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Research Article

Experimental analysis of condensation heat transfer enhancement of steam at low pressures using modified twisted tape insert

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Abstract

This paper presents an experimental attempt of enhancement of condensation heat transfer coefficient of steam in the double pipe heat exchanger using modified twisted tape insert as an enhancement technique compared to conventional simple twisted tape insert. The experiments were conducted for dry saturated steam having approximate dryness fraction X=1 at low pressures separately in two test sections of heat exchanger having horizontal pipe employing simple twisted tape in first test section and modified baffled twisted tape along with nozzle type arrangement in path of flow for swirl flow generation in second test section. Readings were taken for different flow rates of steam as well as varying inlet steam temperatures and observations have been made for effective heat transfer exchange in the form of changing inlet and outlet temperatures of condensate and coolant. Experimental as well as analytical comparison has been done in between results of simple twisted tape and modified twisted tape. Results show that for same twist ratio Y=5, baffled tape creates more swirl generations in steam path as compared to simple tape resulting in providing more contact area for heat exchange process thus ultimately causing slight enhancement in condensation heat transfer rate of steam at the expense of reasonable pressure drop. In addition, graphs have also been plotted in between heat transfer rate and flow rate of steam as well as inlet steam temperature showing relations between these entities.

Keywords: *Condensation heat transfer, baffled tape, twist ratio, pressure drop.*

1. Introduction

Heat exchangers are used in different processes ranging from conversion, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. Some common examples include steam generation & condensation in power & cogeneration plants; sensible heating & cooling in thermal processing of chemical, pharmaceutical & agricultural products; fluid heating in manufacturing & waste heat recovery etc. The need to increase the thermal performance of heat exchangers, thereby affecting energy, material & cost savings have led to development & use of many techniques termed as Heat transfer augmentation. The attempt of the investigators is to increase the magnitudes of the heat transfer coefficients both at inner and outer walls of the tube. Use of Heat transfer enhancement techniques lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. So, while designing a heat exchanger using any of these techniques, analysis of heat transfer rate & pressure drop has to be done. Moreover a comparative work has to be done between these techniques to select the best way for increasing thermal efficiency of heat exchanger.

Limited number of studies can be found in the literature with regard to condensation of vapors in a horizontal tube with twisted tapes also along with steam as a medium rather than refrigerant. John Henri Royal [5] has made an attempt to model the effects of twisted tape on the in tube condensation process. He found that twisted tape in contact with tube wall acts as fin generating swirl flows in path, for experiment he used 0.0149 in. thick twisted tape having width 0.527 inch.

Results shows increase in overall heat transfer coefficients with mass fluxes as well as equivalent diameters of tubes. P.k.sarma and colleagues shows how pitch to diameter ratio of tape inserts affects condensation heat transfer coefficient positively. The value of H/D lies between 2.5 to 10. At pressure 1.05-2atmosphere and local Reynolds number varying from 100-1000 it is found beneficial to employ low values of H/D=2.5 which is the same value for enhancement ratio for given system conditions. Mohammed Abd Raboh, Hesham Mostafa studies condensation heat transfer of steam inside helical coil, their findings show that condensation heat transfer coefficient for steam increases with decreasing pipe diameter and increases with coil pitch upto certain value i.e. p=40mm. An

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empirical correlation for nusselt number as a function of Reynolds number and examined operating entities are also established. Lopina and Bergles presented data regarding heat transfer and pressure drop in swirl flow created by tapes. S.Nagasarda,A.V.Sitaramraju,L Shyamsunder proposed work for review on twisted tape heat transfer enhancement, they show that enhancement of heat transfer with twisted tape as compared to plain tube varied from 36 to 48% for full width tape. This enhancement is mainly caused due to centrifugal force generated by swirl motion of fluid. Gaurav Johar, Virendar Hasda has incorporated use of modified twisted tape inserts in heat transfer enhancement work for tube side flow of liquids. Many of the work in the area of two phase heat transfer has been done mainly with refrigerants as a working medium. It is clear from previous papers and upto the knowledge that most of work in two phase flows has been made by using simple twisted tapes along with refrigerant as working medium. Thus the main objective behind this attempt is to find out condensation heat transfer enhancement using steam as working medium and that also by employing modified twisted tape. For experimental work, full width twisted tapes are used. Two designs of twisted tapes used are- Simple full width twisted tapes, Baffled full width twisted tapes. Same twist ration has been employed purposely for both twisted tapes for better comparison criterion.

