Design, Fabrication and Testing Of Helical Tube in Tube Coil Heat Exchanger

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***Abstract*— In present experimental work I have designed the Helical Tube In Tube coil Heat Exchanger for a given input data. By taking the reference of designing Helical Coil In shell Heat Exchanger I have designed the Tube In Tube Coil Heat Exchanger. While designing, considered the inner tube diameter as 6.4 mm and outer tube diameter as 12.5 mm . After going through the number of steps in designing process I come to conclusion that No. Of turns required are 6 and length of tube required is 2.5m.**

On the basis of design, by some suitable manufacturing process fabricated the coil. And Experimental Set Up is also prepared as per requirement. Tested the Heat Exchanger in Parallel and Counter Flow Configuration. Observations are noted down for mass flow rate and temperature difference of Hot fluid and water.

On the basis of observations, calculated the LMTD, Capacity Ratio, Universal Heat Transfer coefficient and Effectiveness for Parallel flow and Counter Flow Configuration and compared both the configuration. Also plotted the graph for the same and concluded the work.

***Index Terms*—Helical Tube, LMTD, Heat Exchanger.**

I. DESIGN METHODOLOGY

Here I will design the Helical Tube in Tube Coil Heat Exchanger For the Given Input Data

1.1 Input Data :-

Input data	Inner Tube (Veg.oil base)	Annulus (water)
Mass flow rate M (kg/h)	0.3	600
Inlet temperature (°C)	75	30
Outlet temperature (°C)	40	42
Specific Heat Cp (KJ/kg k)	1.67	1
Thermal Conductivity k (kcal/h m ° C)	0.78	0.609
Viscosity of oil μ (kg /m h)	1.296	1.12

1.2 Schematic Cut way of Heat Exchanger: -

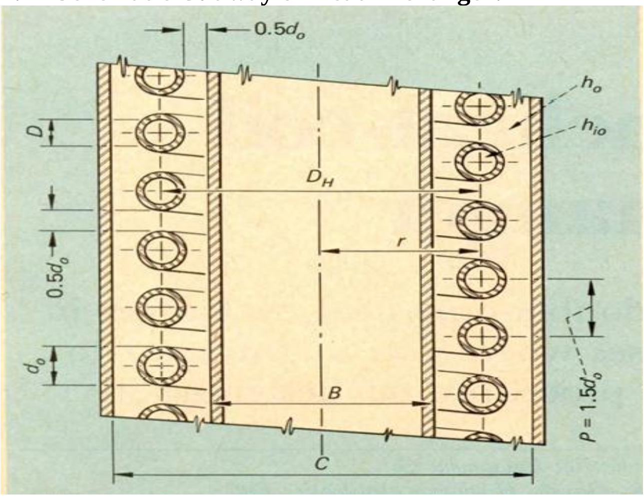

Fig. 1.1 Schematic Cut Way of Heat Exchanger

Where,

r = Mean Coil Radius (m)
p = Pitch (m)
d_o = Diameter of Inner Tube (m)
D = Diameter of outer Tube (Annulus) (m)
De = Equivalent Outside Diameter of Coil (m)
C = Outside Wetted diameter of Annulus (m)
B = Inside wetted diameter of Annulus (m)
DH_2 = Outside diameter of Helix of Inner Coil (m)
DH_1= Inside diameter of Helix of Inner Coil (m)
N = No. of turns of coil
L = Length of tube to make N turns (m)
Gs = Mass flow velocity of fluid (Kg/m^2 h)
M = Mass flow rate of fluid (Kg/h)
A = Area of Coil (m^2)
N_{Re} = Reynolds Number
Q = Heat Load (Kcal / h)
U = Overall Heat Transfer Coefficient (Kcal /h m^2 °C)

1.3 Reference Data :-

To Design the Heat Exchanger for given input data I have taken following data to start the actual design. Because I have to assume some data on practical /manufacturing base. Thus Following data is taken as Input to design the Heat Exchanger

- Diameter Of Inner Tube (d_o) = 6.4 mm
- Diameter Of Annulus (D) = 12.5 mm
- Mean Coil radius (r) = 62.5 mm (Due To Space Constraints and Mandrel Size)
- Pitch (p) = 1.5 d_0 = 1.5 * 6.4 = 9.6 mm , but I took pitch p = 30 mm

Minimum pitch should be 20 mm , taking into consideration the manufacturing process , the inner tube is covered with outer tube with 12.5 mm diameter thus it is not

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possible to maintain pitch of less than 25 mm , hence pitch is taken to be 30 mm

1.4 Problem and its Solution

- Problem

  Design (Calculate) No. Of Turns(N) and Length of Tube to make N turns for the Given Input Data.

