Optimizing Physical Dimension of Heat Exchanger Using Insert to Improve Its Portability

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Abstract: ***In the present work, the dimension of shell and tube heat exchanger has been optimized. After reviewing different types of inserts, its advantages and disadvantages method of manufacturing, it was decided to study the center rod wire coil inserts, which appears to be most efficient than others. Both analytical analysis and CFD simulation has been done. Model was made on SolidWorks software and imported in ANSYS 14.5.In ANSYS 14.5, Fluent is used as a solver. The result shows that performance of shell and tube heat exchanger was increased with insert and further the dimension has been optimized. The overall heat transfer increased by 182% in analytical analysis and by 199% in CFD simulation results. The length of shell and tube heat exchanger was reduced from 1000mm to 360mm and number of baffle also minimized from 15 to 06. The TEMA standard is also considered for design heat exchanger. Based on obtained results, the results are compared.***

Keywords: Heat transfer enhancement, Insert, TEMA, Optimization

1. Introduction

Tube side enhancement technologies are increasingly used to improve the performance of tubular heat exchangers. Enhancement devices are becoming standard practice for exchangers handling fluids of moderate or high viscosity. The characteristics of the fluid dynamics in tube with inserts are fundamentally different to the characteristics in plain tube design. The characteristics in the boundary layer, which affects the tube side heat transfer coefficient, are of special interest. The conditions provided by fluid dynamics through plain tubes are not identical for either heating or cooling. A thermally inefficient boundary layer, with minimal radial movement to or from tube wall, is created due to frictional drag at the wall and viscous shear forces within the fluid. This laminar layer can significantly reduce the tube side heat transfer coefficient and hence the overall heat exchanger performance.

1.1 Turbulator inserts

In plain tubes (no inserts), fluid flow is essentially laminar, and skin friction retards the flow of fluid in contact with the tube wall. At the same time this outer fluid cools faster and becomes more viscous, further retarding the flow. The result is a buildup of concentric fluid layers, with the hot fast-flowing inner fluid surrounded by cooler, slower flowing outer fluid. These outer layers-boundary layers-insulate the hotter fluid from the cool tube wall resulting in a very low heat transfer rate. Wire loop inserts eliminate boundary layers by completely disrupting laminar flow. When installed in a tube the wire loops keep the fluid in a constant state of turbulence, preventing the formation of thick boundary layers and continually presenting hot fluids to the cool tube wall. The basic principle is to promote fluid mixing, convert laminar flow to turbulence flow pattern, maintaining turbulence flow pattern and improve the tube side heat transfer coefficient. Heat transfer relies on conduction (across the fluid) and convection (physical mixing).Even with the viscous fluids at low velocities the wire loop insert provides extremely efficient mixing giving vastly improved heat transfer. The insert is made from a continuous wire which is formed into loops. The loops are spirally wound around a small diameter rod and solder bonded in place.

2. Literature Survey

Shashank S.Choudhari and Taji S.G[1]. In this work study heat transfer characteristics and friction factor of horizontal double pipe heat exchanger with coil wire inserts made up of different materials are investigated. Cu insert has higher heat transfer enhancement of 1.58 times as compared to plane tube. On other hand aluminium and stainless steel insert has heat transfer enhancement of 1.41 and 1.31 as compared to plane tube respectively.

Watcharin Noothong et al[2]. Influences of the twisted tape insertion on heat transfer and flow friction characteristics in a concentric double pipe heat exchanger have been studied experimentally. Heat transfer enhancement efficiency investigated. Sami D. Salman et al[3]. Work on CFD analysis of Heat transfer and friction factor Characteristics in a circular tube fitted with Parabolic-cut twisted tape inserts. The results have been revealed that the Nusselt number and the friction factor in the tube with Parabolic-cut twisted tape (PCT) increase with decreasing twist ratios (y) and cut depth (w).

Sajid Hussein Ali Al – Abbasi[4]. This work includes the results of CFD analysis of enhancement of turbulent flow heat transfer in a horizontal circular tube with different shapes of inserts (disc, diamond and trapezoidal).The average Nusselt numbers was increased with respect to plane tube.

