coefficients and total pressure drop data for macro tubes. Compared to macro tube heat exchangers, the MC-STHE's experimental total pressure drop was found to be 2.3 times greater. (Hasankucuk et al. 2019)

It investigates the computational fluid dynamics (CFD) to examine and research shell and tube heat exchangers including innovative three-zone baffles with a range of baffle forms. The heat transfer rate and pressure drop showed maximum discrepancies of 7.3% and 7.6%, respectively, between CFD analyses and experimental data, according to the results.

They came at the simulation-based conclusion that the three zonal baffle outperforms other baffle configurations. They came to the conclusion that the three-zonal baffles enhanced the performance of the STHE from the perspectives of pressure loss and heat transfer rate. (TahsinEngin et al. 2020)

In this study unique configuration for Unilateral ladder-type helical baffles (STHX-ULHB) were included into a shell-and-tube heat exchanger that was introduced. examined the STHX-ULHB's heat transfer and pressure drop capabilities experimentally. The results of the experiment show that when the mass flow rate increases, the Ultra-Low Height Baffles (ULHB) shell and tube heat exchanger (STHX) exhibits a significant enhancement in both the shell-side heat transfer coefficient (h) and the overall heat transfer coefficient (K). In comparison to STHX-SB, the pressure drop of STHX-ULHB is likewise reduced by 12.1–45.9%. (Min Zeng et al. 2019)

In this study Multiple Twisted Tape Inserts with TiO2/Water Nanofluid Enhance Heat Transfer. They have added (i) several twisted tapes arranged differently and (ii) varying quantities of TiO2 nanoparticles as the working fluid. The increased contact surface area, residence time, swirl intensity, and fluid mixing with multi-longitudinal vortice flow that came from using more twisted tape inserts, they found, improved thermal performance. They have observed a greater thermal performance while employing water containing TiO2 nanoparticles as a working fluid as opposed to pure water. (Smith Eiamsa-ard et al. 2014)

The numerically investigated the thermal-hydraulic performance of a unique annular tube made up of inner and outer twisted oval tubes, as well as a comparison study of an annular tube made up of two straight oval tubes. The inner twisted oval tube clearly improves the fluid mixing in the annulus. They discovered that when compared to the inner straight tube, the inner twisted oval tube's Nusselt number and friction factor increased, respectively. further notes that in the laminar regime, thermal performance is more important. (KeWei Song et al. 2020)

In this study investigated the improvement of heat exchanger efficiency while keeping overall costs and energy consumption constant. Together with the experimental investigation, they have created a theoretical model to verify the findings. They found that, given the identical fluid inlet temperatures and mass flow rates, the convective heat transfer coefficient achieved in the case of operation with Nano-fluid is marginally higher than that of the base fluid. The outcomes demonstrated the new system's feasibility from an economic and environmental standpoint. (Z. Said et al. 2019)

The investigation reviews the background and current advancements in the fields of heat transfer enhancement and heat exchanger network retrofitting, offering a critical analysis from the perspective of achieving workable solutions with positive cash flows while minimising operability-related problems with emissions, controllability, and flexibility. The review draws several important findings, including the necessity for future research to create more complex models in order to accurately represent the issue, find the best solution, and include recent developments in heat transfer enhancement technology into analysis and optimisation. (Jiri JaromirKlemes et al. 2020)

The thermal, hydraulic, and thermodynamic performances in a shell and tube heat exchanger fitted with wired-nails circular–cut rod insert on tube side are investigated experimentally. The experimental results reveal that the proposed inserts configurations have a significant improvement on heat exchanger thermal and thermodynamic performances and a drawback in hydraulic performance. The WNCR5 configuration enhances U, ε, NTU, η by (210%-280%, 185%-224%, 132%–149%, 180%) and (130%-210%), respectively compared with the plain tube configuration. (S. A. Marzouk et al. 2019)

Using a genetic algorithm (GA) in conjunction with numerical simulation, heat transfer and fluid flow are optimised in a three-dimensional channel subjected to a constant heat flux boundary condition. This optimisation involves a vertical twisted tape arrangement in a channel that is subjected to MWCNT-water Nano fluid. The optimisation of vertical twisted tape arrangement in a channel has been achieved by combining a Re-averaged Navier-Stokes study of fluid flow and heat transfer with an optimisation method to maximise heat transfer performance and minimise pressure loss. (FarzadPourfattah et al. 2020)

The investigations on Research is done on the fluid flow and heat transfer behaviours of heat exchangers with eight different helical baffle configurations. These include the new sextant helical (SH) scheme, the continuous helical (CH) scheme, and the quadrant helical (QH) scheme with various axial overlapped ratios. In summary, the sextant helical baffle heat exchanger has good thermo-hydraulic and thermodynamic performance and can be regarded as a modified design with strong market potential. (Xing Cao et al. 2020)

This research focuses on the optimisation of water flow and heat transfer within the segmental baffle shell and tube heat exchanger (SB-STHE) using a combination of longitudinal ribbed tubes and baffles. The obtained results are contrasted with experimental data and published numerical results. The thermo-hydraulic behaviour of STHE with the new baffles and ribbed tube in a 3D geometry is studied in this work using the CFD approach. Because of its usage in energy optimisation and extending the device's lifespan, this kind of baffle and tube arrangement may be a good alternative to the present SB-STHE. (Ali Akbar et al. 2019)

This numerical study, by numerical analysis, the thermal–hydraulic performance of a standard twisted tape and a modified version known as twisted tape with trapezoidal ribs for three slant angles (b = 30, 45, and 60 degrees) have been contrasted. It may work well as an insert when using heat exchangers in thermal systems that use less energy. This increases the heat exchanger's heat transfer rate, which is essential for lowering operating costs overall. (Mohamed Zaki Hayat et al. 2020)

This study presents the STHE design is optimised using the generalised disjunctive programming (GDP) approach. Disjunctions are used to model all of the discrete decisions for each selection. The problem is formulated as a mixed integer nonlinear programming (MINLP) problem, involving selection for 12 technology combinations (4 tubeside methods, 3 shellside methods). When compared to the findings published by Pan et al. (2013), the model's results demonstrate their efficacy. After testing both local and global solvers, global solver BARON produced overall better-quality solutions but at a much higher computational cost. (Zekun Yang et al. 2020).

2. EXPERIMENTAL METHODOLOGY

2.1 REFERENCE JOURNAL

In the reference journal M.M. Abut Al-Sood et al. to enhance the thermal, hydraulic, thermodynamic performance have taken four baffle configuration. And tested each baffle configurations with various shell side flow rates varied between 12-15 LPM. From this journal CSSB configuration with shell side flow rate of 15 LPM has taken into consideration. The theoretical calculation for respective configuration has been carried and the parameters obtained from the journal are listed in the Table 1.

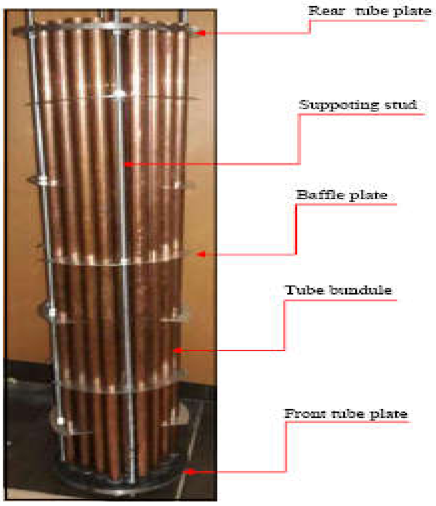
Table 1: Reference journal STHX CSSB parameters and values

PARAMETERS	VALUES
SHELL SIDE PARAMETERS	
Material	Carbon Steel
Inner diameter	200 mm
Thickness	2.5 mm
Hot water inlet temperature	82 Celsius
Cold water inlet temperature	28 Celsius
Hot water mass flow rate	0.18 kg/s
Cold water mass flow rate	0.216 kg/s
TUBE SIDE PARAMETERS	
Material	Alloy 122 copper
Outer diameter	19 mm
Thickness	1.5 mm

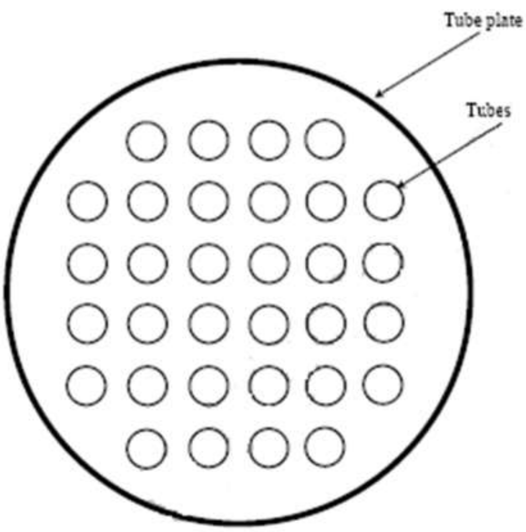
Effective length	1000 mm
Number	32
Layout pattern	Square 90
Tube pitch	28.5 mm
BAFFLE PARAMETERS	
Cut ratio	20 %
Number	6
Baffle pitch	142 mm

2.2 EXPERIMENTAL SETUP – REFERENCE JOURNAL

The working fluid for both hot and cold streams is water. The hot water volume flow rate on the tube side was set at 18 LPM, while the cold water volume flow rate on the shell side varied from 12 to 17 LPM in the cited journal. The shell side cold water volume flow rate in this study was set at 15 LPM, and the tube side hot water volume flow rate was the same as that shown in figs. 1(a) and (b) of the reference journal. In every test scenario, the temperatures of the hot and cold water inlets were maintained at 82 ˚C and 28 ˚C, respectively.



(a)



(b)

Fig 1 (a) Baffle and tube arrangement (b) Tube sheet

The model geometry of the shell and tube heat exchanger with the different baffles and tube inserts used in the HTRI Exchanger suite is given below in fig 2,3& 6 for further understanding of the shell and tube heat exchanger used in this study. The data sheet containing all the input details provided for HTRI and the tube sheet layout of the shell and tube heat exchanger are also attached in fig 4,5,7 & 8.