- Solution

1. Length Of Coil

   $L = N \sqrt{(2\pi r)^2 + p^2}$

   $L = N \sqrt{(2 * \pi * 0.0625)^2 + (0.03)^2}$

   $L = 0.394\ N$

2. Mass flow velocity of fluid through the annulus

   $Gs = M / [\pi/4 \{ (C^2 - B^2) - (DH_2^2 - DH_1^2) \}]$

   $C = 2r + d_o + (2 * 0.5\ d_o)$

   $C = 2 * 0.0625 + 0.0064 + 2 * 0.5 * 0.0064$

   $C = 0.138\ m$

   $B = 2r - d_o - (2 * 0.5\ d_o)$

   $B = 2 * 0.0625 - 0.0064 - 2 * 0.5 * 0.0064$

   $B = 0.112\ m$

   $DH_2 = 2r + d_o$

   $DH_2 = 2 * 0.0625 + 0.0064$

   $DH_2 = 0.131\ m$

   $DH_1 = 2r - d_o$

   $DH_1 = 2 * 0.0625 - 0.0064$

   $DH_1 = 0.118\ m$

   $Gs = 0.3 / [\pi/4 \{ (0.138^2 - 0.112^2) - (0.131^2 - 0.118^2) \}]$

   $Gs = 117.046\ Kg/m^2\ h$

3. Reynolds Number

   $N_{Re} = Gs\ De / \mu$

   $N_{Re} = 117.046 * 0.138 / 1.296$

   $N_{Re} = 12.46$

4. Heat Transfer Coefficient (h_o)

   $h_o\ De / k = 0.6 (N_{Re})^{0.5}$

   $h_o = 0.6 * (12.46)^{0.5} * 0.78 / 0.138$

   $h_o = 11.97\ K\ Cal / h\ m^2\ °c$

   Also we know that ,

   $1 / U = /h_o$

   Therefore $U = h_o$

   $U = 11.97\ Kcal / h\ m^2\ °c$

5. Area Of Coil

   $A = Q / U\ \Delta T$

   $Q = m\ C_p\ \Delta T$

   $Q = 0.3 * 1.67 * (75-40)$

   $Q = 17.535$ Kcal

   $A = 17.535 / 11.97 * (75-40)$

   $A = 0.042\ m^2$

6. Number of Coil Turns (N)

   $N = A / \pi\ d_o\ L / N$

   $N = 0.042 / 3.142 * 0.0064 * 0.394$

   $N = 5.3$

   Hence Selected No. Of Turns N = 6

And Length of Tube L = 0.394 * 6 = 2.364 m

Thus minimum length of coil =2.364 m

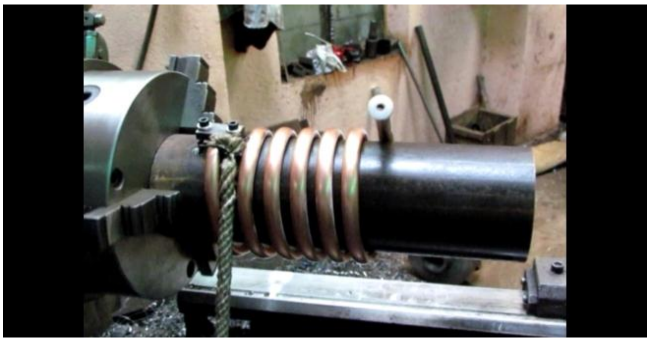
Considering the fittings and other joints required at entry and exit of the set-up, actual length of coil with fittings and connections is accounted and taken to be 2.5 m .