S. Naga Sarda et al[5]. This work shows the results obtained from experimental investigations of the augmentation of turbulent flow heat transfer in a horizontal tube by means of varying width twisted tape inserts with air as the working fluid. It has been observed that the enhancement of heat transfer was more for full width twisted tap inserts than reduced width twisted tap inserts.

P.S.Desale and N.C.Ghuge[7]**.** The advantages of wire coil inserts in comparison to other heat exchanger performance enhancement techniques can be their low cost, they don't change mechanical strength of original plain tube, their installation and removal is easy and they can be installed in the existing heat exchanger with smooth tube.

Pravin Sawarkar, and Kishor Rambhad[8]**.** In this work Ring Sector with Central Rod insert has been used at different pitch and diameter (P/D) ratio. The Performance was maximum at P/D=4.

Arezuo Ghadi, et al[9]. In this Paper has been studied that performance of heat exchanger increased with the used of wire coil insert. Nusselt number was peak in small (P/D) ratio. Computational Fluid Dynamics predict the experimental result with good accuracy.

3. Analytical Analysis

This Section deals with the analytical analysis of shell and tube heat exchanger. Analytical analysis was done for both condition without and with insert .The Kern method was used for designed shell and tube heat exchanger. TEMA standard was also considered for designed shell and tube heat exchanger .Kern method one of the good method for find out the thermal output and design shell and tube heat exchanger. The TEMA (tubular heat exchanger manufactures association) globally accepted method for design.

In this work one shell and tube heat exchanger was designed. It is counter flow and one shell and tube pass heat exchanger. It is hydraulic oil cooler. Oil was used as hot fluid and water as cold fluid. In first case that is without insert oil was used in shell side and water was used in tube side. In second case that is with insert water was used in shell side and oil was used in tube side. Number of tube is 12 and 15 baffle are considered. The thickness of tube 0.711mm length is 1000mm which is made of cooper. The baffle plate is also made of copper. Shell inner diameter 108.20 mm, 1000mm long and 3.05mm thickness which made of carbon steel. It is as per tubular heat exchanger manufactures association BEM type.

Following are correlations which are used to design of heat exchanger.The fundamental equation for heat transfer across a surface are given by

$$Q = m_h\, cp_h\, \Delta T = m_c\, cp_c\, \Delta T = U\, A\, F\, \Delta T_{lm}$$

Where m_h and m_c is mass flow rate of hot and cold fluid.cp_h and cp_c specific heat at constant pressure for hot and cold fluid.U overall heat transfer coefficient . A is surface area and F correction facter.ΔT_{lm} LMTD (log mean temperature diffrence).

$$\text{Reynolds No.}(\text{Res}) = \frac{Gs\ X\ D}{\mu}$$

Where Gs is mass velocity, triangular pitch is used for tube bundle geometry. Tube pitch is taken 1.25times of tube outer diameter .Baffle cut has been considered 25%. The correlation for heat transfer coefficient

$$h = \frac{JHx\ K\ x(Pr)^{1/3}\,(\mu/\mu w)^{0.14}}{d}$$

The above equation is for inside (hi) and outside (ho) heat transfer coefficient. JH Heat transfer factor which is depends on Reynolds number. The value of JH was directly adopted from chart [15]. In with insert case inside heat transfer coefficient was found by the performance characteristic chart of center rod wire coil insert [10].

Overall heat transfer coefficient

$$1/U_O = 1/h_o + (d_o/d_i)\ x\ 1/h_i + (d_o/k)\ \ln(d_o/d_i) + f_o + (d_o/d_i)\ f_i$$

U_O overall heat transfer coefficient. f_o outside and f_i inside fouling factor.

Pressure drop

a. Shell Side

$$\Delta Ps = \frac{fx\ Gs^2 x\ Ds\ x\ (N+1)}{5.22\ x\ 10^{10} x\ De\ x\ S\ x\ \varphi t}$$

b. Tube Side

$$\Delta Ps = \frac{f\ x\ Gt^2 x\ L\ x\ n}{5.22\ x\ 10^{10} x\ Di\ x\ \phi t\ x\ s}$$

f is friction factor which is depend on Reynolds number .The value of f was directly adopted from chart [15].In with Insert case tube side pressure drop was found by performance characteristic chart of center rod wire coil Insert [10].