2. Heat Exchanger and other specifications

A double pipe heat exchanger is fabricated having two concentric pipes in operation. Material for both pipes is copper, outer pipe having 1.75 inch Dia. Compared to inner pipe which is approx ½ inch in Diameter. Dry saturated steam at low pressures employed from pressure cooker flows through inner pipe while coolant i.e. cold water flows through annulus passage in counter current direction. Demister pad or sponge pad is placed in the path of steam to absorb as many water particles as it can and provide approx dry steam for further operation. Two test sections of heat exchanger are used, one consisting of simple twisted tape insert while other section consist of modified baffled twisted tape insert along with nozzle type arrangement at the entrance of the pipe. Nozzle arrangement is nothing but a piece of copper cut in nozzle shape and having protrusions on its surface in inclined manner which are attached on inner surface of steam pipe providing swirly flow.

Inner pipe ID, d= 22mm
Inner pipe OD, d =25mm
Outer pipe ID, D= 53 mm
Outer pipe OD, D= 61mm
Material of construction= copper
Heat transfer length= 1m
Twisted tapes: 2NO.
1) Simple twisted tape
2) Modified baffled twisted tape
Width: 16mm
Thickness: 1.80mm
Material: stainless steel.

Strips of rectangular shape are used as baffles of size 16mm*10mm*1.80mm.
Twist ratio Y=5
Pitch= 2.72inch/180^0 twist.
Condition of steam: dry saturated X=1
Saturated steam temperature: 100.16^0c (Abs)

3. Experimentation

Experimental test section consist of two concentric tubes in which steam flows through tube and cold water flows in counter flow through annulus. The outer tube is coated with asbestos rope to prevent heat loss to surroundings.

Fig.1 Actual experimental test sections.

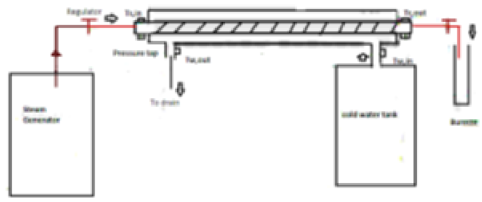

Fig.2 Schematic diagram of experimental setup

Tests are performed for three different flow rates 0.53, 0.58, 0.67 kg/min. Steam flow rate is calculated by measuring volume of water evaporating per unit given time while flow rate of coolant being measured by rotameter. Steam as required at low pressures hence generated by household pressure cooker having range of pressure up to 1.8 to 2 bar is allowed to pass through demister pad at low pressures ranging about 0.0118 bar to 0.1144 bars so that wet steam loses its water particles and we get steam which is in approximate dry saturated condition required for condensation process. This steam is then allowed to flow through inner pipe of heat exchanger where simple or baffled twisted tape along with nozzle shape arrangement is deployed in the path. On the other hand coolant i.e. cold water is allowed to pass through outer tube in counter flow direction using pump power which in turn provide continuous flow. This procedure repeated for all different flow rates and temperatures at inlet and outlet conditions are measured both for steam as well as coolant water by using thermocouples and temperature indicator. Data is plotted in form of observations and combined chart has been prepared.

Fig.3 Actual experimental setup

Fig .4 Nozzle shape arrangement at entrance of pipe Containing baffled twisted tape

4. Heat Transfer Calculations

Sample Correlations to be used for calculation of Condensation Heat Transfer coefficient:

1) Average condensation heat transfer coefficient (h):

$$\frac{1}{h}=\left[\frac{1}{hoverall}-\frac{1}{ho}\right] \quad (1)$$

Where, $h_{overall}$= overall heat transfer coefficient (W/mk).
h_o= heat transfer coefficient on the coolant side (W/mk).

2) Overall heat transfer coefficient ($h_{overall}$):

$$hoverall\times\Delta Tm=qw \quad (2)$$

Where,
q_w = wall heat flux (W/m)

$$\Delta Tm=\frac{(Ts-Ti)-(Ts-To)}{\ln\left[\frac{Ts-Ti}{Ts-To}\right]}$$

T_s= saturation temperature of steam at system pressure P.
T_i= temperature of coolant at inlet.
T_o= temperature of coolant at exit of test section.

3) Heat transfer coefficient on coolant side (h_o):

$$ho\times\Delta T1=qw \quad (3)$$

Where,

$$\Delta T1=\frac{(Tw1-Ti)-(Tw2-To)}{\ln\left[\frac{Tw1-Ti}{Tw2-To}\right]}$$

Tw1= temperature of wall of tube at inlet of coolant.
Tw2= temperature of wall of tube at outlet of coolant

5. Observations

Table 1.1 Sample observations for simple twisted tape including parameters for steam and cooling water:

Sr no	M_s (kg/s)	$P_{s,in}$ (kpa)	$T_{s,in}$ (^{0}c)	$T_{c,out}$ (^{0}c)	M_w (kg/s)	$T_{w,in}$ (^{0}c)	$T_{w\ out}$ ^{0}c
1	0.00896	1.18	100.3	34.1	0.2731	10.6	30.9
2	0.00972	9.09	102.4	46.7	0.2746	11.4	31.7
3	0.01131	11.4	103.0	49.7	0.2746	11.1	36.1