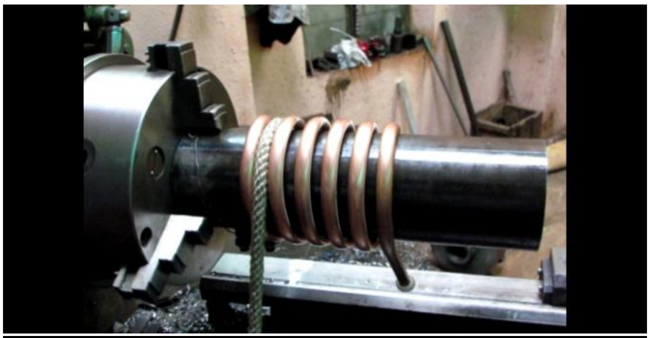
II. FABRICATION AND EXPERIMENTAL SETUP

2.1 Fabrication Of Coil

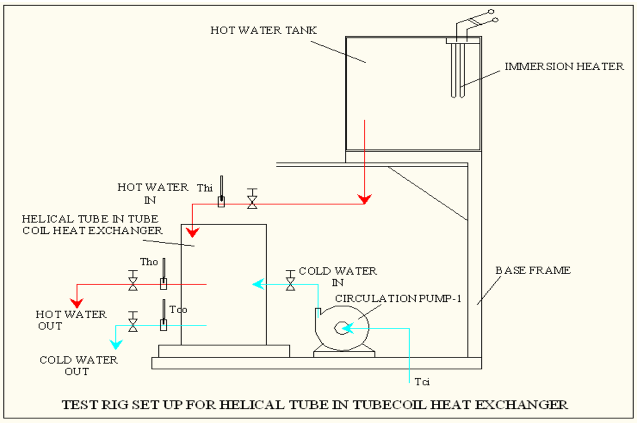
The heat exchangers coil is manufactured from copper material. The inner tube having dia. 6.4 mm and outer tube of dia. 12.5 mm. Pitch is of 30 mm . The curvature radius of the coil is 62.5 mm and the stretched length of the coil is 2000 mm. While the bending of tubes very fine sand filled in tube to maintain smoothness on inner surface and this washed with compressed air. The care is taken to preserve the circular cross section of the coil during the bending process. The end connections soldered at tube ends and two ends drawn from coiled tube at one position

To maintain the pitch (p) 30 mm we take the rope of diameter 20 mm and maintain the pitch as shown in photo. Below are some photos while manufacturing the coil.





2.2 Proposed Experimental Set Up :



TEST RIG SET UP FOR HELICAL TUBE IN TUBECOIL HEAT EXCHANGER

2.3 Actual Experimental Set Up :

We fitted the coil on a Stand for the purpose of mobility and ease of storage. We connected helical coil to Storage Tank through Rubber Pipe. We will heat the fluid in storage tank by the water heater. Hot fluid is flowing through the inner tube while cold fluid will flow through the annulus. As we arranged the storage tank on the top side, hot fluid will flow through the gravity. To circulate the cold fluid we will use the submersible water pump, necessary electrical connection are arranged as per requirement. To control the flow , valves are given at necessary location

III. TESTING OF HEAT EXCHANGER

Input Data For Testing :-

○ Hot Fluid through Inner Tube

- SAE 20 W 40 Oil

○ Cold Fluid through Outer Tube (Annulus)

- Water

○ Properties Of SAE 20 W 40 Oil

- SPECIFIC GRAVITY = 0.913

- SPECIFIC HEAT = 0.406 Btu / lb-F =1.7 KJ/KGK

Note:

1 kJ/(kg K) = 0.2389 kcal/(kg ^oC) = 0.2389 Btu/(lb_m ^oF)

- Hence specific heat of SAE20W40 = 0.406 x1/ 0.2389 = 1.6999 = 1.7 kJ/kg-k

○ Properties Of Water

- Specific Heat of water at (25 to 30 ^{0} C) = 4.187 kJ/kg-k

3.1 Procedure For Testing:-

We will Test the Heat Exchanger in two Configurations

1. Parallel Flow Configuration
2. Counter Flow Configuration

○ Procedure For Testing In Parallel Flow Configuration

1. Heat oil in the top tank up to desired temperature by heater

2. Start flow of oil in downward direction

3. Start cooling water pump, and send water top to bottom

4. Take mass flow readings for hot oil: Collect the Hot oil in measuring flask up to desired level and note down the time required to fill the hot oil up to desired level. It will give you the reading ml/Sec. Convert that reading into Kg/Hr