Table 3.1: Input parameter

Heat load	09 kw
Oil Flow	0.85 kg/sec
Oil Inlet Temperature	60 ^{o}c max
Water Inlet Temperature	30 ^{o}c max
Water Flow	1.66 kg/sec
Oil	ISO-VG 46

Table 3.2: Design consideration

Max oil Pressure Drop	60 kpa
Max water pressure drop	30 kpa
Fouling factor-oil side	0.000171969 m^2-^{0}c/w
Fouling factor water side	0.000171969 m^2-^{0}c/w

Table 3.3: Properties of Oil and Water

Properties	Unit	Water	Oil
Average Temp	^{0}c	30.65	57.45
Density	kg/m^3	996	850
Sp. Heat	kJ/kg-^{0}c	4.1742	2.093
Viscosity	m^2/sec	0.810 x 10^{-06}	23 x 10^{-06}

Thermal Conductivity	w/m-^{0}c	0.621	0.153
Prandtl No.	-	5.3	267.6

Table 3.4: Thermal Output by analytical analysis without insert

Outlet Temperature oil	54.9^{o}c
Outlet Temperature of water	31.3 ^{o}c
LMTD (Counter Flow)	26.75 ^{o}c
ho (Outside heat transfer coefficient)	815.06 w/m^2-^{o}c
hi (Inside heat transfer coefficient)	2516.60 w/m^2-^{o}c
U design (Over all heat transfer coefficient)	495.66 w/m^2-^{o}c
Q (Heat Load)	09.52 kw
Pressure drop oil side	18.7kpa
Pressure drop water side	0.33kpa

3.1 Insert Specification

Center rod wire has been selected because performance of center wire coil insert best than others [10].

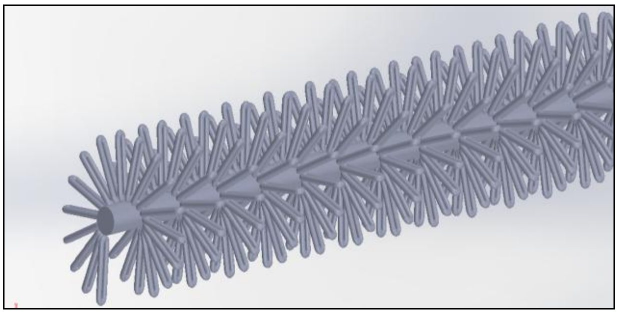

Figure 3.1: Center rod wire coil insert

Internal winding 19: 131
19 loop per turn.
131 turns per meter
Wire diameter: 0.711mm

Table 3.5: Thermal Output by analytical analysis with insert

Outlet Temperature oil	54.9^{o}c
Outlet Temperature of water	31.3 ^{o}c
LMTD (Counter Flow)	26.75 ^{o}c
ho (Outside heat transfer coefficient)	6480.71 w/m^2-^{o}c
hi (Inside heat transfer coefficient)	909.466 w/m^2-^{o}c
U design (Over all heat transfer coefficient)	1400.24 w/m^2-^{o}c
Q (Heat Load)	26.89 kw
Pressure drop oil side	52 kpa
Pressure drop water side	28.6 kpa

4. CFD Simulation

4.1 Model

Model of shell and tube heat exchanger has been designed based on same dimension which was considered in analytical analysis. It was made in SolidWorks software.

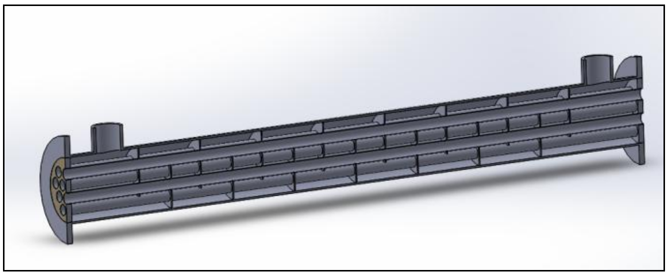

Figure 4.1: Sectional view of heat exchanger without insert

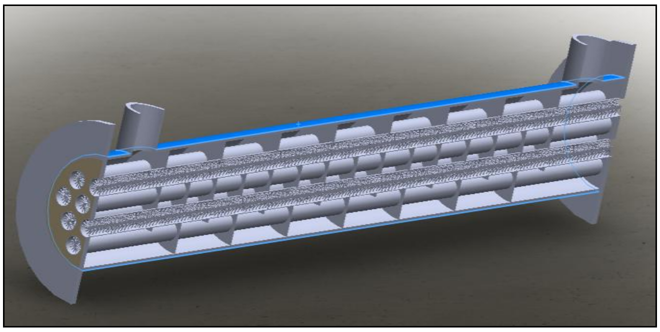

Figure 4.2: Sectional view of heat exchanger with insert

4.2 Meshing

Model of shell and tube heat exchanger was made in SolidWorks software and imported in ANSYS 14.5 for CFD Simulation. Meshing was done in ANSYS 14.5 .Tetrahedral mesh is generated.

