HEAT EXCHANGERS

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FINAL WORK

DESIGN OF A HEAT EXCHANGER FOT HEAT RECOVERY FROM EXHAUST GASES IN A VEHICLE CONTROL STATION.

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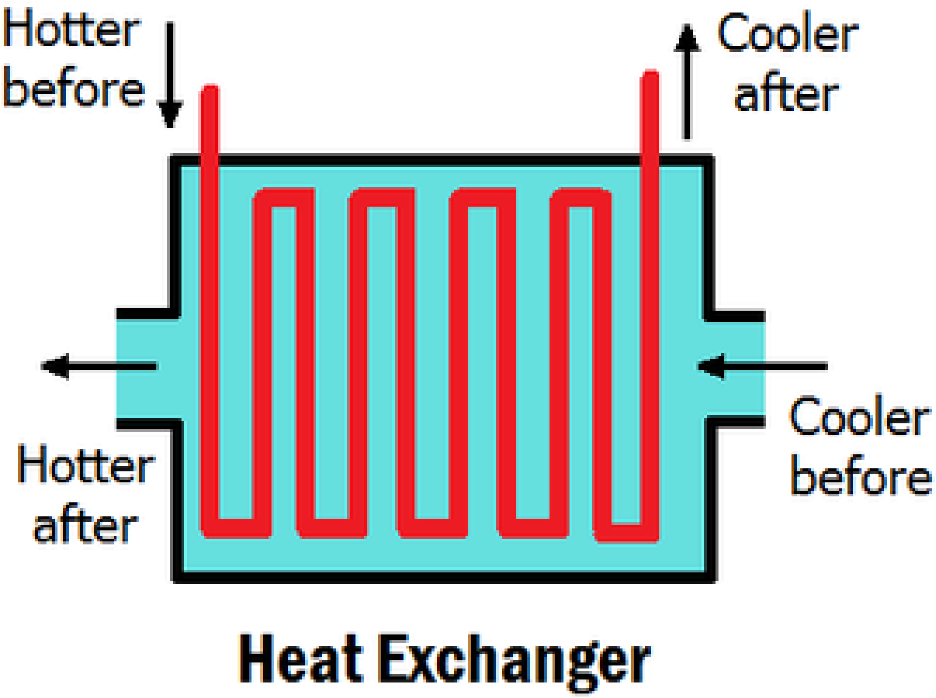
Academic course: 2018/2019.

HEAT EXCHANGERS



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1.INTRODUCTION.

Over the past quarter of 20th century, the importance of heat exchangers has increased immensely from the view point of energy conservation, conversion, recovery, and successful
implementation of new energy sources.

Currently, the economic returns keep being the most important task in most companies. Besides, although the emission of many atmospheric pollutants have been reduced notably during the last decades, concentrations of air pollutants remain being very high and air quality problems persist, so heat exchanger's importance is also increasing from the standpoint of enviromental concerns such as termal, air and water pollution.

With the aim of managing both points and improving the recovering of energy in a vehicle control station, this work present the design of a heat exchager that takes advantage of the exhaust gases in a central station of vehicles to heat water.

Heat transmission is the transfer of energy as a result of a driving force that we call temperature difference. Moreover, favorable temperature gradient is essential for heat transfer because if there is a situation of thermal equilibrium, there will not be heat transfer.

When two fluids that are at different temperatures are placed in thermal contact, the heat flows from the fluid of highest temperature towards the lower temperature fluid.

In addition, it is known that heat transmission is essential in the design of ovens, refrigerants, evaporators, reactors, dryers, heat exchangers,etc. So that, this work will show the main methods of heat exchange (LMTD and NTU Method), the different types of heat exchangers and the different criteria for selecting one type of heat exchanger or another one.

For the design of the heat exchanger, it has to be considered the fact that the heat exchange is between water and gas since the hot fluid is the exhaust gas and the cold one is the water that has to be heated. Moreover, in order to design the heat exchanger that fits correctly in the vehicle control station, the known data of these fluids have to be expose.:

In one hand, the known conditions of the gases are:

- Temperature of the gases at the entrance of the exchanger: 80º (353K)

- Temperature of the gases at the outlet of the exchanger: 40º (313K)

- Volumetric flow rate: 200 $m3$/h

In the other hand, the known conditions of the water are:

- Temperature of the cold water at the entrance of the exchanger: 10º (283K)

- Temperature of the cold water at the outlet of the exchanger: 35º (308K).

2.CLASSIFICATION OF HEAT EXCHANGERS.

Different heat transfer aplications require different types of hardware and different configurations of heat transfer equipment. Classification can be made according to construction features, to geometric classification, to transfer processes and to flow arrengements.

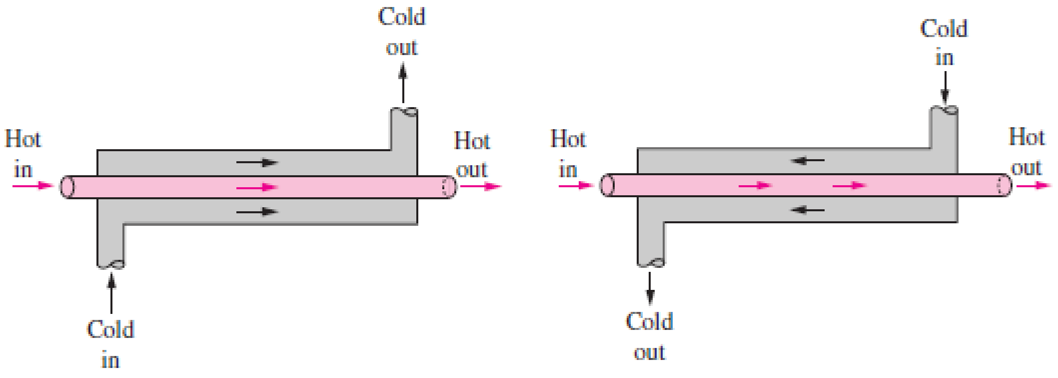
2.1. CLASSIFICATION ACCORDING TO CONSTRUCTION FEATURES.

2.1.1.TUBULAR HEAT EXCHANGERS.

Tubular heat exchangers are built of circular tubes. One fluid flows inside the tubes and the other flows on the outside of the tubes. Tube diameter, the number of tubes, the tube length, the pitch of the tubes, and the tube arrangement can be changed.

2.1.1.1.DOUBLE-PIPE HEAT EXCHANGERS.

The major use of double-pipe exchangers is for sensible heating or cooling of process fluids where small heat transfer areas (to 50 m2) are required. This configuration is also very suitable when one or both fluids are at high pressure. The major disadvantage is that double-pipe heat exchangers are bulky and expensive per unit transfer surface. Two types of flow arrangement are possible in a double-pipe heat exchanger: in parallel flow, both the hot and cold fluids enter the heat exchanger at the same end and move in the same direction. In counter flow, on the other hand, the hot and cold fluids enter the heat exchanger at opposite ends and flow in opposite directions.