2.3STHX WITH CSSB IN HTRI

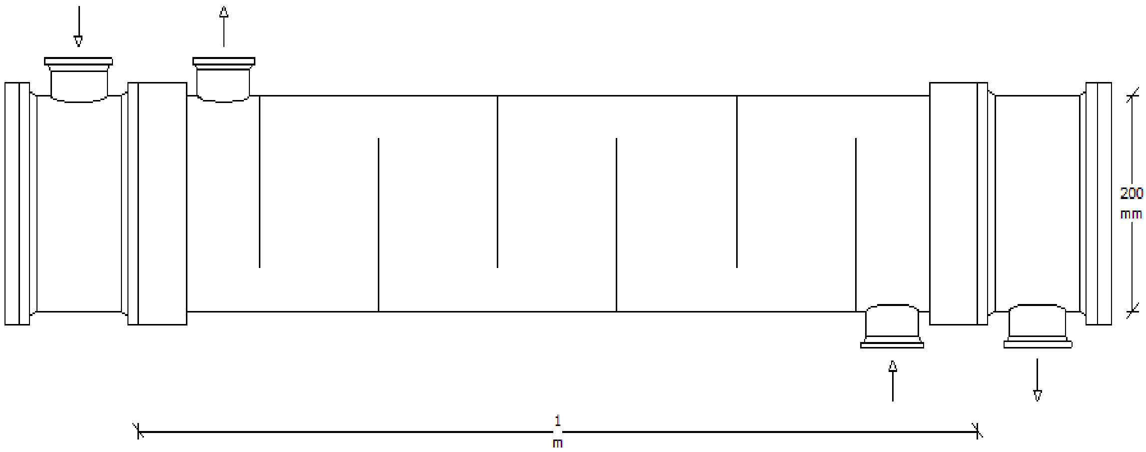


Fig 2 Exchanger drawing of STHX with CSSB

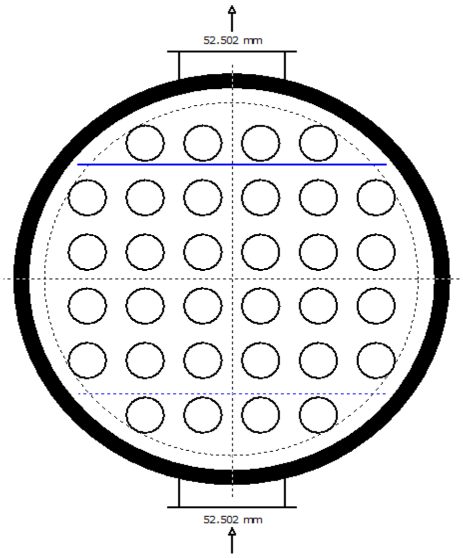
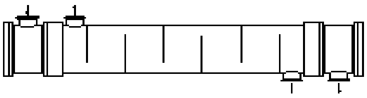


Fig 3 Tube layout of STHX with CSSB

Service of Unit			Item No.		
Type AEL		Orientation Horizontal	Connected In	1 Parallel	1 Series
Surf/Unit (Gross/Eff) 1.910 / 1.692 m2		Shell/Unit 1	Surf/Shell (Gross/Eff)	1.910 / 1.692	m2

PERFORMANCE OF ONE UNIT					
Fluid Allocation		Shell Side		Tube Side	
Fluid Name		Water		Water	
Fluid Quantity, Total	kg/s	0.1800		0.2160	
Vapor (In/Out)	wt%	0.00	0.00	0.00	0.00
Liquid	wt%	100.00	100.00	100.00	100.00
Temperature (In/Out)	C	28.00	51.61	82.00	62.37
Density	kg/m3	996.24	987.31	970.55	981.97
Viscosity	mN-s/m2	0.8325	0.5324	0.3457	0.4502
Specific Heat	kJ/kg-C	4.1807	4.1799	4.1972	4.1838
Thermal Conductivity	W/m-C	0.6121	0.6423	0.6683	0.6530
Critical Pressure	kPa				
Inlet Pressure	kPa	0.000		0.000	
Velocity	m/s		2.04e-2		3.44e-2
Pressure Drop, Allow/Calc	kPa	0.000	0.024	0.000	0.013
Average Film Coefficient	W/m2-K	682.80		760.63	
Fouling Resistance (min)	m2-K/W	0.000000		0.000000	
Heat Exchanged	0.0178 MegaWatts	MTD (Corrected)	32.0 C	Overdesign	0.49 %
Transfer Rate, Service	328.42 W/m2-K	Calculated	330.03 W/m2-K	Clean	330.03 W/m2-K

CONSTRUCTION OF ONE SHELL				Sketch (Bundle/Nozzle Orientation)
		Shell Side	Tube Side	
Design Pressure	kPaG	2413.2	2413.2	
Design Temperature	C	60.00	110.00	
No Passes per Shell		1	1	
Flow Direction		Upward		
Connections	In mm	1 @ 52.502	1 @ 52.502	
Size &	Out mm	1 @ 52.502	1 @ 52.502	
Rating	Liq. Out mm	@	1 @	



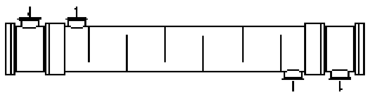
Tube No. 32.000 OD 19.000 mm	Thk(Avg) 1.500 mm Length 1.000 m	Pitch 28.425 mm Tube pattern 90
Tube Type Plain	Material Copper	Pairs seal strips 1
Shell ID 200.00 mm	Kettle ID mm	Passlane Seal Rod No. 0
Cross Baffle Type Perpend. Single-Seg.	%Cut (Diam) 20	Impingement Plate None
Spacing(c/c) 142.00 mm	Inlet 87.850 mm	No. of Crosspasses 7
Rho-V2-Inlet Nozzle 6.94 kg/m-s2	Shell Entrance 2.46 kg/m-s2	Shell Exit 2.48 kg/m-s2
	Bundle Entrance 2.06 kg/m-s2	Bundle Exit 2.08 kg/m-s2
Weight/Shell 303.06 kg	Filled with Water 347.40 kg	Bundle 48.41 kg

Fig 4 Rating data sheet of STHX with CSSB

2.3.1 STHX WITH CSSB AND TWISTED TAPE IN HTRI

Service of Unit			Item No.		
Type AEL		Orientation Horizontal	Connected In 1 Parallel	1 Series	
Surf/Unit (Gross/Eff) 1.910 / 1.692 m2		Shell/Unit 1	Surf/Shell (Gross/Eff)	1.910 / 1.692 m2	
PERFORMANCE OF ONE UNIT					
Fluid Allocation		Shell Side		Tube Side	
Fluid Name		Water		Water	
Fluid Quantity, Total	kg/s	0.1800		0.2160	
Vapor (In/Out)	wt%	0.00	0.00	0.00	0.00
Liquid	wt%	100.00	100.00	100.00	100.00
Temperature (In/Out)	C	28.00	53.93	82.00	60.44
Density	kg/m3	996.24	986.22	970.55	982.98
Viscosity	mN-s/m2	0.8325	0.5127	0.3457	0.4633
Specific Heat	kJ/kg-C	4.1807	4.1806	4.1972	4.1830
Thermal Conductivity	W/m-C	0.6121	0.6447	0.6683	0.6512
Critical Pressure	kPa				
Inlet Pressure	kPa	0.000		0.000	
Velocity	m/s		2.04e-2		3.58e-2
Pressure Drop, Allow/Calc	kPa	0.000	0.024	0.000	0.028
Average Film Coefficient	W/m2-K	689.75		1061.8	
Fouling Resistance (min)	m2-K/W	0.000000		0.000000	
Heat Exchanged	0.0195 MegaWatts	MTD (Corrected)	29.8 C	Overdesign	0.44 %
Transfer Rate, Service	387.04 W/m2-K	Calculated	388.72 W/m2-K	Clean	388.72 W/m2-K

CONSTRUCTION OF ONE SHELL				Sketch (Bundle/Nozzle Orientation)
		Shell Side	Tube Side	
Design Pressure	kPaG	2413.2	2413.2	
Design Temperature	C	60.00	110.00	
No Passes per Shell		1	1	
Flow Direction		Upward		
Connections	In mm	1 @ 52.502	1 @ 52.502	
Size &	Out mm	1 @ 52.502	1 @ 52.502	
Rating	Liq. Out mm	@	1 @	



Tube No. 32.000 OD 19.000 mm	Thk(Avg) 1.500 mm	Length 1.000 m	Pitch 28.425 mm Tube pattern 90
Tube Type Plain	Material Copper		Pairs seal strips 1
Shell ID 200.00 mm	Kettle ID mm		Passlane Seal Rod No. 0
Cross Baffle Type Perpend. Single-Seg.		%Cut (Diam) 20	Impingement Plate None
Spacing(c/c) 142.00 mm	Inlet 87.850 mm		No. of Crosspasses 7
Rho-V2-Inlet Nozzle 6.94 kg/m-s2	Shell Entrance 2.46 kg/m-s2		Shell Exit 2.49 kg/m-s2
	Bundle Entrance 2.06 kg/m-s2		Bundle Exit 2.08 kg/m-s2
Weight/Shell 303.06 kg	Filled with Water 347.40 kg		Bundle 48.41 kg