4.3 Simulation Results

Simulation was carried out in ANSYS 14.5 Fluent. Properties of oil and water were used same which was considered (Table No. 3.3) in analytical analysis.

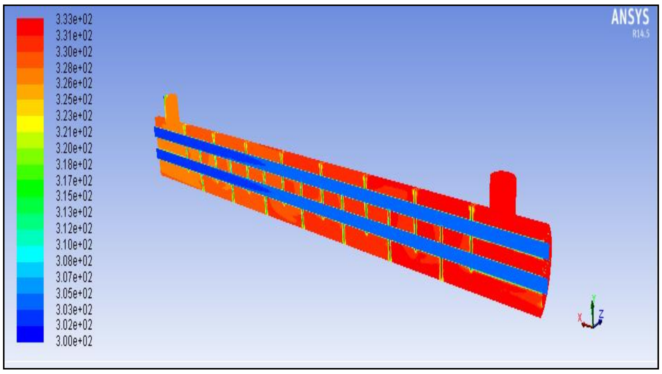

Figure 4.3: Temperature (K) contour without insert

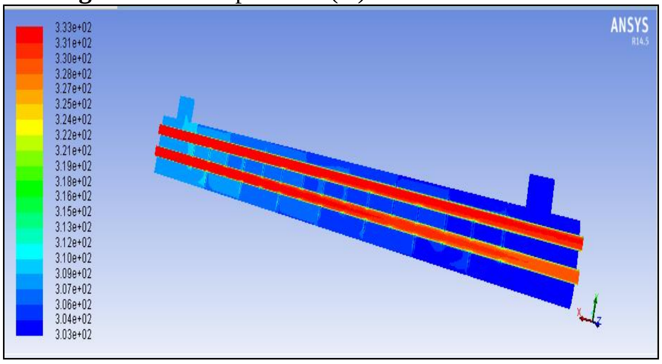

Figure 4.4: Temperature (K) contour with insert

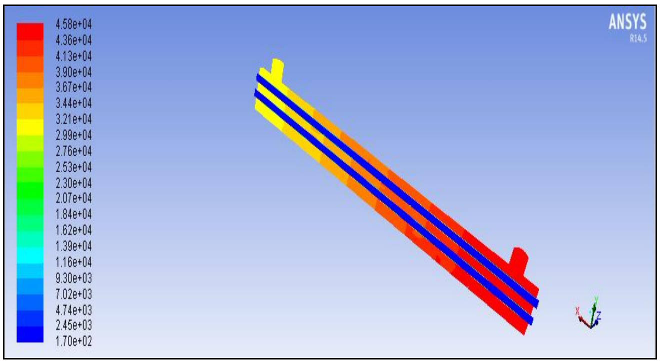

Figure 4.5: Pressure (Pascal) contour without insert

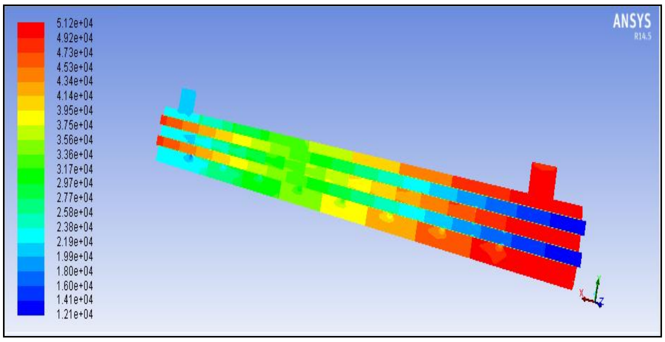

Figure 4.6: Pressure (Pascal) contour with insert

4.4 Representation of Results in Graphical

These are following graphical representations of CFD simulation results along the X-axis. Following are the temperature and pressure variations from inlet to outlet.