(a) Parallel flow

(b) Counter flow

FIGURE 1. Different flow regimes and associated temperature profiles in a double-pipe heat exchanger. ([1]).

2.1.1.2.SHELL-AND-TUBE HEAT EXCHANGERS.

Perhaps the most common type of heat exchanger in industrial applications. They are characterized by containing a large number of tubes in a shell with their axes parallel to that of the shell. This kind of heat exchanger are not suitable for use in automotive and aircraft applications because of their relatively large size and weight.

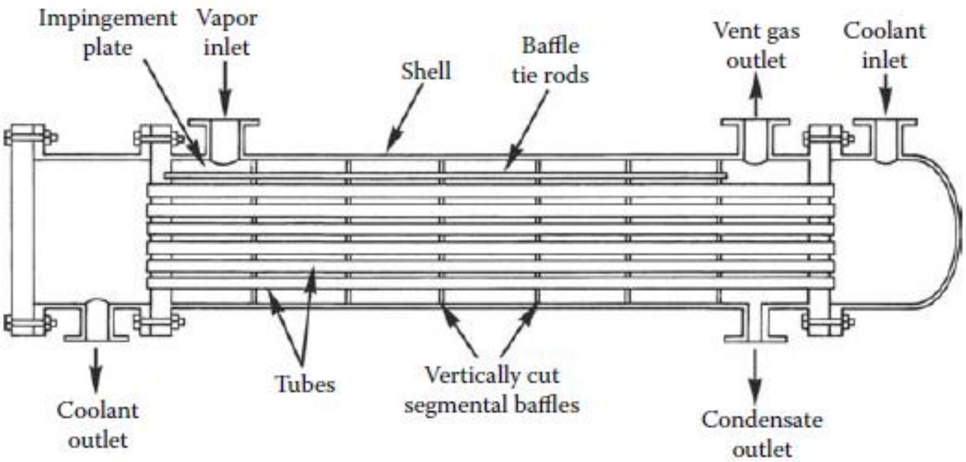


FIGURE 2. Shell-and-tube heat exchanger as a shell-side condenser.([2])

2.1.1.3.SPIRAL-TUBE-TYPE HEAT EXCHANGERS.

This consists of spirally wound coils placed in a shell or designed as coaxial condensers and coaxial evaporators that are used in refrigeration systems. They are used for thermal expansion and clean fluids, since cleaning is almost impossible.

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2.1.2. PLATE HEAT EXCHANGERS.

Plate heat exchangers are built of thin plates forming flow channels. The fluid streams are separated by flat plates which are smooth or between which lie corrugated fins. They are usually limited to fluid streams with pressures below 25 bars and temperature below about 250°C.

2.1.2.1. GASKETED PLATE HEAT EXCHANGERS.

A gasketed plate heat exchanger consists of a series of thin plates with corrugation or wavy surfaces that separate the fluids. **Gasketed plate heat exchangers are typically used for heat exchange between two liquid streams.**

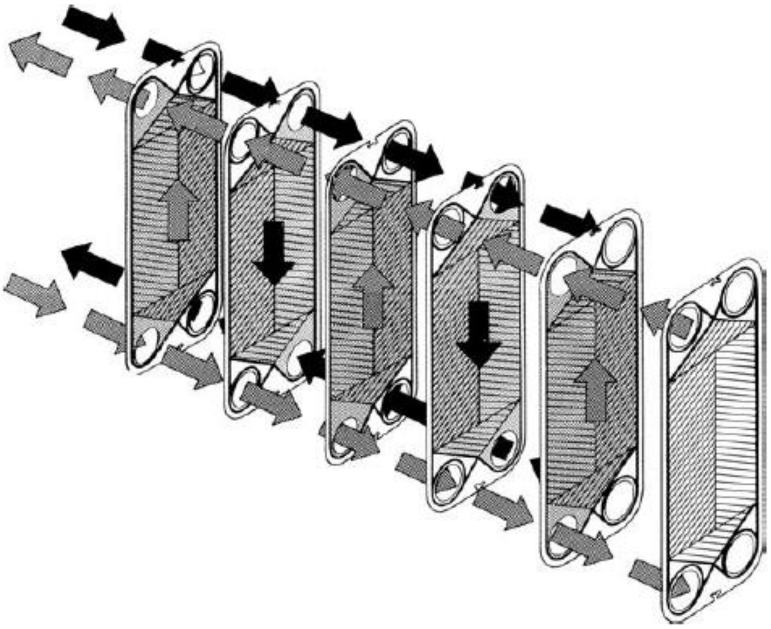


FIGURE 3. A diagram showing the flow paths in a gasketed plate heat exchanger. ([3])

2.1.2.2. SPIRAL PLATE HEAT EXCHANGERS.

Spiral plate heat exchangers are formed by rolling two long, parallel plates into a spiral using a mandrel and welding the edges of adjacent plates to form channels. Sizes range from 0.5 to 500 m2 of heat transfer surface in one single spiral body. The maximum operating pressure (up to 15 bar) and operating temperature (up to 500°C) are limited.

2.1.2.3. LAMELLA HEAT EXCHANGERS.

Consists of a set of parallel, welded, thin plate channels or lamellae (flat tubes or rectangular channels) placed longitudinally in a shell.

The plate bundle can be easily removed for inspection and cleaning. This design is capable of pressure up to 35 bar and temperature of 200°C for Teflon® gaskets and 500°C for asbestos gaskets.

2.1.3. EXTENDED SURFACE HEAT EXCHANGERS.

This kind of heat exchanger are devices with fins or appendages on the primary heat transfer surface (tubular or plate) with the object of increasing heat transfer area. Because of the fact that the heat-transfer coefficient on the gas side is much lower tan those on the liquid side, finned heat transfer surfaces are used on the gas side to increase the heat transfer area. Fins are widely used in gas-to-gas and gas-to-liquid heat exchangers whenever the heat-transfer coefficient on one or both sides is low.

The plate-fin heat exchangers are primarily used for gas-to-gas applications and tube-fin exchangers for liquid-to-gas heat exchangers**.**

2.1.3.1.PLATE-FIN HEAT EXCHANGER.

The fluid streams are separated by flat plates, between which are sandwiched corrugated fins. These heat exchangers are very compact units with a heat transfer area per unit volume of around 2,000 m2/m3. Special manifold devices are provided at the inlet to these exchangers to provide good flow distributions across the plates and from plate to plate.