Fig 5 Rating data sheet of STHX with CSSB and twisted tape

2.3.2 STHX WITH HELICAL BAFFLE IN HTRI

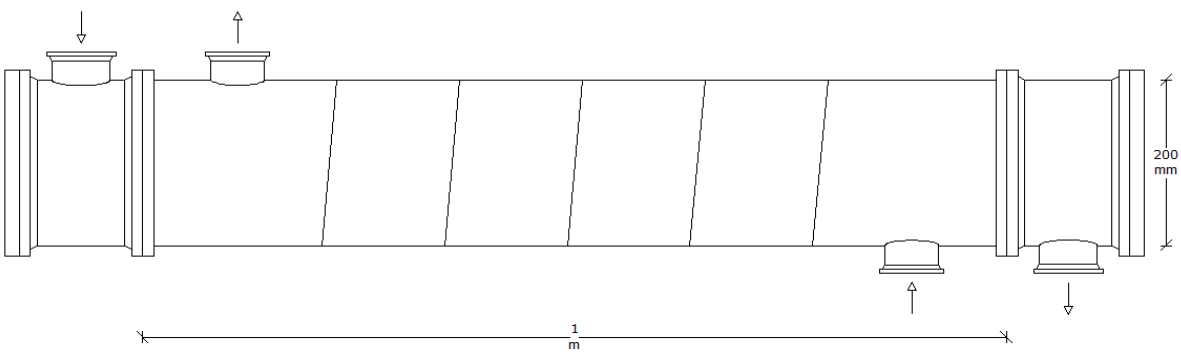


Fig 6 Exchanger drawing of STHX helical baffle

Service of Unit			Item No.		
Type AEL		Orientation Horizontal		Connected In 1 Parallel 1 Series	
Surf/Unit (Gross/Eff) 1.910 / 1.692 m2		Shell/Unit 1		Surf/Shell (Gross/Eff) 1.910 / 1.692 m2	
PERFORMANCE OF ONE UNIT					
Fluid Allocation		Shell Side		Tube Side	
Fluid Name		Water		Water	
Fluid Quantity, Total	kg/s	0.1800		0.2160	
Vapor (In/Out)	wt%	0.00	0.00	0.00	0.00
Liquid	wt%	100.00	100.00	100.00	100.00
Temperature (In/Out)	C	28.00	53.77	82.00	60.57
Density	kg/m3	996.24	986.30	970.55	982.91
Viscosity	mN-s/m2	0.8325	0.5140	0.3457	0.4624
Specific Heat	kJ/kg-C	4.1807	4.1805	4.1972	4.1830
Thermal Conductivity	W/m-C	0.6121	0.6446	0.6683	0.6514
Critical Pressure	kPa				
Inlet Pressure	kPa	0.000		0.000	
Velocity	m/s		2.68e-2		3.44e-2
Pressure Drop, Allow/Calc	kPa	0.000	0.011	0.000	0.013
Average Film Coefficient	W/m2-K	933.43		762.24	
Fouling Resistance (min)	m2-K/W	0.000000		0.000000	
Heat Exchanged	0.0194 MegaWatts	MTD (Corrected)	30.2 C	Overdesign	0.15 %
Transfer Rate, Service	379.14 W/m2-K	Calculated	379.72 W/m2-K	Clean	379.72 W/m2-K
CONSTRUCTION OF ONE SHELL				Sketch (Bundle/Nozzle Orientation)	
		Shell Side	Tube Side		
Design Pressure	kPaG	2413.2	2413.2		
Design Temperature	C	60.00	110.00		
No Passes per Shell		1	1		
Flow Direction		Upward			
Connections	In mm	1 @ 52.502	1 @ 52.502		
Size &	Out mm	1 @ 52.502	1 @ 52.502		
Rating	Liq. Out mm	@	1 @		
Tube No. 32.000 OD 19.000 mm		Thk(Avg) 1.500 mm	Length 1.000 m	Pitch 28.425 mm	Tube pattern 90
Tube Type Plain		Material Copper		Pairs seal strips	1
Shell ID 200.00 mm		Kettle ID mm		Passlane Seal Rod No.	0
Cross Baffle Type	Single Helical	%Cut (Diam)	20	Impingement Plate	None
Spacing(c/c) 142.00 mm		Inlet	300.85 mm	No. of Crosspasses	10
Rho-V2-Inlet Nozzle 6.94	kg/m-s2	Shell Entrance	2.46 kg/m-s2	Shell Exit	2.49 kg/m-s2
		Bundle Entrance	0.12 kg/m-s2	Bundle Exit	0.12 kg/m-s2
Weight/Shell 300.71	kg	Filled with Water	345.31 kg	Bundle	46.06 kg

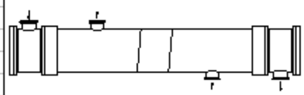


Fig 7 Rating data sheet of STHX *with* helical baffle

2.3.3 STHX WITH HELICAL BAFFLE AND TWISTED TAPE IN HTRI

Service of Unit			Item No.		
Type AEL		Orientation Horizontal		Connected In 1 Parallel 1 Series	
Surf/Unit (Gross/Eff) 1.910 / 1.692 m2		Shell/Unit 1		Surf/Shell (Gross/Eff) 1.910 / 1.692 m2	
PERFORMANCE OF ONE UNIT					
Fluid Allocation		Shell Side		Tube Side	
Fluid Name		Water		Water	
Fluid Quantity, Total	kg/s	0.1800		0.2160	
Vapor (In/Out)	wt%	0.00	0.00	0.00	0.00
Liquid	wt%	100.00	100.00	100.00	100.00
Temperature (In/Out)	C	28.00	56.75	82.00	58.10
Density	kg/m3	996.24	984.85	970.55	984.18
Viscosity	mN-s/m2	0.8325	0.4903	0.3457	0.4802
Specific Heat	kJ/kg-C	4.1807	4.1815	4.1972	4.1820
Thermal Conductivity	W/m-C	0.6121	0.6476	0.6683	0.6490
Critical Pressure	kPa				
Inlet Pressure	kPa	0.000		0.000	
Velocity	m/s		2.68e-2		3.58e-2
Pressure Drop, Allow/Calc	kPa	0.000	0.011	0.000	0.029
Average Film Coefficient	W/m2-K	942.17		1099.7	
Fouling Resistance (min)	m2-K/W	0.000000		0.000000	
Heat Exchanged	0.0216 MegaWatts	MTD (Corrected)	27.5 C	Overdesign	0.03 %
Transfer Rate, Service	465.93 W/m2-K	Calculated	466.08 W/m2-K	Clean	466.08 W/m2-K
CONSTRUCTION OF ONE SHELL				Sketch (Bundle/Nozzle Orientation)	
		Shell Side	Tube Side		
Design Pressure	kPaG	2413.2	2413.2		
Design Temperature	C	60.00	110.00		
No Passes per Shell		1	1		
Flow Direction		Upward			
Connections	In mm	1 @ 52.502	1 @ 52.502		
Size &	Out mm	1 @ 52.502	1 @ 52.502		
Rating	Liq. Out mm	@	1 @		
Tube No. 32.000 OD 19.000 mm		Thk(Avg) 1.500 mm	Length 1.000 m	Pitch 28.425 mm	Tube pattern 90
Tube Type Plain		Material Copper		Pairs seal strips	1
Shell ID 200.00 mm		Kettle ID mm		Passlane Seal Rod No.	0
Cross Baffle Type	Single Helical	%Cut (Diam)	20	Impingement Plate	None
Spacing(c/c) 142.00 mm		Inlet	300.85 mm	No. of Crosspasses	10
Rho-V2-Inlet Nozzle 6.94	kg/m-s2	Shell Entrance	2.46 kg/m-s2	Shell Exit	2.49 kg/m-s2
		Bundle Entrance	0.12 kg/m-s2	Bundle Exit	0.12 kg/m-s2
Weight/Shell 300.71	kg	Filled with Water	345.31 kg	Bundle	46.06 kg

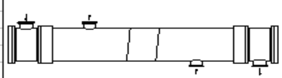


Fig 8 Rating data sheet of STHX with helical baffle and twisted tape

2.3.4 INPUT AND OUTPUT PARAMETERS OF STHE

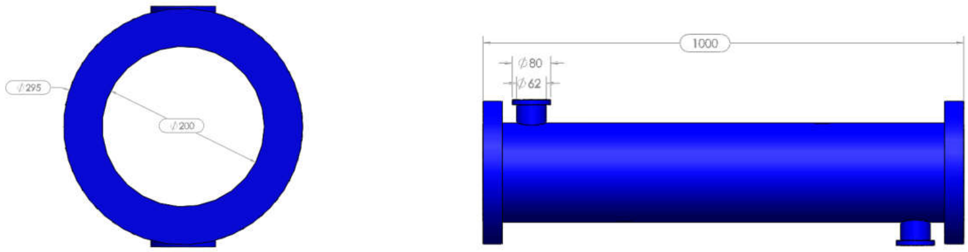
Table 2: Input and Output parameters and values of heat exchangers

Parameters	**Reference journal**	**CSSB**	**Helical Baffle θ=5°**	**Twisted Tape t=0.5mm y=90mm w=16 y/w=5.625**	**Twisted tape + Helical Baffle**
Temperature T=hot fluid temp t=cold fluid temp	T1=82 T2=65.67 t1=28 t2=47.6	T1=82 T2=62.37 t1=28 t2=51.61	T1=82 T2=60.57 t1=28 t2=53.77	T1=82 T2=60.25 t1=28 t2=54.16	T1=82 T2=58.10 t1=28 t2=56.75
Exergy efficiency (η_{er})	24%	29.47%	38.15%	40%	55.55%
Overall heat transfer Coefficient, U_0 (W/m^2k)	230	330	379.72	395.12	466.08
Pressure drop tube side,ΔP_T (K Pa)	0.13	0.013	0.013	0.029	0.029
Pressure drop shell side,ΔP_S (K Pa)	2.85	0.024	0.011	0.024	0.011

2.3.5 MODEL GEOMETRY – CFD

SOLIDWORKS is utilised in the construction of the CFD model geometry. The journal [1] provides the shell and tube heat exchanger dimensions. As illustrated in figures 9 to

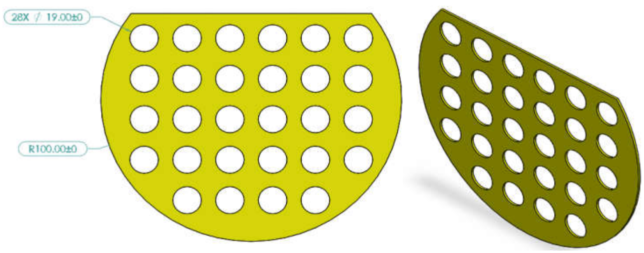
15, the various components of the shell and tube heat exchanger are the shell, tube, baffles, tube sheet, front end, rear end, and twisted tape.