5. Also note down the temperature of Hot Oil at Inlet and Outlet

6. Take mass flow readings for cold water: Collect the Watero in measuring flask up to desired level and note down the time required to fill the hot oil up to desired level. It will give you the reading in Ltr/Sec. Convert that reading into Kg/Hr

7. Also Note down the Temperature Of water at Inlet and Outlet

○ Set Up Arrangement In Parallel Flow Configuration: -

○ Procedure For Testing In Counter Flow Configuration:-

1. Heat oil in the top tank up to desired temperature by heater

2. Start flow of oil in downward direction

3. Start cooling water pump, and send water bottom to top

4. Take mass flow readings for hot oil: Collect the Hot oil in measuring flask up to desired level and note down the time required to fill the hot oil up to desired level. It will give you the reading ml/Sec. Convert that reading into Kg/Hr

5. Also note down the temperature of Hot Oil at Inlet and Outlet

6. Take mass flow readings for cold water: Collect the Water in measuring flask up to desired level and note down the time required to fill the hot oil up to desired level. It will give you the reading in Ltr/Sec. Convert that reading into Kg/Hr

7. Also Note down the Temperature Of water at Inlet and Outlet

○ Set Up For Counter Flow Configuration

IV. OBSERVATIONS

4.1 Parallel Flow Configuration :-

4.1.1 Mass Flow Rate of Hot Oil

Sr. No.	Volume In Beaker (mL)	Time (Sec)	Mass Flow (Kg/sec)
1.	200	31	0.0058
2.	400	56	0.0065
3.	600	86	0.0064
4.	800	116	0.0063
5.	1000	146	0.00625

4.1.2 Mass Flow Rate of Water

Sr. No.	Volume In Beaker (mL)	Time (Sec)	Mass Flow (Kg/sec)
1.	200	16	0.0125
2.	400	29	0.013
3.	600	44	0.0136
4.	800	60	0.0133
5.	1000	70	0.0142

4.1.3 Temperature Reading

(Unit: ° C)

Sr. No.	Water Inlet Temp. (Tci)	Water Outlet Temp. (Tco)	ΔT WATER	Hot Oil Inlet Temp. (Thi)	Hot Oil Outlet Temp. (The)	ΔT OIL
1.	28	34	6	90	61	29
2.	28	35	8	89	60	29
3.	28	36	8	90	58	32
4.	28	36	9	91	57	34
5.	28	37	10	90	55	35

4.2 Counter Flow Configuration : -

4.2.1 Mass Flow Rate Of Hot OIL

Sr. No.	Volume In Beaker (mL)	Time (Sec)	Mass Flow (Kg/sec)
1	200	35	0.005
2	400	76	0.0048
3	600	114	0.0048
4	800	156	0.0047
5	1000	190	0.0048

4.2.2 Mass Flow Rate Of Water

Sr. No.	Volume In Beaker (mL)	Time (Sec)	Mass Flow (Kg/sec)
1.	200	18	0.01
2.	400	34	0.012
3.	600	55	0.011
4.	800	76	0.0105
5.	1000	93	0.0107

6.2.3 Temperature Reading

(Unit: °C)

Sr No.	Water Inlet Temp. (Tci)	Water Outlet Temp. (Tco)	ΔT WATER	Hot Oil Inlet Temp. (Thi)	Hot Oil Outlet Temp. (The)	ΔT OIL
1.	28	36	8	90	53	37
2.	28	38	10	89	51	38
3.	28	35	7	90	49	41
4.	28	38	10	88	50	38
5.	28	39	11	92	52	40

V. RESULTS

5.1 Parallel Flow Configuration :-

Result Table

Sr. No.	(m Cp ΔT)$_{Oil}$	(m Cp ΔT)$_{Water}$	LMTD (θm)	Overall Heat Transfer Coefficient (U)	Capacity Ratio	Effectiveness
	KJ /Sec	KJ /sec	° C	W/m2 ° K	C	ε
1	0.286	0.314	42.1	161.71	0.189	0.47
2	0.32	0.435	40.35	189.08	0.2	0.48
3	0.348	0.456	38.6	217.8	0.19	0.52
4	0.364	0.501	38.23	226.78	0.192	0.54
5	0.372	0.595	35.57	248.92	0.178	0.56