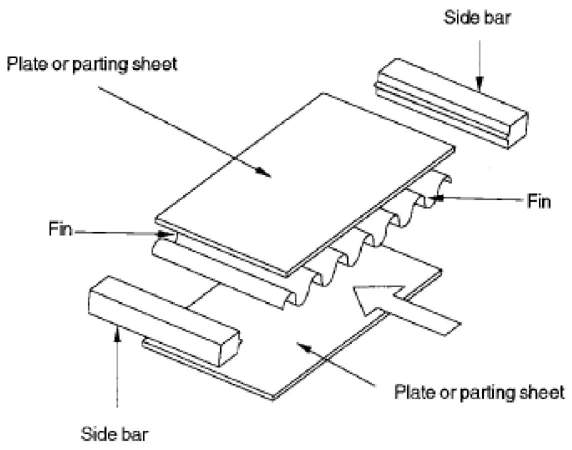


FIGURE 4. Parts of a plate-fin heat exchanger.([4])

2.1.3.2 TUBULAR-FIN HEAT EXCHANGERS.

A tubular-fin heat exchanger consists of an array of tubes with fins fixed on the outside. A heat exchanger having a surface area density on at least one side of the heat transfer surface greater than 700 m2/m3 is arbitrarily referred to as a compact heat exchanger. These heat exchangers are generally **used for applications where gas flows on at least one side of the heat transfer surface.** These heat exchangers are generally plate-fin, tube-fin, and regenerative.

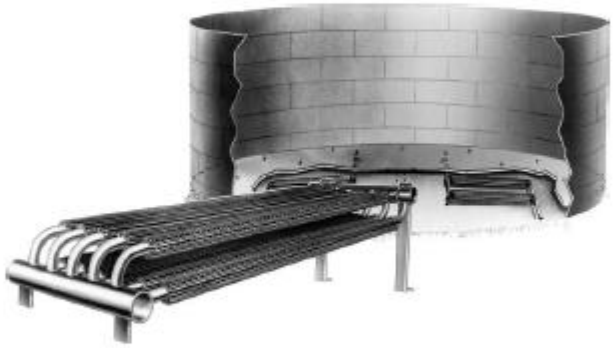


FIGURE 5. Longitudinally finned tubes. ([5])

2.2. CLASSIFICATION ACCORDING TO TRANSFER PROCESSES.

Heat exchangers are classified according to transfer processes into indirect- and direct contact types. The difference between both types is that in a indirect-contact heat

exchanger, the fluid streams are separated by an impervious dividing wall and heat transfer.
In the opposite side, in a direct-contact heat exchanger, heat transfers continuously from the hot fluid to the cold fluid through a dividing wall.

2.3. CLASSIFICATION ACCORDING TO NUMBER OF FLUIDS.

The most common type of heat exchanger are those where two fluid are involved since most processes of heating, cooling, heat recovery, and heat rejection transfer heat between two fluids.
Other types as threefluid heat exchangers are also used. For example, they are widely used in cryogenics and some chemical processes such as air separation systems.
Finally, it must be known that heat exchangers with as many as 12 fluid streams have been used in some chemical process applications too.

2.4. CLASSIFICATION ACCORDING TO FLOW ARRENGEMENTS.

The choice of a particular flow arrangement is principally based on the required exchanger effectiveness, available pressure drops, minimum and maximum velocities allowed, fluid flow paths, packaging envelope, allowable thermal stresses, temperature levels, piping and plumbing considerations.
There are two different types, the Single-Pass Exchangers and the Multipass Exchangers.
The concept of multipassing applies separately to the fluid and heat exchanger. A fluid is considered to have made one pass if it flows through a section of the heat exchanger through its full length. After flowing through one full length, if the flow direction is reversed and fluid flows through an equal- or different-sized section, it is considered to have made a second pass of equal or different size. A heat exchanger is considered as a single-pass unit if both fluids make one pass in the exchanger or if it represents any of the single-pass flow arrangements when the multipass fluid side is unfolded.
In addition,in one hand different types of single-pass heat exchanger are found such as counter flow exchanger, parallel flow Exchange, crossflow Exchange, Split-flow Exchange and dicided-flow Exchange.
In the other hand, Multipass Exchangers can be Multipass Crossflow Exchangers, Multipass Shell-and-Tube Exchangers or Multipass Plate Exchanger.

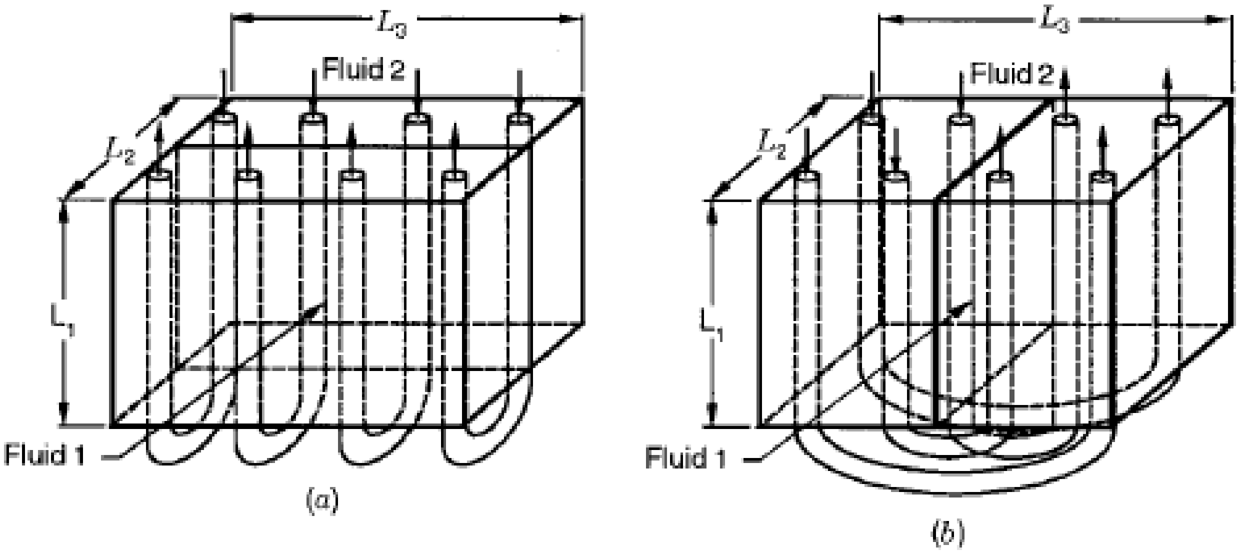


FIGURE 6. (a) Two-pass cross-counterflow Exchange; (b) single-pass crossflow exchanger. ([6]).

Finally, with the objective of summarizing the classificaition is exposed the next scheme.