(a) (b)

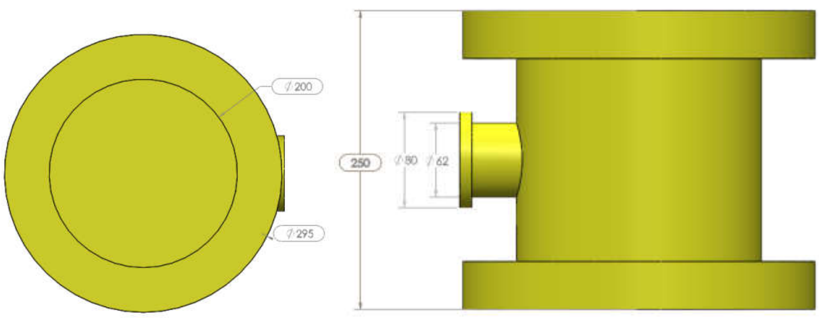
Fig 9 (a) Shell side view (b) Shell front view

Fig 10 Tube



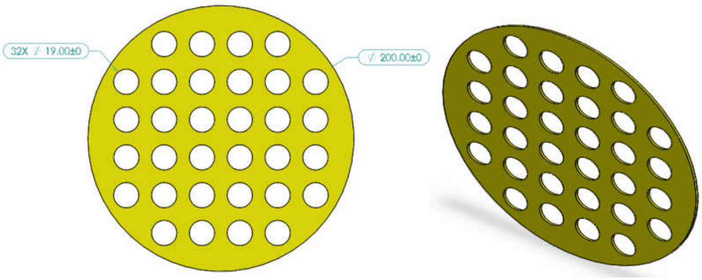
(a) (b)

Fig 11 (a) Baffle front view (b) Baffle isometric view



(a) (b)

Fig 12 (a) Front end view (b) Front end Front view



(a) (b)

Fig 13 (a) Tube sheet front view (b) Tube sheet isometric view

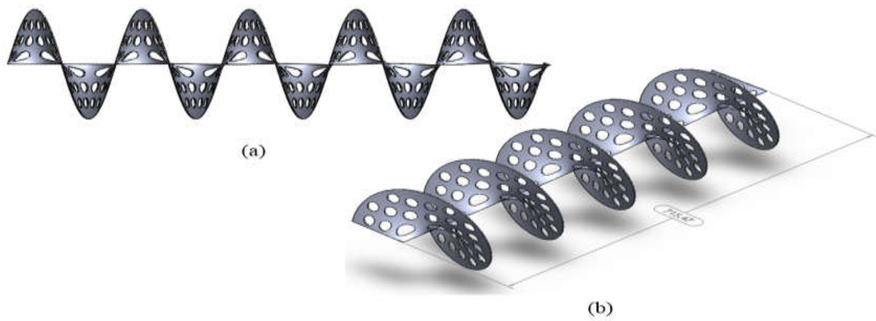
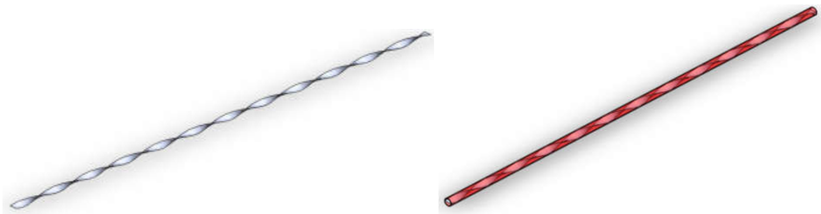


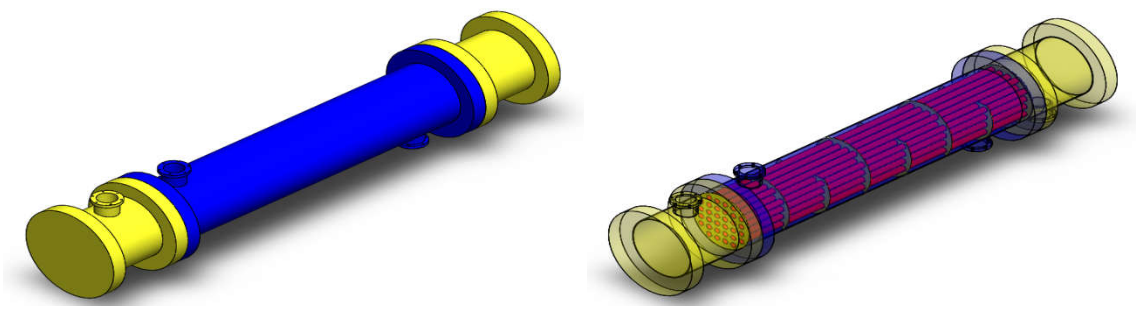
Fig 14 (a) 5° Helical baffle front view (b) 5° Helical baffle isometric view



(a) (b)

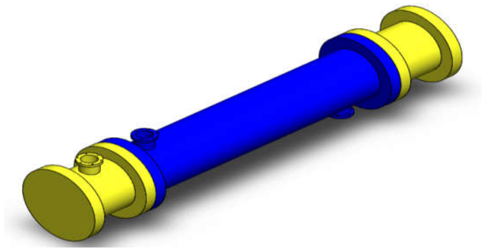
Fig 15 (a) Twisted tape isometric view (b) Twisted tape isometric view in transparency

Six segmental baffles are placed along the length of the STHE, with a 142mm gap between each baffle. With a helix angle of 5°, helical baffles are an alternative to segmental baffles. The 90mm pitch twisted tape has a 5.63 twist ratio. It is inserted into the tubes to induce turbulence and lengthen the tube side fluid's residence period. The twisted tape is 16 mm in width and 0.5 mm in thickness. As seen in fig. 16 and 17, the tube's length and the twisted tape's length equal 1000 mm.

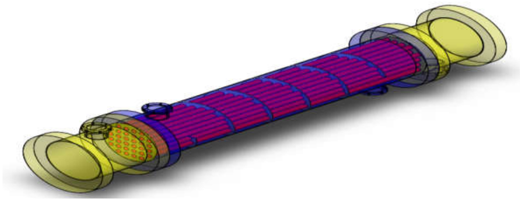


(a) (b)

Fig 16 (a) Isometric view of STHX CSSB (b) Isometric view of STHX CSSB in Transparency



(a)



(b)

Fig 17 (a) Isometric view of STHX with helical baffle (b) Isometric view of STHX with helical baffle in transparency

2.3.6 BOUNDARY CONDITIONS FOR CFD ANALYSIS

Table 3: Boundary conditions

PARAMETERS	BOUNDARY CONDITION TYPE	SHELL	TUBE
Inlet	Velocity Inlet	0.0204m/s	0.0344 m/s
Outlet	Pressure Outlet	0	0
Wall	No slip condition	No heat flux	Coupled
Temperature	Inlet temperature	28^0C	82^0C
Mass flow rate		0.18	0.216
Liquid Material		Water	Water
Metal Material		Carbon Steel	Copper
Energy Condition		ON	

3. CALCULATION METHODS OF PERFORMANCE

3.1. HEAT CAPACITY RATE

The heat capacity rate of a fluid is given by product of mass flow rate and specific heat of the respective fluids. The parameters are mentioned in Table 3.

$C_c = m^o{}_c * c_{p\,(c)}$

$C_h = m^o{}_h * c_{p\,(h)}$

3.2. NUMBER OF TRANSFER UNITS (NTU)

The number of transfer units is given by

$$NTU = \frac{A * Uo}{C_{min}}$$

$$A = \pi DL$$

Where Uo represents the overall heat transfer coefficient and A signifies the heat transfer area.

3.3. EFFECTIVENESS

$$\text{Effectiveness, } \boldsymbol{\varepsilon} = \frac{m_c C_c}{C_{min}} * \frac{(t| \quad |2 - t_1)}{(T| \quad |1 - t_1)}$$

The outlet temperature of the hot fluid (T_2) is calculated using the energy balance equation,

$$Q^o{}_{(h)} = Q^o{}_{(c)}$$

$$m^o{}_c * c_{p\,(c)} * \Delta T_c = m^o{}_h * c_{p\,(h)} * \Delta T_h$$

where ΔT is the temperature difference between inlet and outlet.

3.4. % ERROR

$$\%\text{ error} = \frac{(t| \quad |2_0 - t_2)}{t_2} * 100$$

$$\%\text{ error} = \frac{(T_2 - T_{2_0})}{T_2} * 100$$

Wheret_{2_0} and T_{2_0} obtained oulet temperatures of hot and cold fluid in HTRI.

3.5. CALCULATIONS OF THERMO-HYDRAULIC PARAMETERS

Overall Heat Transfer Coefficient, U_o =230 W/m^2k

Mass flow rate of cold fluid, $m^o{}_c$= 0.216 kg/s

Mass flow rate of hot fluid, $m^o{}_h$= 0.18 kg/s

Specific heat capacity of cold fluid, $c_{p\,(c)}$ = 4.186 KPa

Specific heat capacity of hot fluid, $c_{p\,(h)}$ = 4.186 KPa

NTU=0.522

Effectiveness, ε =0.36

Temperature of hot fluid, T_1=82°C

Temperature of cold fluid, t_1=28°C

Outlet Temperature of hot fluid, T_2=65.67°C

Outlet Temperature of cold fluid, t_2=47.6°C

% error $_{(h)}$ =9.01%

% error $_{(c)}$ =7.58%

4. RESULTS AND DISCUSSIONS

For each of the four STHX configurations—cold water flowing through the shell side and hot water flowing through the tube side—a computational fluid dynamics analysis was performed. STHX performance is contrasted with that of the reference journal. The CSSB, CSSB with twisted tape, helical baffle, and helical baffle with twisted tape are the four alternative configurations. The following are the numerous charts that relate to the four distinct configurations of STHE, including flow trajectories, temperature, velocity, pressure, turbulence intensity, and vorticity.