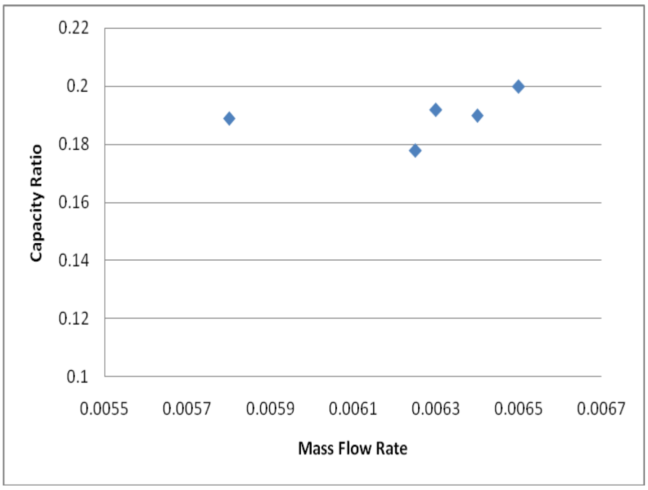
5.2 Counter Flow Configuration:

Result Table

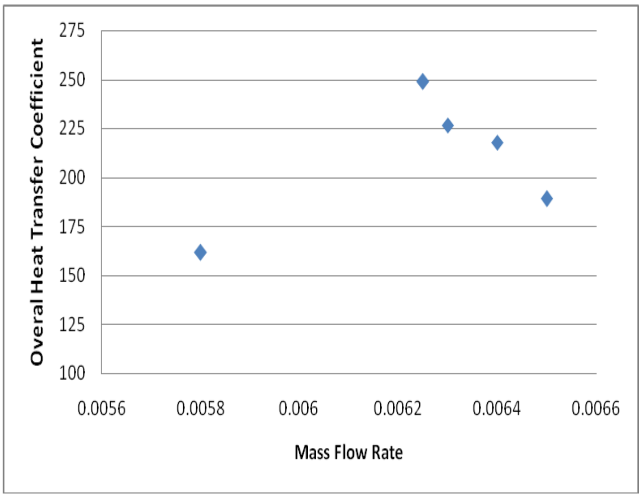
Sr. No.	(m Cp ΔT)$_{Oil}$	(m Cp ΔT)$_{Water}$	LMTD (θm)	Overall Heat Transfer Coefficient (U)	Capacity Ratio	Effectivness
	KJ/Sec	KJ/Sec	° C	W/m2 ° K	C	ε
1	0.315	0.335	37.65	198.89	0.215	0.60
2	0.310	0.502	35.16	209.98	0.159	0.62
3	0.335	0.322	35.31	225.57	0.178	0.66
4	0.304	0.440	34.11	211.96	0.182	0.63
5	0.326	0.493	36.61	212.31	0.178	0.63

5.3 Graph For the Trends Of Results In Parallel Flow and Counter Flow Configuration

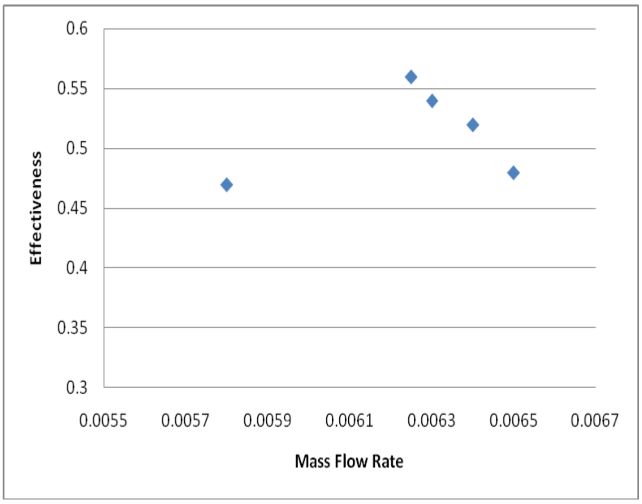
5.3.1 Trends Of Results In Parallel Flow Configuration