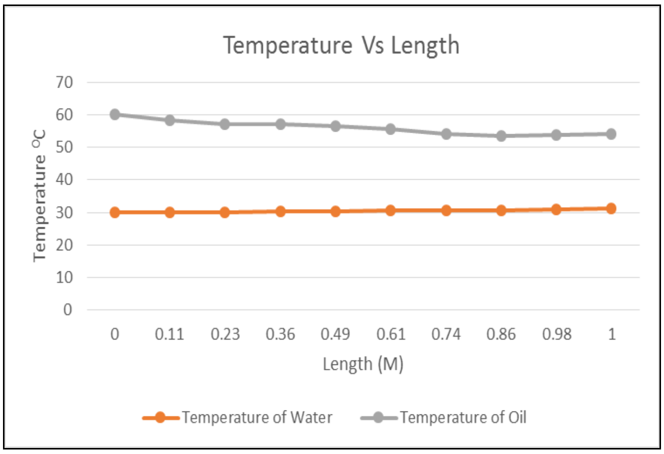

Figure 4.7 : Temperatures at differnet point along the length from inlet to outlet (without insert)

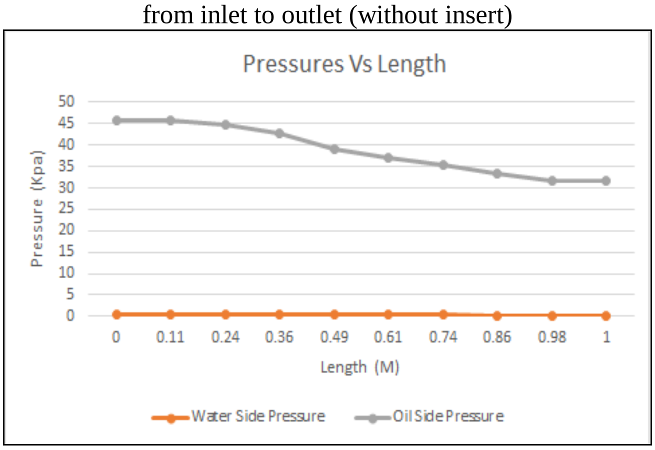

Figure 4.8 : Pressures at differnet point along the length from inlet to outlet (without insert)

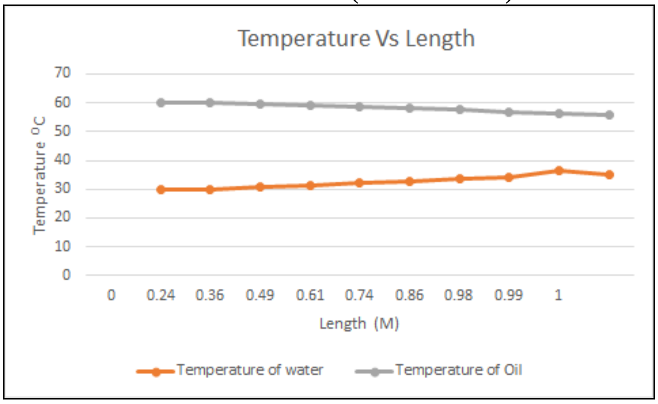

Figure 4.9 : Temperatures at differnet point along the length from inlet to outlet (with insert)

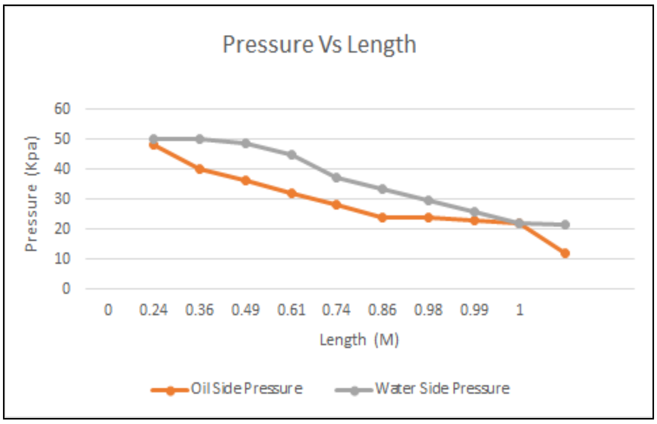

Figure 4.10 : Pressures at differnet point along the length from inlet to outlet (with insert)

5. Results and Discussion

The aim of this work was to optimize the physical dimension of shell and tube heat exchanger. The results have been found from two methods. First is analytical analysis for both conditions with and without insert and second is CFD simulation it is also for both conditions with and without insert. CFD simulation was performed on ANSYS 14.5 Fluent.