4.1. STHX TUBE SIDE TEMPERATURE PLOTS

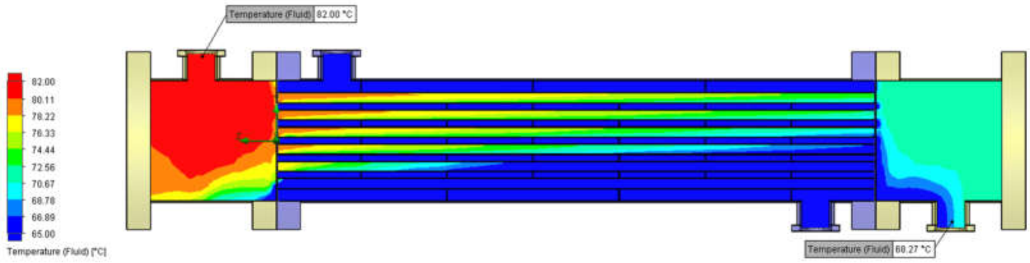


Fig 18 STHX with CSSB

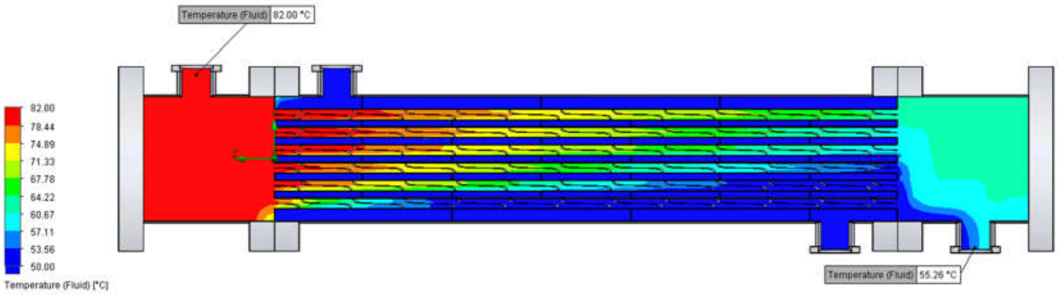


Fig 19 STHX with CSSB and Twisted Tape

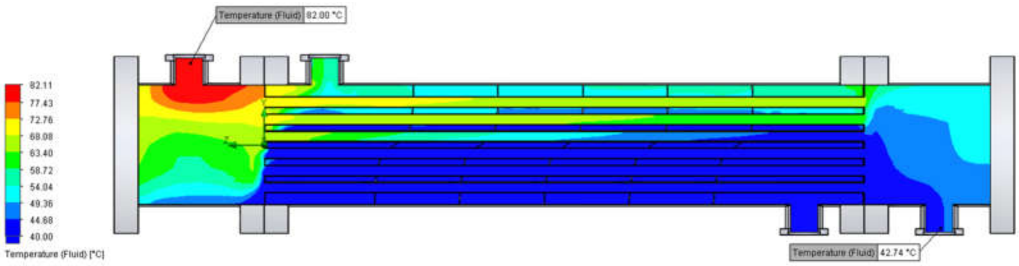


Fig 20 STHX with Helical Baffle

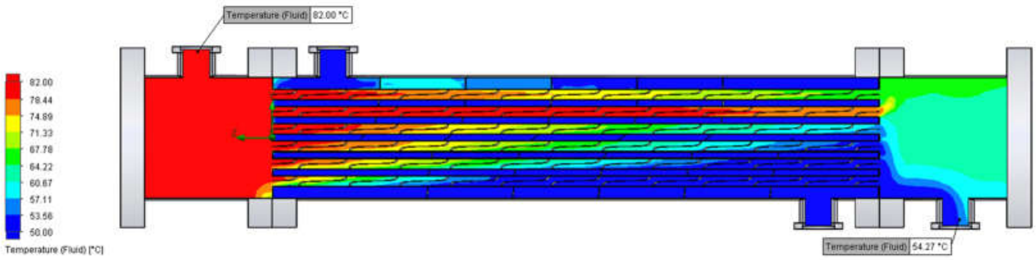


Fig 21 STHX with Helical Baffle and Twisted Tape

From the above plots, it is found that the exit temperature at the tube outlet is matching with the literature results and the deviation between the two is 3.9 %. From the plots, it is obvious that there is considerable difference in temperature between the four cases considered for the CFD analysis in fig 18 to 21.

4.2. STHX SHELL SIDE TEMPERATURE PLOTS

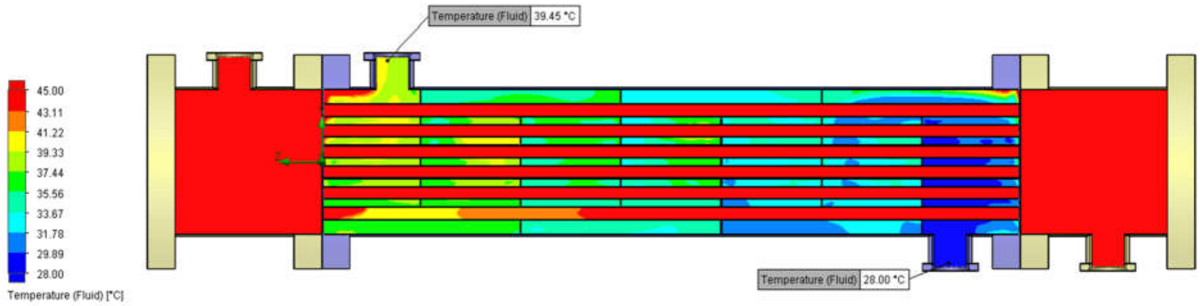


Fig 22 STHX with CSSB

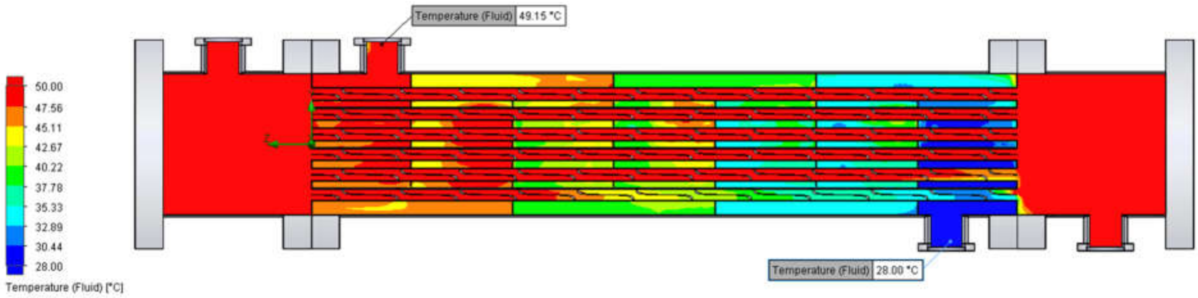


Fig 23 STHX with CSSB and Twisted Tape

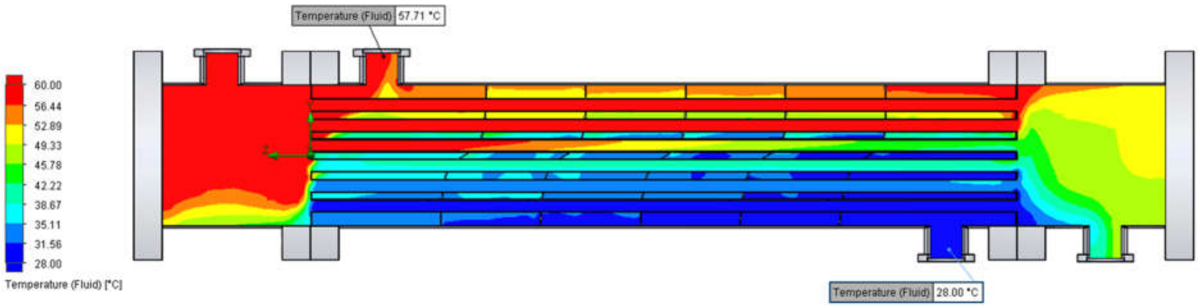


Fig 24 STHX with Helical Baffle

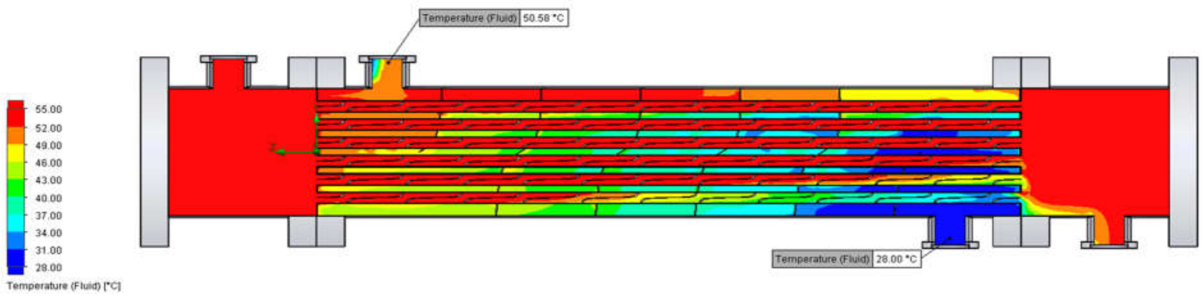


Fig 25 STHX with Helical Baffle and Twisted Tape

From the shell side plots of the STHE, it is seen that the temperature gradually increases from 28°C to 49.15°C at the outlet of the shell side in fig 22 to 25.In all four baffle configurations, there is a notable temperature differential between the fluid's inlet and outlet within the shell side of the shell and tube heat exchanger.

4.3. STHX VELOCITY PLOTS

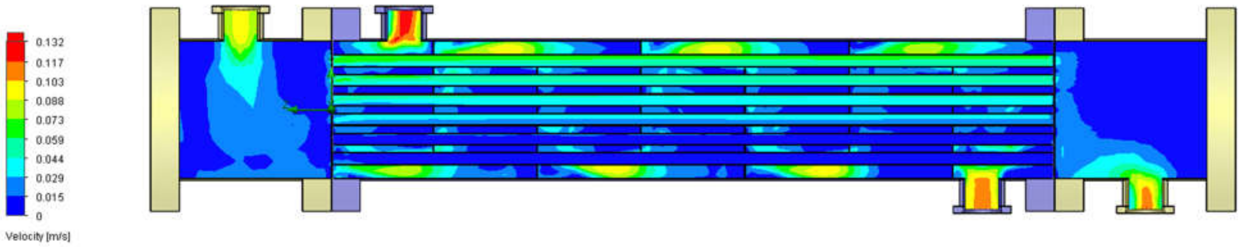


Fig 26 STHX with CSSB

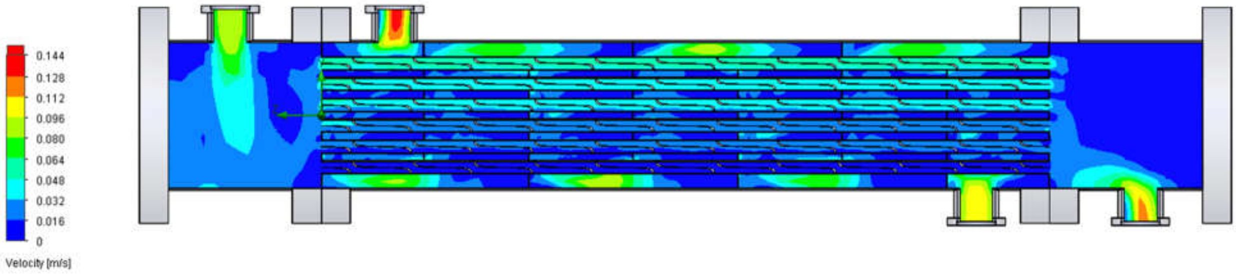


Fig 27 STHX with CSSB and Twisted Tape

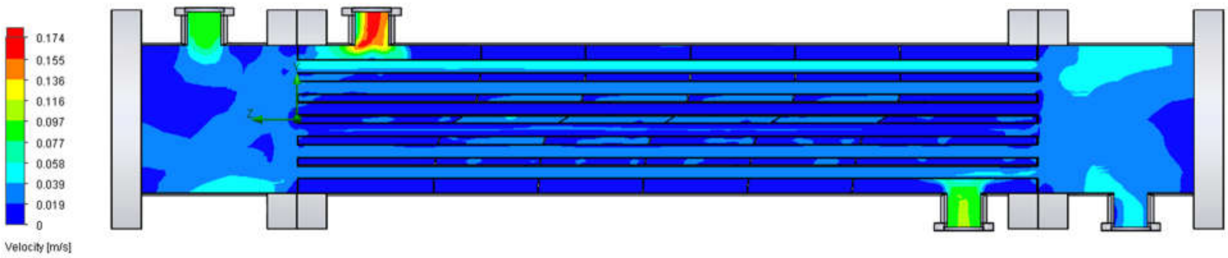


Fig 28 STHX with Helical Baffle

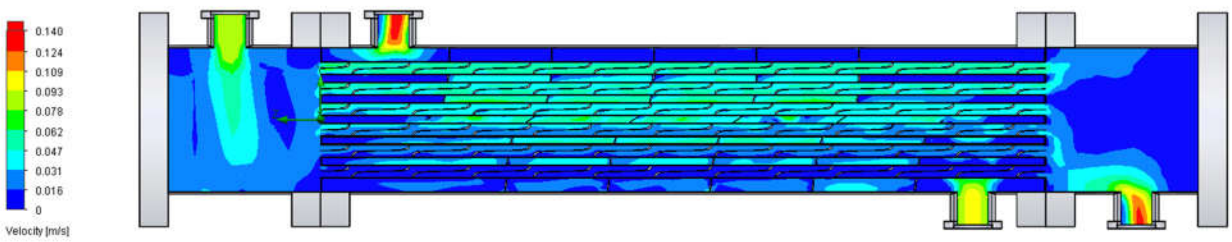


Fig 29 STHX with Helical Baffle and Twisted Tape

The maximum velocity is nearly equal to 0.14 m/s for all four configurations at the exit surface of the shell and tube side (Fig 26 - 29), the velocity for all four configurations at the inlet is about 0.08 m/s. The magnitude of velocity reduces to zero the baffle surface. Upon comparison, The Shell and tube heat exchanger with helical baffle and twisted tape provide smoother flow with high heat transfer coefficient.