5.3.1.1 Mass Flow Rate Vs Capacity Ratio



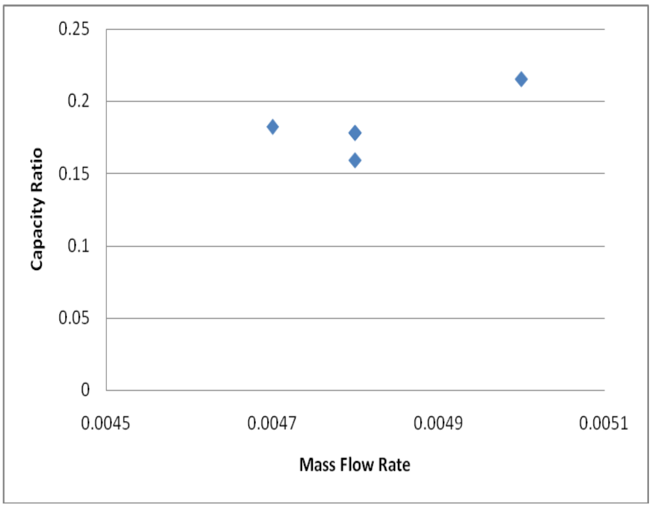
5.3.1.2 Mass Flow Rate Vs Overall Heat Transfer Coefficient



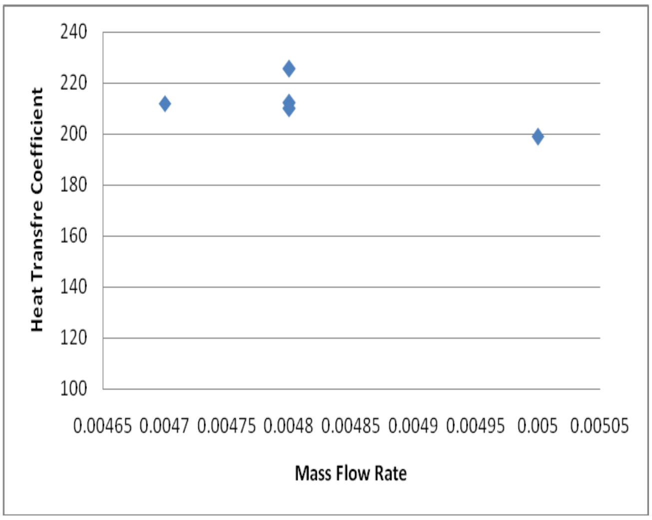
5.3.1.3Mass Flow Rate Vs Effectiveness

7.3.1.3

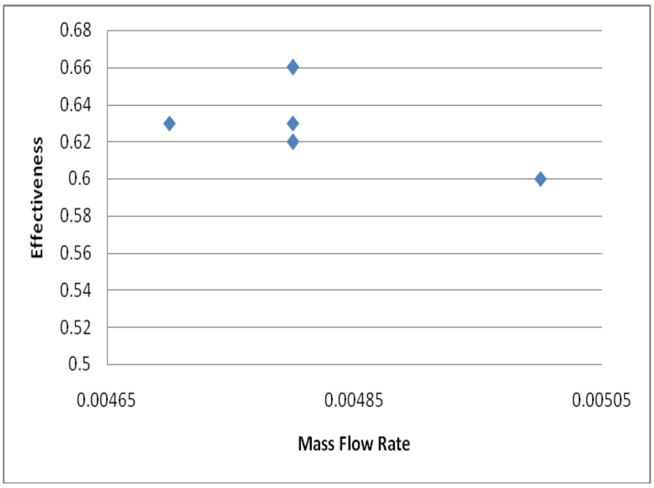
5.3.2 Trends Of Results In Counter Flow Configuration



5.3.2.1 Mass Flow Rate Vs Capacity Ratio



5.3.2.2 Mass Flow Rate Vs Heat Transfer Coefficient



5.3.2.4 Mass Flow Rate Vs Effectiveness

VI. CONCLUSION

1. Capacity ratio of designed heat exchanger in counter flow configuration increases with increase in mass flow rate with maximum capacity ratio of 0.215
2. Capacity ratio of designed heat exchanger in parallel flow configuration increases with increase in mass flow rate with maximum capacity ratio of 0.2
3. Designed Helical coil in coil heat exchanger in counter flow configuration is 1.27 (ie, 0.66/0.52) times effective than the Helical coil in coil heat exchanger in parallel flow configuration

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