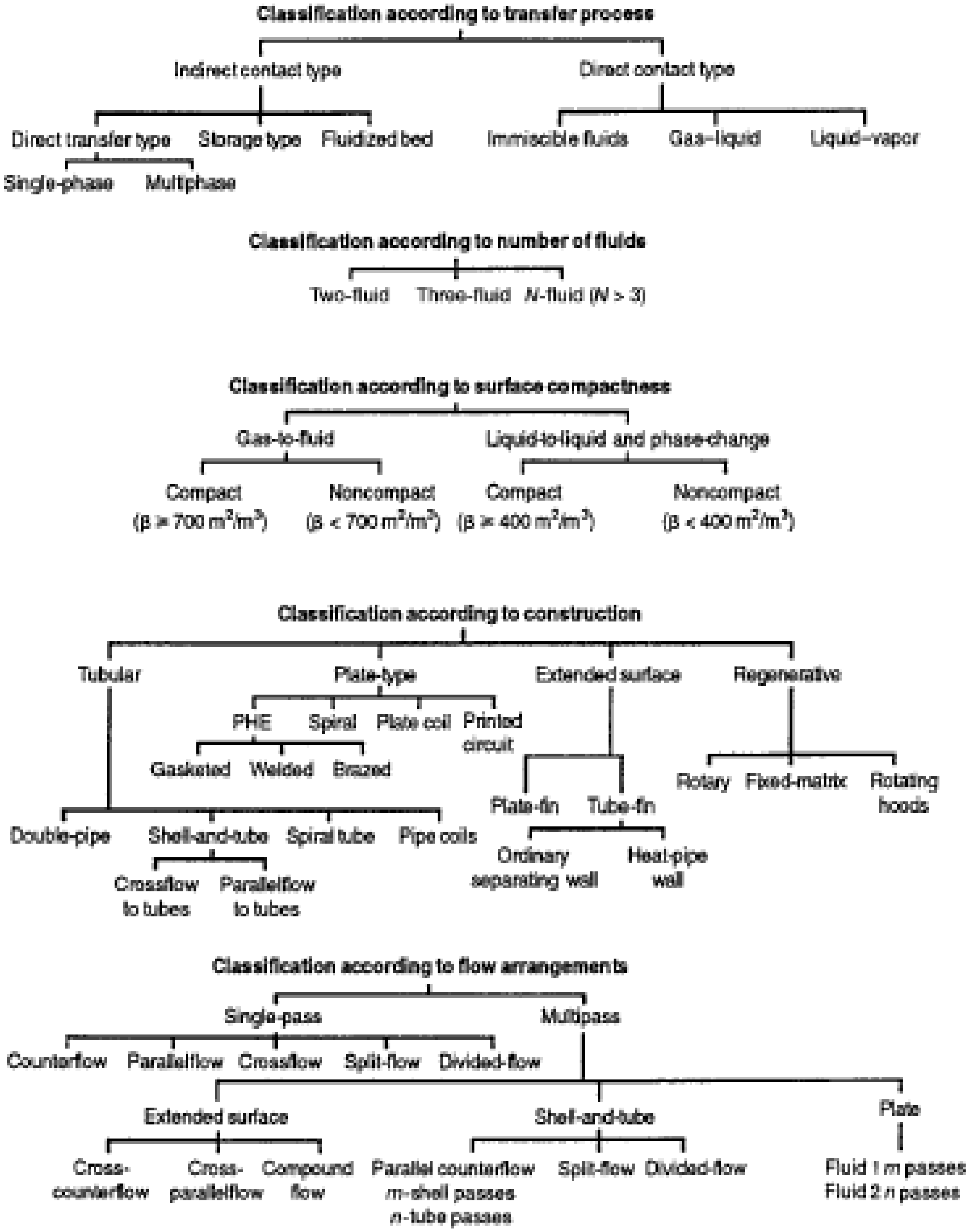


FIGURE 7. Classification of heat exchangers. ([7]).

3. SELECTION OF HEAT EXCHANGERS.

The type of heat exchanger to be selected depends primarily on the type of fluids involved, the size and weight limitations, and the presence of any phasechange processes. For example, a heat exchanger is suitable to cool a liquid by a gas if the surface area on the gas side is many times that on the liquid side. On the other hand, a plate or shell-and-tube heat exchanger is very suitable for cooling a liquid by another liquid.

One type of heat exchanger that could fit in the conditions would be the compact heat exchangers, which is specifically designed to realize a large heat transfer surface area per unit volumen. This type of heat exchanger enable us to achieve high heat transfer rates between two fluids in a small volume, and they are commonly used in applications with strict limitations on the weight and volume of heat exchangers.

Compact heat exchangers are commonly used in gas-to-gas and gas-to liquid (or liquid-to-gas) heat exchangers to counteract the low heat transfer coefficient associated with gas flow.

In summary, the chosen heat exchanger will be suitable if the surface area on the gas side is many times that on the liquid side.

From this information and considering the classification of the previous section, it is posible to discard plate heat exchangers because of the fact they are well suited for liquid-to-liquid heat exchange applications, provided that the hot and cold fluid streams are at about the same pressure.

On the other hand, inside tubular heat exchangers, both *double-pipe heat exchanger* and *shell-and-tube heat exchanger* could be a good option, but spiral-and-tube heat exchanger is discarded because they are used for thermal expansion and clean fluids, since cleaning is almost impossible.

In conclusion, although many different types of exchangers could be selected and each one would lead to different results, taking into account the different criteria, the two types of heat exchanger which have been chosen are both double pipe heat exchanger and tube heat exchanger.

The final choice after the analysis of the results in the practical part of the work is the tube heat exchanger.

Once the selection of the heat exchanger has been carried out, the two main methods of calculation of heat transfer will be shown.

4. THE LOG MEAN TEMPERATURE DIFFERENCE METHOD (LMTD).

LMTD Method is very suitable for determining the *size* of a heat exchanger to realize prescribed outlet temperatures when the mass flow rates, the inlet and outlet temperatures of the hot and cold fluids are specified.

The temperature difference between the hot and cold fluids varies along the heat exchanger, and it is convenient to have a mean temperature difference ΔTm for use in the relation Q =U*As*ΔTlm ([8]).

This equation (9) comes from integrating q=$\int_1^2 dq$, being dq=UΔT(x)dA(x) where only the Overall Heat Transfer U is constant.

In addition, ΔTlm is the log mean temperature difference, which is the suitable form of the average temperature difference for use in the analysis of heat exchangers. It makes no difference which end of the heat exchanger is designated as the inlet or the outlet.

$$\text{LMTD}=\Delta\text{Tlm}=\frac{\Delta T1-\Delta T2}{\ln(\frac{\Delta T1}{\Delta T2})} \quad ([9])$$

being ΔT1= Th,i-Tc,o and ΔT2=Th,o-Tc,i for a counter-flow exchanger and ΔT1=Th,i-Tc,i and ΔT2=Th,o-Tc,o for a parallel-flow exchanger.