4.4. STHX PRESSURE PLOTS

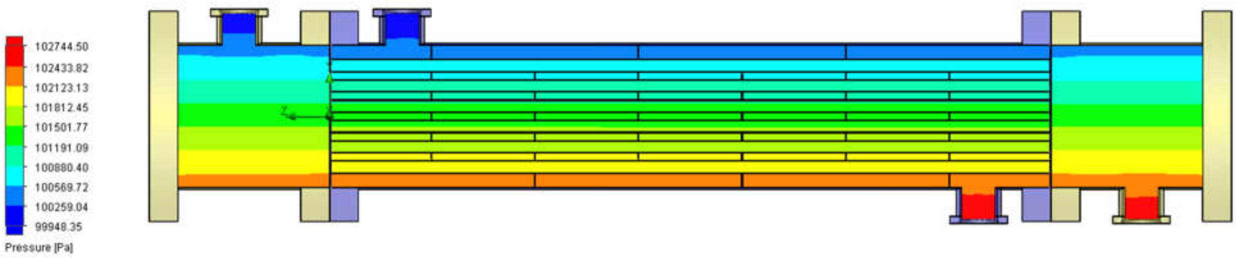


Fig 30 STHX with CSSB

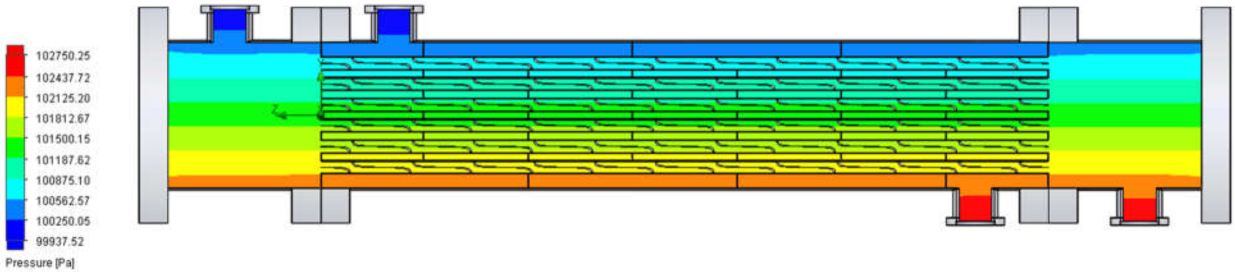


Fig 31 STHX with CSSB and Twisted Tape

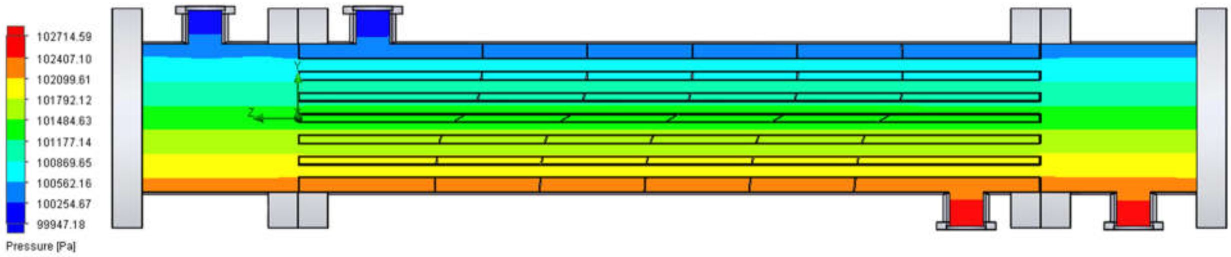


Fig 32 STHX with Helical Baffle

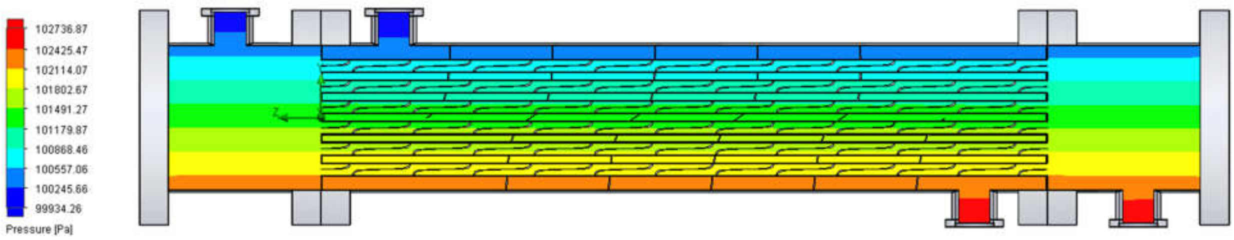


Fig 33 STHX with Helical Baffle and Twisted Tape

The maximum pressure for STHX models with CSSB (Fig 30), CSSB with Twisted Tape CSSB (Fig 31), Helical baffle (Fig 32), Helical Baffle with Twisted Tape (Fig 33) was approximately equal to atmospheric pressure.

4.5. STHX TURBULENCE INTENSITY PLOTS

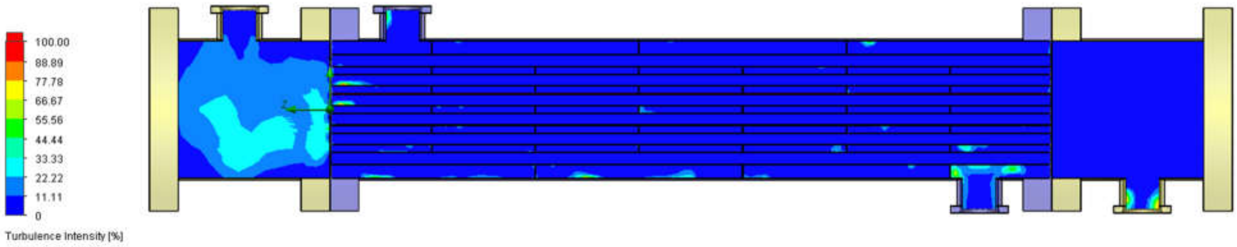


Fig 34 STHX with CSSB

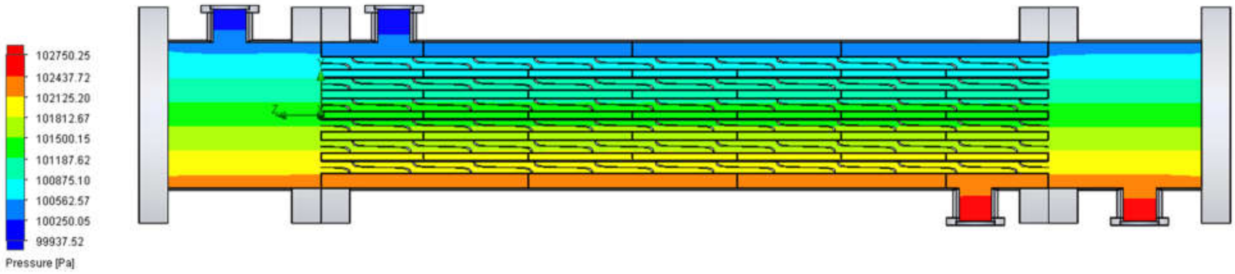


Fig 35 STHX with CSSB and Twisted Tape

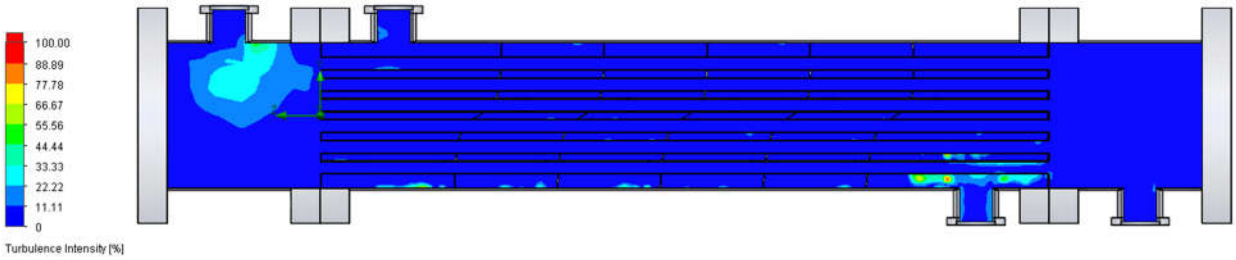


Fig 36 STHX with Helical Baffle

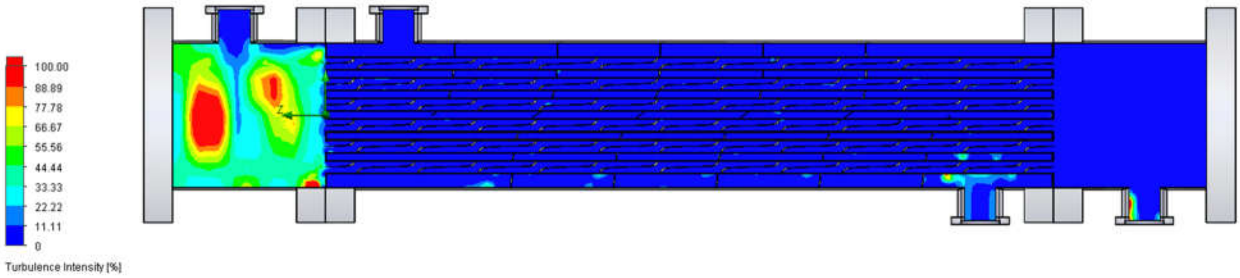


Fig 37 STHX with Helical Baffle and Twisted Tape

The turbulence intensity for the four different baffle configurations are given (Fig 34-37). The turbulence intensity is high in the configurations with twisted tape than that of the configurations without the tube inserts. So, the tube inserts are effective in creating the turbulence in the shell and tube heat exchanger.