Table 1.2 Sample observations for modified baffled twisted tape along with nozzle type arrangement including parameters for steam and cooling water

Sr no	M_s (kg/s)	$P_{s,in}$ (kpa)	$T_{s,in}$ (^{0}c)	$T_{c,out}$ (^{0}c)	M_w (kg/s)	$T_{w,in}$ (^{0}c)	T_w out ^{0}c
1	0.00896	1.18	100.3	33.3	0.2731	10.6	32.5
2	0.00972	9.09	102.4	43.8	0.2746	11.4	35.4
3	0.01131	11.4	103.0	48.3	0.2746	11.1	38.9

6. Results and Discussions

Depending on various observations made during experimentation process, following graphs are plotted for given entities showing relations in between them.

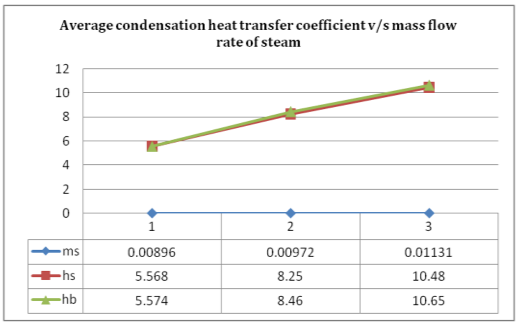

Fig.5 Plot between average condensation heat transfer coefficient v/s rates of flow of steam

First graph shows relation between average condensation heat transfer coefficient and mass flow rate of the steam. Second graph shows relation between average condensation heat transfer coefficient and inlet temperature of steam. Finally third graph shows relation between inlet temperature and mass flow rate of steam.

In the above graph it is clear that there is slight enhancement in average condensation heat transfer coefficient in case of baffled twisted tape as compared to simple twisted tape against mass flow rate of steam.

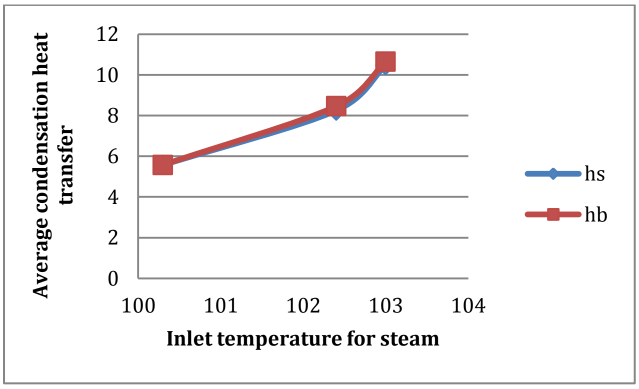

Fig.6 Plot between average condensation heat transfer coefficient v/s inlet temperatures of steam.

As inlet saturation temperature of steam goes on increasing there is increase in average condensation heat transfer coefficient value.

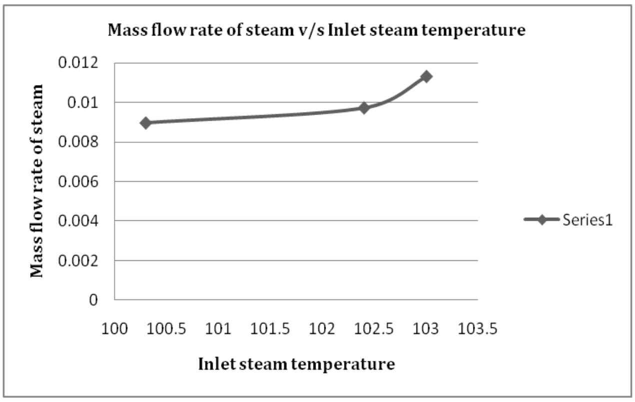

Fig.07 Plot between mass flow rate v/s inlet temperatures of steam

As inlet temperature for steam goes on increasing the percentage conversion of water into steam also increases resulting into increased flow rate.

7. Thermal analysis using Computational Technique (CFD)

Computational Fluid Dynamics (CFD) provides a qualitative and quantative prediction of fluid flows by means of mathematical modeling, numerical methods (discretization and solution techniques) ,software tools (solvers, pre- and post processing utilities) CFD enables scientists and engineers to perform 'numerical experiments' (i.e. computer simulations) in a 'virtual flow laboratory. The results of a CFD simulation are never 100% reliable because the input data may involve too much guessing or imprecision the mathematical model of the problem at hand may be inadequate the accuracy of the results is limited by the available computing power.

Assumptions made in this system:
1) Steady state thermal analysis
2) Flow at the inlet surface is assumed to be uniform
3) Incompressible flow and homogeneous materials are considered
4) Working fluid- Water and Steam

Table 1.3 Boundary condition details For Reading no.01

	Flow Rate	Inlet Temp
Steam	0.00896 kg/sec	100.2⁰c
Water	0.2731 kg/sec	10.8⁰c
Wall	-----	Ta=25⁰c, h=6w/m²k

Note: Ta and h represent the ambient condition.