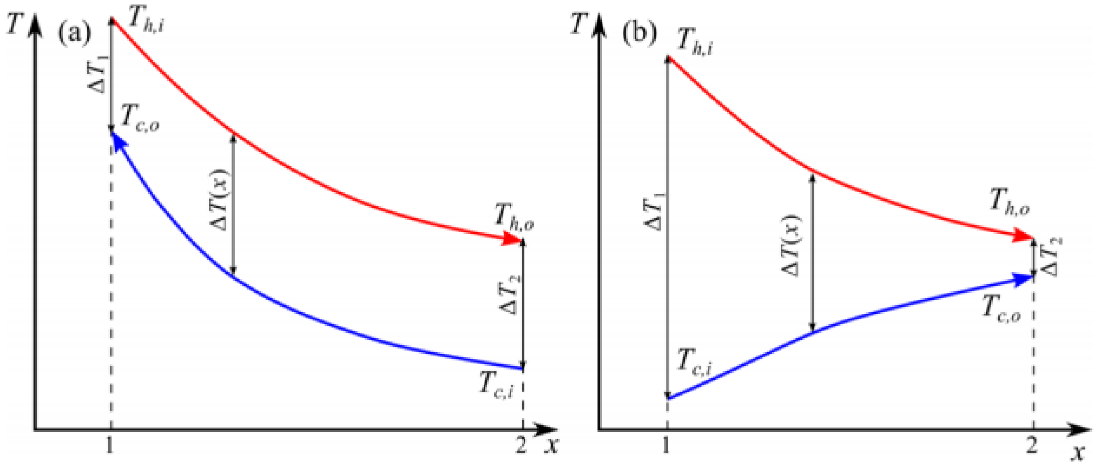


FIGURE 8-9. Temperature profiles in (a) counter-flow and (b) parallel-flow single pass heat exchangers. ([10])

5. THE EFFECTIVENESS-NTU METHOD.

The LMTD method is useful in order to calculate the Overall Heat Transfer coefficient U based on experimental values of the inlet and outlet temperatures and the flow rates. However, if they are not known, it would be required an iterative approach that make difficult the calculations.

In order to solve this problem, it is possible to use the effectiveness NTU Method whose main advantage is that it can predict the outlet temperatures.

ε is the effectiveness of the heat-exchanger and is defined as

$\varepsilon = \frac{q}{qmax}$ [(11)]

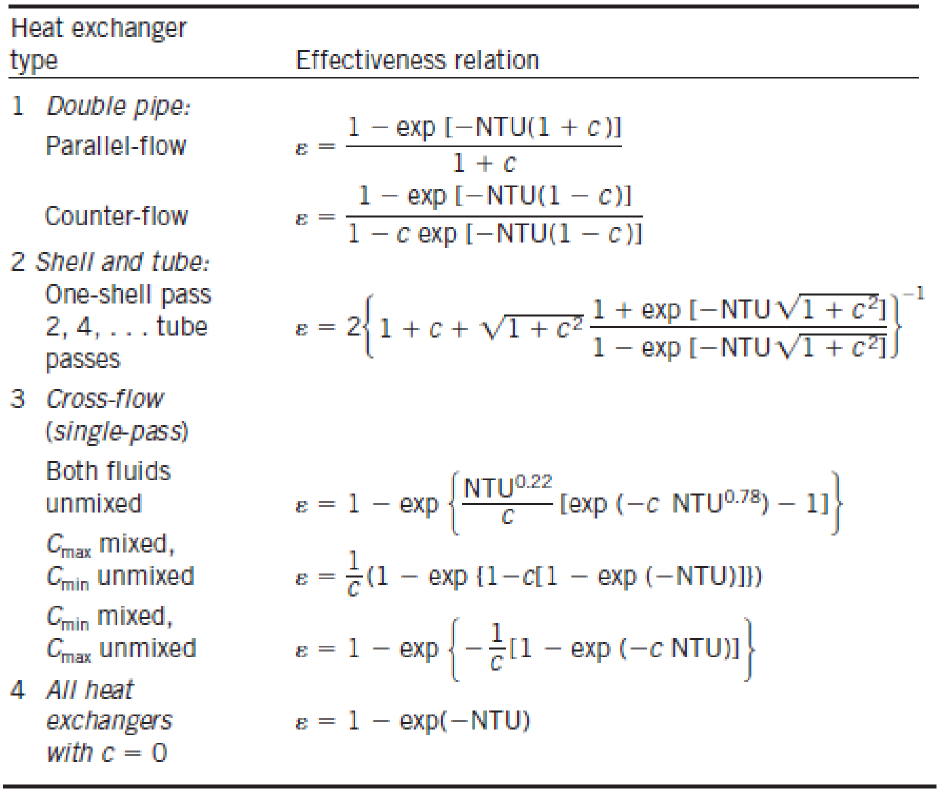
where q is the actual rate of heat transfer and qmax is the máximum posible rate of heat transfer,

q max=Cmin(Th,i-Tc,i) [(12)].

The process consists on obtaining the outlet temperatures from an energy balance after getting q using equations (11) and (12).

In addition, the efficiency ε depends on different characteristics such as flow pattern, heat echanger geometry and the number of transfer units

NTU = $\frac{UA}{Cmin}$.



Heat exchanger type	Effectiveness relation
1 *Double pipe:*	
Parallel-flow	$\varepsilon = \frac{1 - \exp[-NTU(1 + c)]}{1 + c}$
Counter-flow	$\varepsilon = \frac{1 - \exp[-NTU(1 - c)]}{1 - c\exp[-NTU(1 - c)]}$
2 *Shell and tube:*	
One-shell pass 2, 4, . . . tube passes	$\varepsilon = 2\left\{1 + c + \sqrt{1 + c^2}\,\frac{1 + \exp[-NTU\sqrt{1 + c^2}]}{1 - \exp[-NTU\sqrt{1 + c^2}]}\right\}^{-1}$
3 *Cross-flow (single-pass)*	
Both fluids unmixed	$\varepsilon = 1 - \exp\left\{\frac{NTU^{0.22}}{c}[\exp(-c\ NTU^{0.78}) - 1]\right\}$
C_{max} mixed, C_{min} unmixed	$\varepsilon = \frac{1}{c}(1 - \exp\{1 - c[1 - \exp(-NTU)]\})$
C_{min} mixed, C_{max} unmixed	$\varepsilon = 1 - \exp\left\{-\frac{1}{c}[1 - \exp(-c\ NTU)]\right\}$
4 *All heat exchangers with c = 0*	$\varepsilon = 1 - \exp(-NTU)$

FIGURE 10. The effectiveness relation according to the different type of heat exchanger.([13])

6. CALCULATIONS.

First of all, the type of heat exchanger has to be selected according to the conditions of the problema and the characteristics of the heat exchanger. In this problema, after calculating Double Pipe Heat Exchanger, one of the simplest types, it is going to be calculated the Tube Heat Exchanger.