4.6. STHX VORTICITY PLOTS

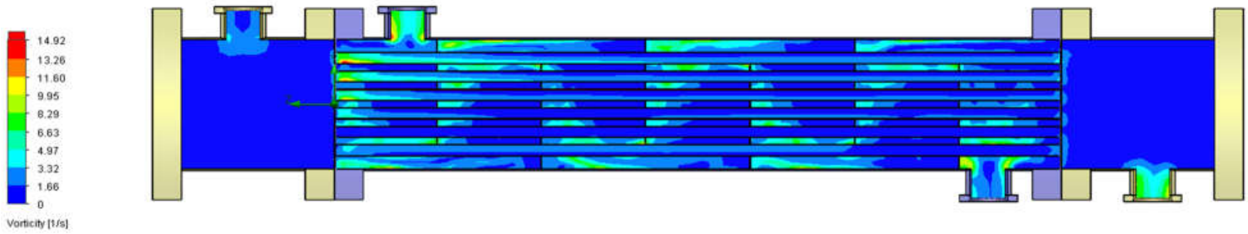


Fig 38 STHX with CSSB

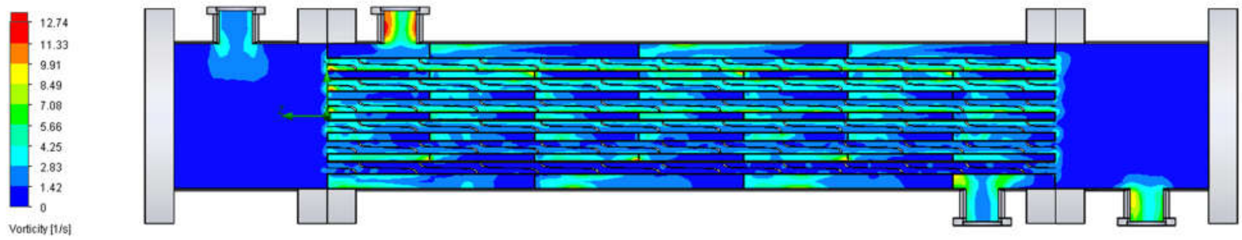


Fig 39 STHX with CSSB and Twisted Tape

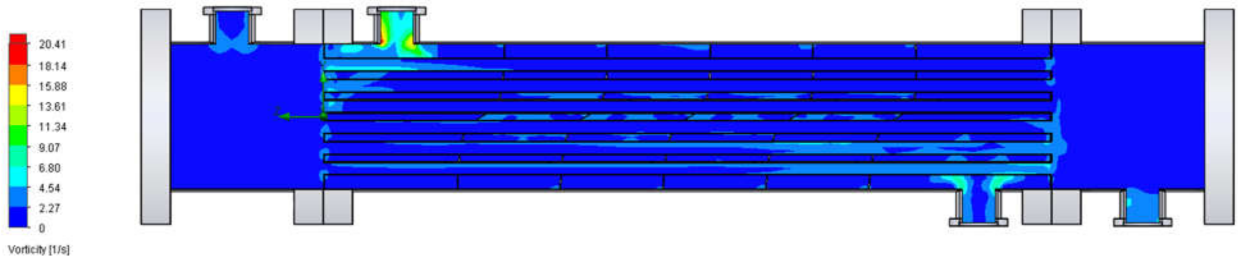


Fig 40 STHX with Helical Baffle

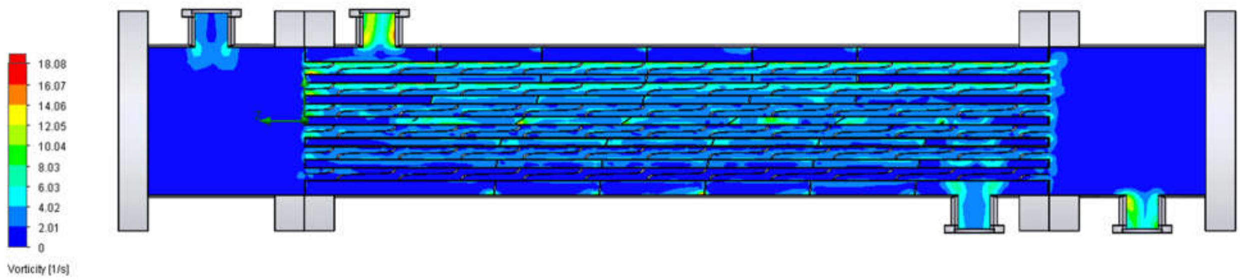


Fig 41 STHX with Helical Baffle and Twisted Tape

The vorticity plots show that the tube inserts induce the rotary motion of the fluid in the tube side. This rotary motion improves the heat transfer between the fluids in the shell and tube heat exchanger in fig 38 to 41.

4.7. STHX TUBE SIDE FLOW TRAJECTORIES

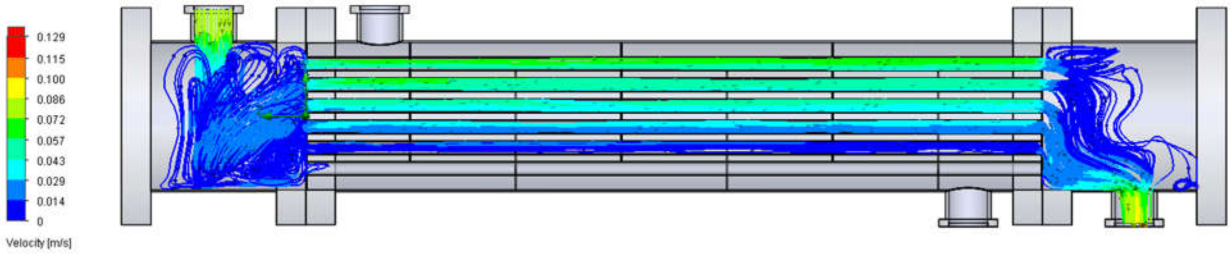


Fig 42 STHX with CSSB

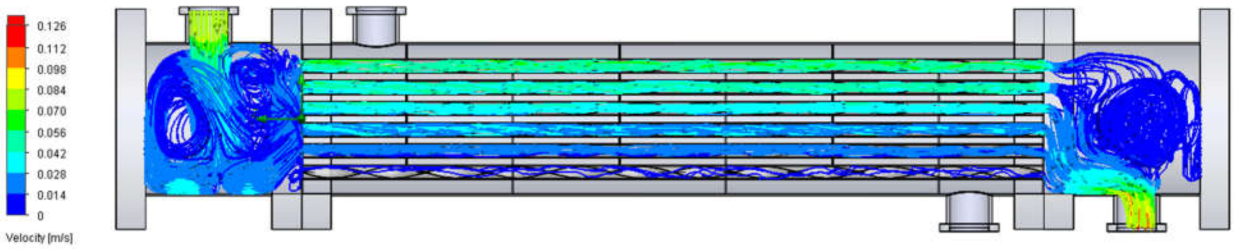


Fig 43 STHX with CSSB and Twisted Tape

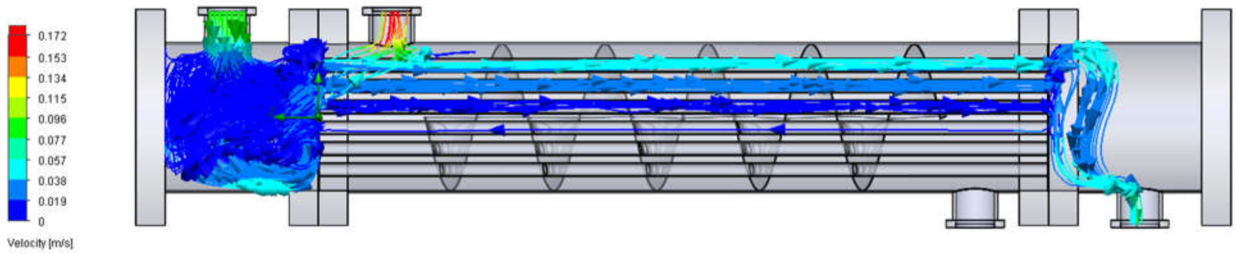


Fig 44 STHX with Helical Baffle

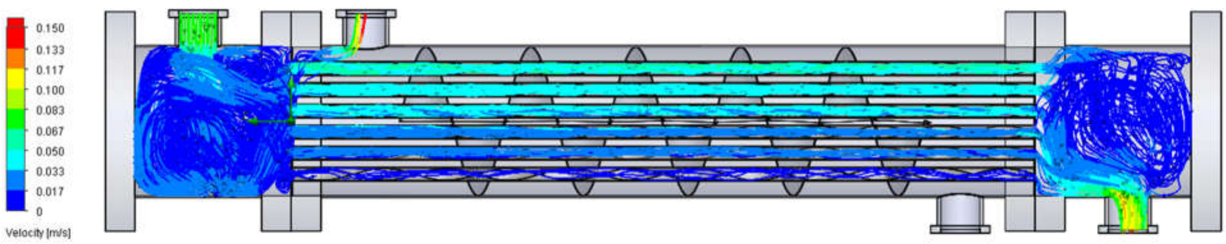


Fig 45 STHX with Helical Baffle and Twisted Tape

The flow trajectories of the four configurations shows that the baffle without tube inserts creates uneven flow among the tubes and the tube inserts provides a better flow pattern than that of the configurations without tube inserts as shown in fig 42 – 45.