Table 5.1: Comparison of analytical result without and with insert

Thermal Output:-	*Unit*	*Without Insert*	*With Insert*
Outlet Temperature oil	^oc	54.9	54.9
Outlet Temperature of water	^oc	31.3	31.3
LMTD (Counter Flow)	^oc	26.75	26.75
ho (Outside heat transfer coefficient)	w/m^2-^oc	815.06	6480.71
hi (Inside heat transfer coefficient)	w/m^2-^oc	2516.60	909.466
U design (Over all heat transfer coefficient)	w/m^2-^oc	495.66	1400.24
Q (Heat Load)	kw	9.52	26.89
Pressure drop oil side	kpa	18.7	52
Pressure drop water side	kpa	0.33	28.6
Design Conclusion:-			

U (Over all Heat Transfer Coefficient)	w/m^2-^oc	495.66	1400.24
Q Heat Load	kw	9.52	26.89
	-	Q=UAF ΔTm	Q=UAF ΔTm
	kw	9.52	9.68
Length	mm	1000	360
Number of Baffle	-	15	06

Table 5.2: Comparison of CFD simulation result without and with insert

Thermal Output:-	**unit**	**Without Insert**	**With Insert**
Outlet Temperature oil	^oc	54.21	56.05
Outlet Temperature of water	^oc	31.27	34.83
LMTD (Counter Flow)	^oc	26.40	25.60
ho (Outside heat transfer coefficient)	w/m^2-^oc	966.20	7448
hi (Inside heat transfer coefficient)	w/m^2-^oc	2150	1050
U design (Over all heat transfer coefficient)	w/m^2-^oc	526.53	1578.74
Q (Heat Load)	kw	9.98	29.01
Pressure drop oil side	kpa	14.40	36.21
Pressure drop water side	kpa	0.433	27.64
Design Conclusion:-			
U (Over all Heat Transfer Coefficient)	w/m^2-^oc	526.53	1578.74
Q Heat Load	kw	9.98	29.01
	-	Q=UA F ΔTm	Q=UAF ΔTm
	kw	9.98	10.44
Length	mm	1000	360
Number of Baffle	-	15	06

Table no. 5.1 and 5.2 shows the comparison of shell and tube heat exchanger with and without insert. In table no 5.1 the comparison of shell and tube heat exchanger with analytical method. The performance of shell and tube heat exchanger increased (Overall heat transfer coefficient 495.66 W/m^2-^oC to 1400.24 W/m^2-^oC) with insert according to analytical analysis. In table no 5.2 the comparison of shell and tube heat exchanger with CFD simulation. The performance of shell and tube heat exchanger increased (Overall heat transfer coefficient 526.53 W/m^2-^oC to 1578.74W/m^2-^oC) according to CFD simulation .It has been seen that after increased heat transfer with use of insert, heat exchanger can be optimized in the physical dimension. After Optimized it will give same heat dissipation with reduced length.

6. Conclusion

An investigation was carried out for optimizing the dimension of shell and tube heat exchanger using insert. Result is found from two ways analytical analysis and CFD simulation. Model was made on SolidWorks software and meshing was done in ANSYS 14.5. Simulation was performed on ANSYS 14.5 Fluent. The error has been found in analytical analysis results and in CFD simulation results. The error was more in pressure drop but it is in allowable limit. Based on the obtained result it can be concluded as follows.

- The performance of shell and tube heat exchanger was increased with insert**.**
- The overall heat transfer coefficient was increased by 182% in the analytical calculation and by 199% in CFD simulation results.
- The length of heat exchanger will be reduced from 1000 mm to 360mm (64%) according to both (analytical and CFD simulation) results.
- Number of baffle plate will be reduced from 15 to 6.

7. Future Scope

CFD simulation can carry out at different Software and Meshing can also perform at different software.

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