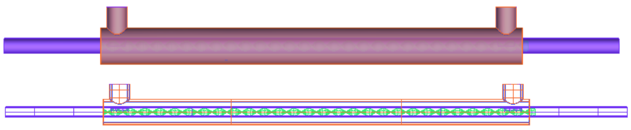

Fig.8 Modeling of Test Section

Table 1.4 Material Properties

Material	Density (kg/m³)	C_p (J/kgk)	K (W/m²k)	Viscosity (Pa.s)
Steam	0.59837	2080.1	0.0251	$1.227e^{-5}$
Water	997	4181.7	0.6069	0.0008899
Steel	7854	434	60.5	--------
Copper	8933	385	401	--------

Results – Temperature Distribution

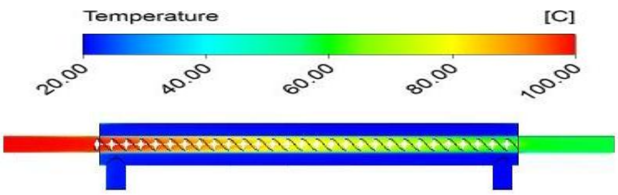

Fig.9 Temperature Distribution for Tube with simple twisted tape inserts.

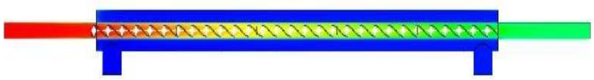

Fig.10 Temperature Distribution for Tube with modified baffled twisted tape inserts.

Table 1.5 Results from software analysis

	Twist1(simple)	Twist2(Baffled)
Water inlet flow(kg/sec)	0.2731	0.2731
Water inlet Temp (^{0}c)	10.8	10.8
Water outlet Temp (^{0}c)	27.33	29.36
Steam Inlet flow (kg/sec)	0.009	0.009
Steam inlet temp(^{0}c)	100.2	100.2
Steam outlet temp(^{0}c)	38.74	37.31
Heat Extraction(W)	782.46	830.02

Table 1.6 Comparative results of Experimental & Software method for Reading no.01

Sr No.	Method	Type of Tape	h (W/mk)	Q_w (J/sec)
1	Experimental	Simple	5.568	295.54
		Baffled	5.574	330.49
2	Software	Simple	5.57	240.66
		Baffled	5.83	270.21

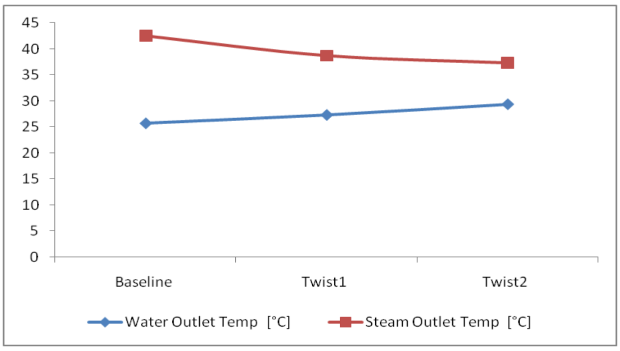

Fig.11 Variation of outlet temperatures of water and steam for simple and baffled twisted tapes

Conclusions

In the present work, we study the impact of simple twisted tape as well as modified twisted tape on condensation heat transfer enhancement. For increasing condenser efficiency in various applications, these exchanger design modifications play a vital role. But among various design modifications also some comparison work has been done here to evaluate which enhancement technique gives better result in increasing coefficient value for same capacity condenser. Simple twisted tapes are widely used since long ago but here an attempt has made to replace conventional mechanism of simple tape with modified baffled twisted tape to check whether it affects the results. Thus it is found that modified tapes creates more swirl generations in path flow of steam as compared to simple tapes which results in increased contact area for heat transfer process ultimately increasing the condensation rate and condensation heat transfer coefficient for steam.

Average condensation heat transfer coefficient is found to increase with inlet steam temperature as well as mass flow rate of steam. Expermental value for average condensation heat transfer coefficient in case of simple tape as well as baffled twisted tape has found to be in good agreement with software analysis results. Mass flow rate of steam is kept variable and at three different mass flow rates experimentation has been performed. In case of simple tape experimental value for average condensation heat transfer coefficient is 5.568 w/mk while software analysis gives 5.57w/mk whereas Baffled twisted tape gives 5.574w/mk experimentally and 5.83 w/mk by software analysis. A valid variation has been found in between experimental and software method. A slight enhancement of 4.45% has been found in case of baffled twisted tape. Thus it is predicted from both experimental and software method that Baffled tape has to be chosen over simple tape in designing heat exchangers for better performance characteristics.

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