4.8. STHX SHELL SIDE FLOW TRAJECTORIES

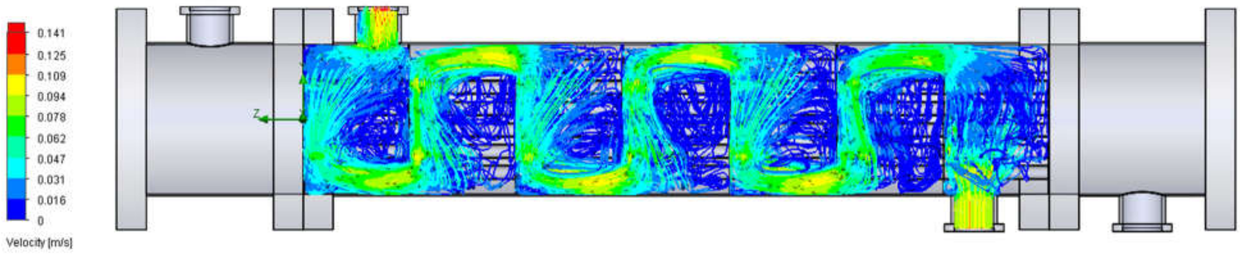


Fig 46 STHX with CSSB

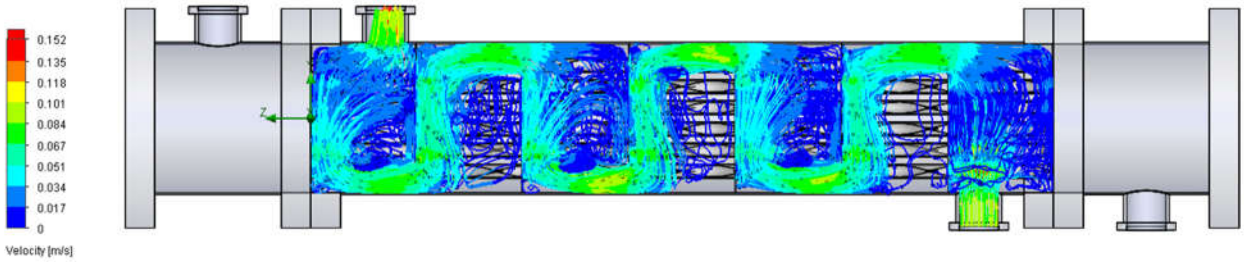


Fig 47 STHX with CSSB and Twisted Tape

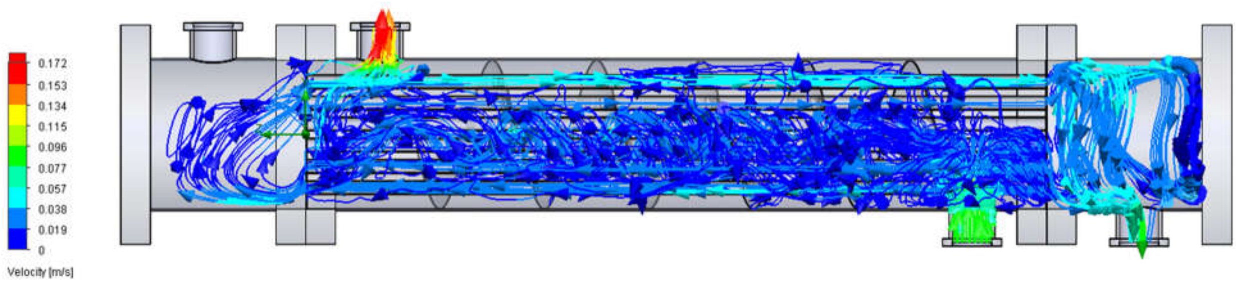


Fig 48 STHX with Helical Baffle

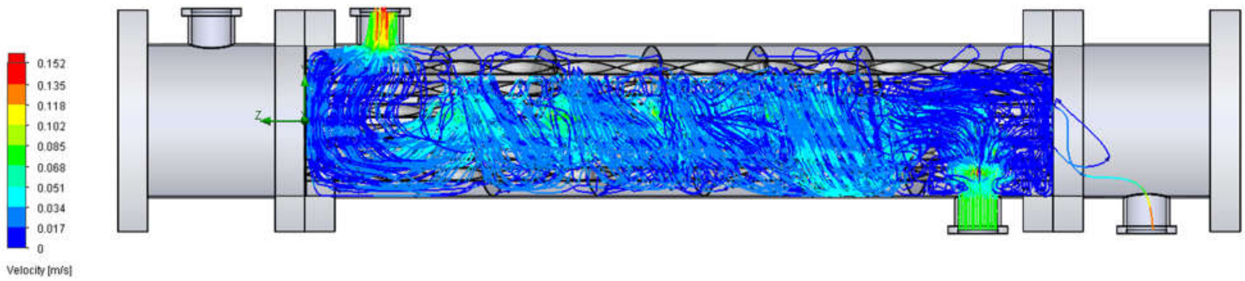


Fig 49 STHX with Helical Baffle and Twisted Tape

It has been observed that the STHX with twisted tape and helical baffle exhibits higher efficiency of 55.5% than other configuration STHX's as mentioned in table 2. The fig 46 - 49 shows the ideal flow trajectories of shell side and tube side fluid indicating the effect of baffles in shell side and twisted tape in the tube side of the shell and tube heat exchanger.

5. CONCLUSION

It has been observed that the heat transfer coefficient and the pressure drop are dependent of the baffle spacing, baffle cut and shell diameter. This is investigated by numerically modelling a shell and tube heat exchanger. A series of Computational Fluid Dynamics (CFD) simulations is conducted for a shell and tube heat exchanger encompassing four distinct configurations.

- From the CFD results, it is observed that the STHX with Twisted Tape and helical baffle has the higher heat transfer coefficient than the other heat exchangers.
- It is found that within the operating conditions, the shell-side heat transfer coefficient of twisted tape with the helical baffle flow heat exchanger is 18.53% more than the heat exchanger without helical baffle.
- It is found that the overall heat transfer coefficient increases by 50% if the twisted tape and helical baffles are installed inside the shell and tube heat exchanger.
- However, the shell-side pressure difference is decreased when the helical baffle is installed in the heat exchanger.
- The Shell and tube heat exchanger with helical baffle in shell side and twisted tape in tube side exhibits higher efficiency of 55.5% which is considerable higher than that of the other three baffle configurations of STHX.

AUTHOR CONTRIBUTION

All persons who meet authorship criteria are listed as authors (Jagadeesh Duraisamy, Vivekanandan Mahendran, Kawin Nallasivam), and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the Environmental Science and Pollution Research.

FUNDING

No Funding was received to assist with the preparation of the submitted work. No Funding was received for conducting the study.

DATA AVAILABILITY

Raw data is available upon request.

ETHICS APPROVAL

This work does not contain any investigations with human participants or animals performed by any of the authors.

CONSENT TO PARTICIPATE

Not applicable.

CONSENT TO PUBLISH

Not applicable.

COMPETING INTERESTS

The authors declare no competing interests.

REFERENCES

Ali Akbar Abbasian Arania, Reza Moradi (2019) Shell and tube heat exchanger optimization using new baffle and tube configuration. Applied Thermal Engineering: Vol 157, pp 113736.

Chao Luo, Kewei Song (2021) Thermal performance enhancement of a double-tube heat exchanger with novel twisted annulus formed by counter-twisted oval tubes. International Journal of Thermal Science: Vol 164, pp 106892.

Farzad Pourfattah, Majid Sabzpooshani, Ozgur Bayer, Davood Toghraie Amin Asadi (2021) On the optimization of a vertical twisted tape arrangement in a channel subjected to MWCNT–water nano fluid by coupling numerical simulation and genetic algorithm. Journal of Thermal Analysis and calorimetry: Vol 144, pp 189-201.

Hasan Kucuk, Murat Unverdi, Mehmet SenanYılmaz (2019) Experimental investigation of shell side heat transfer and pressure drop in a mini-channel shell and tube heat exchanger. International journal of Heat and Mass Transfer: Vol. 143, pp-118493.

Hazzan Azarkish, Mohsen Rakshi (2019) Reliability and reliability-based sensitivity analysis of shell and tube heat exchangers using Simulation. Applied thermal Engineering: Vol 159, pp 113842.
Jian Chen, Xing Lu, Qiuwang Wang, Min Zeng (2019) Experimental investigation on thermal-hydraulic performance of a novel shell and tube heat exchanger with unilateral ladder type helical baffles. Applied thermal Engineering: Vol 161, pp-114099.

Jiri Jaromir Klemes, Qiu-Wang Wang, Min Zeng, Hon Huin Chin, Nathan Sanjay Lal, Nian-Qi Li, Bohong Wang, Xue-Chao Wang, Timothy Gordon Walmsley (2020) Heat transfer enhancement, intensification and optimization in heat exchanger network retrofit and operation.: vol 120, pp 109644.

Mohammed Zaki Hayat, GopalNandan, Arun Kumar Tiwari, Sanjeev Kumar Sharm, Ramakant Shrivastava, Ashok Kumar Singh (2020) Numerical study on heat transfer enhancement using twisted tape with trapezoidal ribs in an internal flow. Materials today: Proceedings: Vol 30, pp 2214-7853.

M.S. El-Saida, M.M. Abou Al-Sood (2019) Shell and tube heat exchanger with new segmental baffles configurations: A comparative experimental investigation. Applied Thermal Engineering: Vol 150, pp 803-810.

Nihat Bicer, Tahsin Engin, Halit Yasar, Ekrem Buyukkaya, Ahmet Aydin, Adna Topuz (2020) Design optimization of a shell-and-tube heat exchanger with novel three-zonal baffle by using CFD and taguchi method. Renewable and Sustainable Energy Reviews, Vol 120, pp 109644.

S.A. Marzouk, M.M. Abou Al-Sood, E.M.S. El-Said, M.K. El-Fakharany (2019) Effect of wired nails circular –rod inserts on tube side performance of shell and tube heat exchanger: Experimental study. Applied Thermal Engineering: Vol 167, pp 114696.

Smith Eiamsa-ard, Kunlanan Kiatkittipong (2014) Heat transfer enhancement by multiple twisted tape inserts and TiO2/water Nano fluid. Applied Thermal Engineering: Vol 70, pp 896-924.

Xing Cao, Dongming Chen, Tingting Du, Zhan Liu, Shui Ji (2020) Numerical investigation and experimental validation of thermo-hydraulic and thermodynamic performances of helical baffle heat exchangers with different baffle configurations. International journal of Heat and Mass Transfer: Vol 160, pp 120181.

Zekun Yang, Yingjie Ma, Nan Zhang, Robin Smith (2020) Design optimization of shell and tube heat exchangers sizing with heat transfer enhancement. Computers and Chemical Engineering: Vol 137, pp 106821.

Z. Said, S.M.A. Rahman, M. El Haj Assad, Abdul HaiAlami (2019) Heat transfer Enhancement and life cycle analysis of a shell and tube Heat Exchanger using stable CuO/water Nano fluid. Sustainable Energy Technologies and Assessments: Vol 31, pp-306-317.