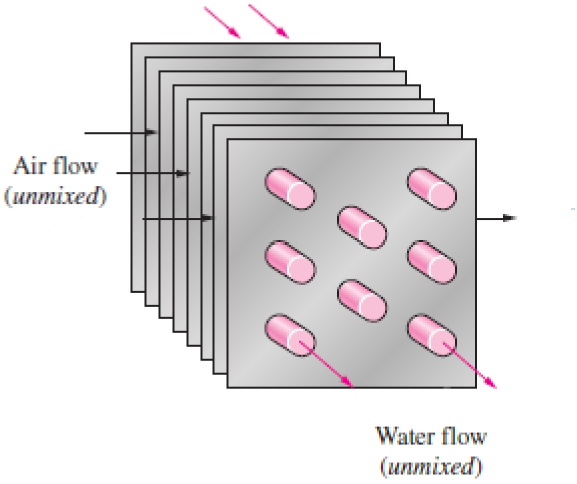


FIGURE 11. Tube heat exchanger with a counter-flow disposition. ([14])

The process followed for the design of the heat exchanger starts calculating the Overall heat transfer coefficient (U). For this tasks, it has to be calculated the heat transfer coefficient both inside and outside.

In one hand, the fluid inside the tube is the water that has to be heated. In the other hand, the fluid outside is the exhaust gas (Unmixed).

For calculating h, it has to be calculated before both mean velocity and number of Reynolds. For calculating of the mean velocity, it will be necessary the volumetric flow and Ac.

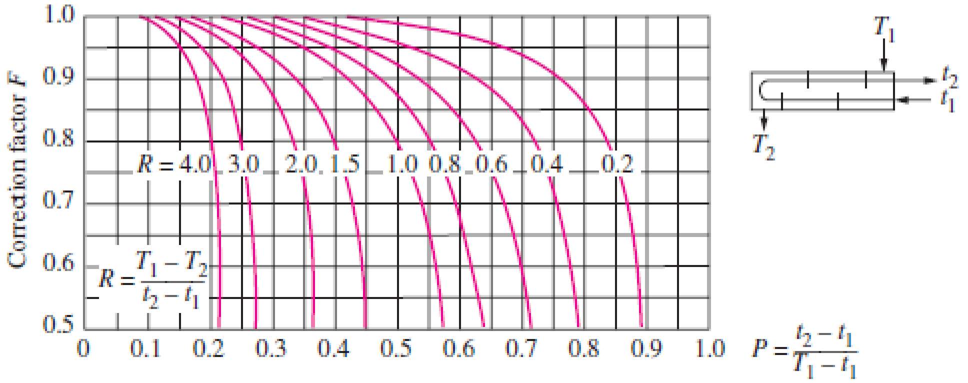
Ac=$\frac{1}{4}\pi Di^2$ for the water side and Ac=h*w-rows*Do*w. Hence, the height and width of the heat exchanger, and also the diameter of the tubes has to be selected. For the design of this heat exchanger, the external diameter of the tube chosen is $\frac{1}{2}''$. The height and width are 0.5 m.

Once it has been calculated h=$\frac{Nu*k}{Dh}$ ([15]), it will be possible to calculate U=$\frac{1}{\frac{1}{hi}+\frac{1}{ho}}$ ([16]).

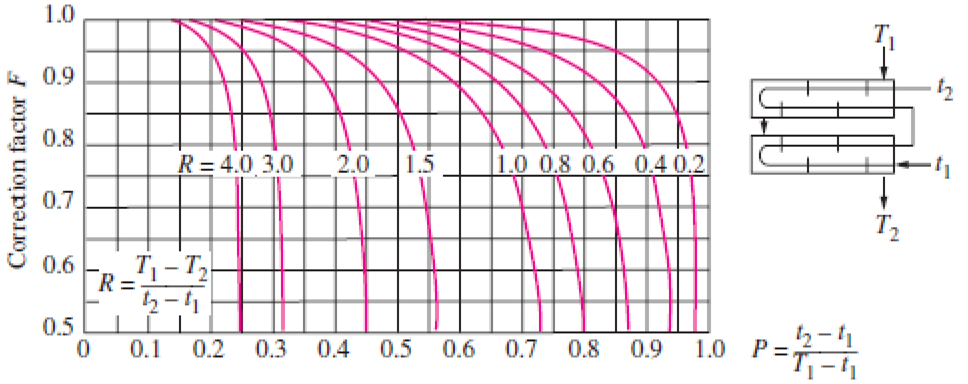
However, before of calculating ho, in order to calculate the mean velocity in the water part , the volumetric flow rate of the water has to be determinated. Calculating the heat transfer with the eq. (9) , and supposing that the heat transfer is the same in the air part and in the water part, $\dot{V}$ can be calculated.

Finally, using LMTD Method, the one that has been exposed in the section 4, and calculating the factor F graphically, it will be possible to get the As.

Q=U*As*F*ΔTlm ([17]).



(*a*) One-shell pass and 2, 4, 6, etc. (any multiple of 2), tube passes



(*b*) Two-shell passes and 4, 8, 12, etc. (any multiple of 4), tube passes

FIGURE 12. Graphic for calculating F in an One-Shell pass and Two-shell passes heat exchanger. ([18])

The calculation sheet made with the excel program is attached, it has been done following the steps described in this section.

The main results about the first step, calculating the coefficient U are the internal heat transfer coefficient, hi= 501,7 ($\frac{W}{m^2}$), the external heat transfer coefficient, ho=5,34 ($\frac{W}{m^2}$)and the overall heat transfer coefficient, U=5,286(W/m^2K).

Moreover, about the second part, the main results are the heat transfer Q=2383.7(W) and being F=0,92 (it has been calculated graphically with the values of R and P), it has been calculated As=13.25m^2.

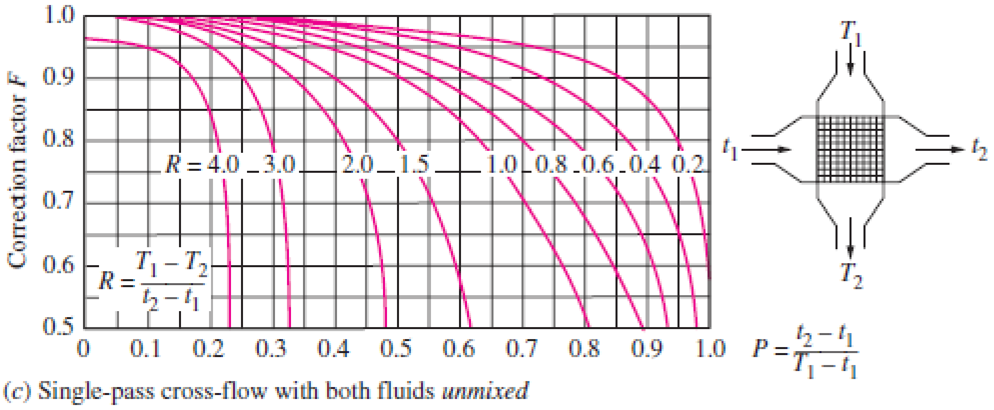
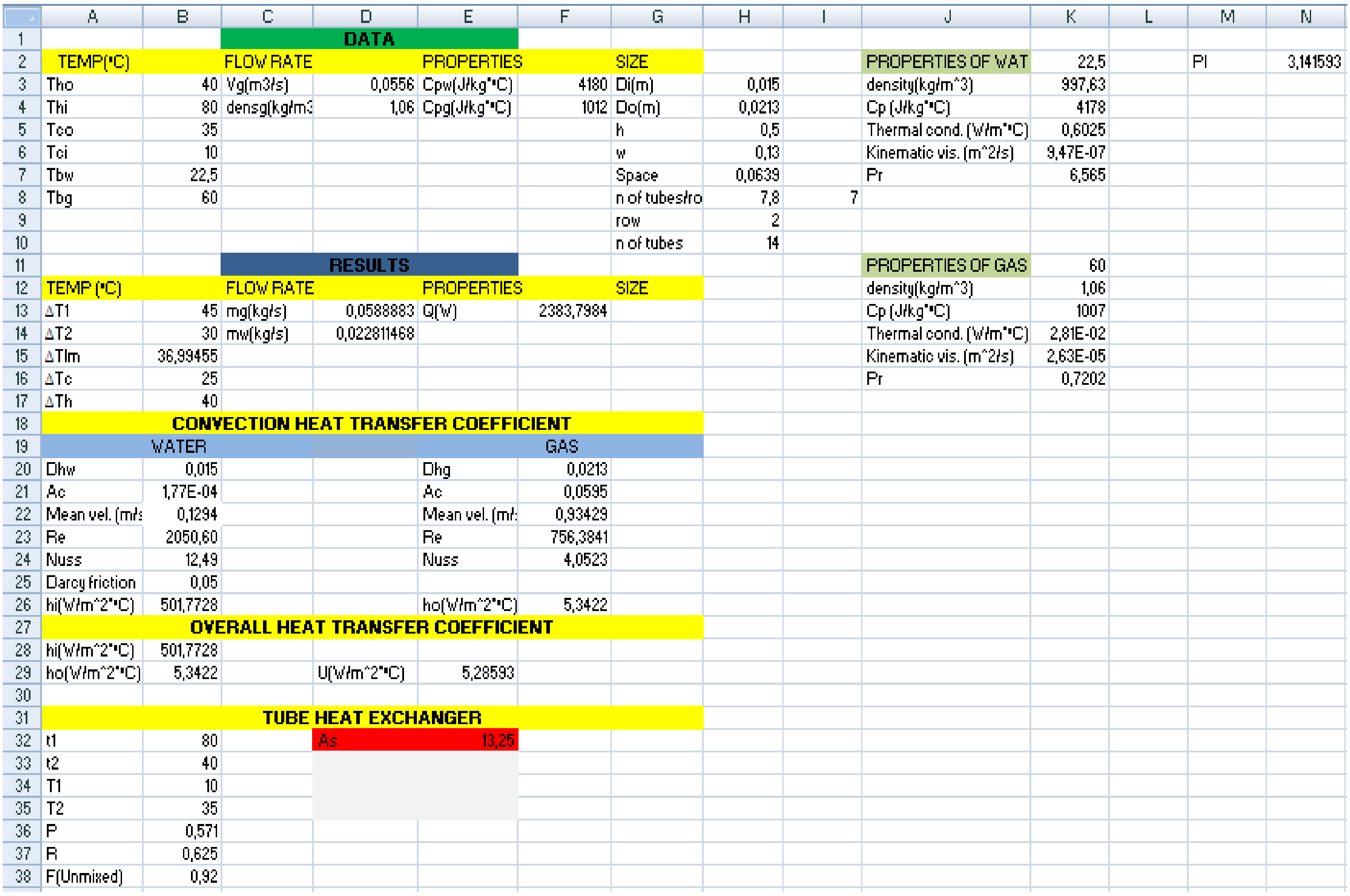


FIGURE 13. Graphic where the correction factor F has been calculated. ([19]).



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1			DATA											
2	TEMP(°C)		FLOW RATE		PROPERTIES		SIZE			PROPERTIES OF WAT	22,5		PI	3,141593
3	Tho	40	Vg(m3/s)	0,0556	Cpw(J/kg°C)	4180	Di(m)	0,015		density(kg/m^3)	997,63			
4	Thi	80	densg(kg/m3	1,06	Cpg(J/kg°C)	1012	Do(m)	0,0213		Cp (J/kg°C)	4178			
5	Tco	35					h	0,5		Thermal cond. (W/m°C)	0,6025			
6	Tci	10					w	0,13		Kinematic vis. (m^2/s)	9,47E-07			
7	Tbw	22,5					Space	0,0639		Pr	6,565			
8	Tbg	60					n of tubes/ro	7,8	7					
9							row	2						
10							n of tubes	14						
11			RESULTS							PROPERTIES OF GAS	60			
12	TEMP (°C)		FLOW RATE		PROPERTIES		SIZE			density(kg/m^3)	1,06			
13	ΔT1	45	mg(kg/s)	0,0588883	Q(W)	2383,7984				Cp (J/kg°C)	1007			
14	ΔT2	30	mw(kg/s)	0,022811468						Thermal cond. (W/m°C)	2,81E-02			
15	ΔTlm	36,99455								Kinematic vis. (m^2/s)	2,63E-05			
16	ΔTc	25								Pr	0,7202			
17	ΔTh	40												
18	CONVECTION HEAT TRANSFER COEFFICIENT													
19	WATER				GAS									
20	Dhw	0,015			Dhg	0,0213								
21	Ac	1,77E-04			Ac	0,0595								
22	Mean vel. (m/s	0,1294			Mean vel. (m/:	0,93429								
23	Re	2050,60			Re	756,3841								
24	Nuss	12,49			Nuss	4,0523								
25	Darcy friction	0,05												
26	hi(W/m^2°C)	501,7728			ho(W/m^2°C)	5,3422								
27	OVERALL HEAT TRANSFER COEFFICIENT													
28	hi(W/m^2°C)	501,7728												
29	ho(W/m^2°C)	5,3422		U(W/m^2°C)	5,28593									
30														
31	TUBE HEAT EXCHANGER													
32	t1	80		As	13,25									
33	t2	40												
34	T1	10												
35	T2	35												
36	P	0,571												
37	R	0,625												
38	F(Unmixed)	0,92												

FIGURE 14. Calculation sheet. ([20])

7. CONCLUSION.

In conclusion, it is intended to emphasize the importance of the energy recovery. It must be taken into account that this recovery will be reflected in the economic aspect of the company, which will save the money previously invested in heating the water.

The most important task of this work has been the selection of the heat exchanger, since depending on the type of heat exchanger the investment will be profitable or not.

The two heat exchanger that has been calculated are the double pipe heat exchanger and the tube heat exchanger, being possible to check the difference between them. The lenght of the pipe in the double pipe heat exchanger is longer than 500 metres. This pipe would be too expensive and it would be impossible to place it inside the vehicle control station.

In summary, having collected information from the different types of heat exchanger, the main methods of heat transfer, the different criteria of selection and having calculated the main characteristics of the tube heat exchanger, the last task will be design it in Autodesk program.

FIGURE 15. Tube heat exchanger. ([21])

The definitive design and heat exchanger drawings are attached below.

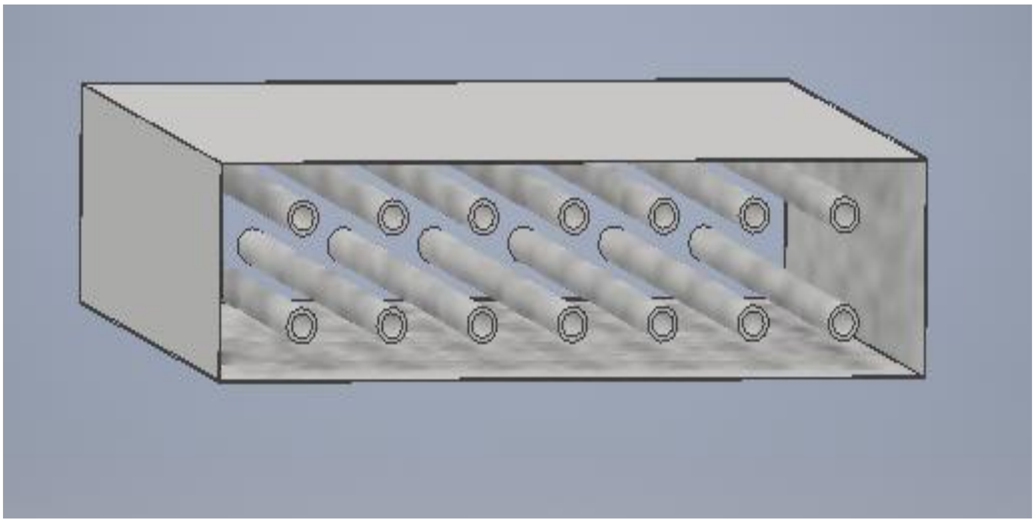


FIGURE 16. Design of the tube heat exchanger. ([22])

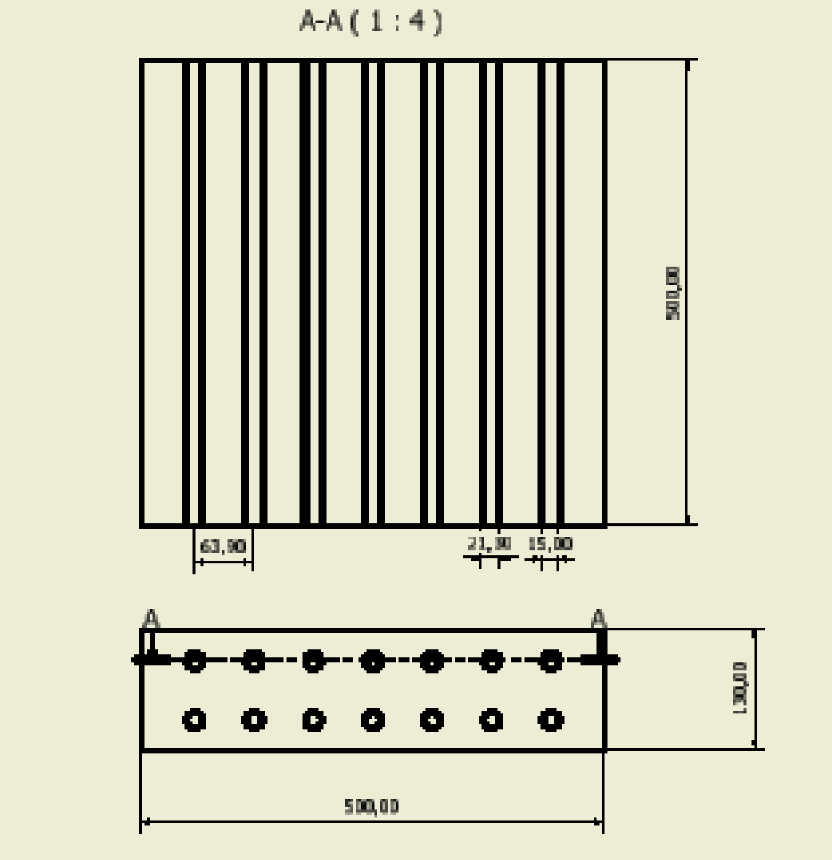


FIGURE 17. Drawing of the tube heat exchanger. ([23])

Finally, the design of the heat exchanger has been done correctly, because of recovery of the heat is going to be possible and also, the size of the definitive heat exchanger fit in the vehicle control station.

8. NOMENCLATURE.

As, total contact area (m^2).
Ac, cross section (m^2).
ΔTlm, log mean temperature difference.
ΔT1, $\Delta T2$, the temperature difference between the two begginings and the two ends (inlet and outlet).
Th,i Temperature of the hot fluid in the inlet of the heat exchanger (ºC).
Th,o Temperature of the hot fluid in the outlet of the heat exchanger(ºC).
Tc,i Temperature of the cold fluid in the inlet of the heat exchanger(ºC).
Tc,o Temperature of the cold fluid in the outlet of the heat exchanger(ºC).
Cmin Minimum heat capacity transfer (W/K).
ε Effectiveness.
Q Heat transfer(W).
Qmax Maximum heat transfer.
hi internal heat transfer coefficient ($\frac{W}{m^2}$)
V̇ Volumetric flow rate ($\frac{m^3}{s}$)
ho external heat transfer coefficient (($\frac{W}{m^2}$)
U Overall heat transfer coefficient (W/m^2K).
NTU Number of exchanger heat transfer units.
F Correction factor.

9. LITERATURE.

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