Heat Exchanger Simulator
Educational
Version 2.0

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Educational Proposal

Heat exchangers are very common equipment in the chemical industries. Among the several kinds of heat exchangers used in the industry, the shell and tube heat exchanger is special due to its versatility, easiness of operation and maintenance and for its high capacity of processing. However, the calculations required for its design is very hard requiring an enormous number of equation and correlation.

Several calculation methods exist to design shell and tube heat exchangers. Among them, Kern, Tinker and Bell-Delaware methods are the most known methods in the open literature. Teaching heat exchangers is considered very complicated due to the great time required to teach the methods. The time needed to perform heat exchanger design calculations, by hand, is high and therefore the students do a small number of exercises. And not always these exercises show the application of the heat exchanger in the industry.

The software HES (Heat Exchanger Simulator) was developed in order to complement the teaching of heat exchangers, bringing to the student a knowledge of the applications of these exchangers and cases where the calculation of these equipment are required in the industry.

Exercises

Shell and Tube Heat Exchangers

❖ Cosmetic Industry [Exercise 1]

In this exercise the student must search for the best operational condition for a given chemical process, respecting the pressure drop limits of the equipment. The initial data presented to the student leads to a pressure drop that is bigger than the recommended for the equipment (10 psi).

Problem

Heating of Water with Thermal heat transfer fluid	
Water (Tubes)	
flow rate	28.8 ton/h
inlet temperature	25 ºC
outlet temperature	40 ºC
Thermal 100G (Shell)	
inlet temperature	150 ºC
unknown flow rate and outlet temperature	
Requirements	
maximum pressure drop	10 psi

The student should change only the process conditions of the heat transfer fluid. The configuration of the heat exchanger should not be changed, since the heat exchanger in the exercise is an existing one.

Expected Results

Water	
should not have it operational conditions changed	
Thermal 100G	
flow rate	3.1 kg/s
outlet temperature	87.3 ºC
shell pressure drop	9.8 psi

Obs: Several students will try to change the number of baffles in the exchanger, what would not be an economical alternative to do with an existing heat exchanger.

❖ Vegetal Oil [Exercise 2]

In this exercise the student will have to design a heat exchanger that will be used in the production of vegetal oil. It will be also required to choose a heat transfer fluid.

Problem

Heating of Vegetal Oil using Thermal heat transfer fluid	
Vegetal Oil (Shell)	
flow rate	150 ton/h
inlet temperature	25 ºC
outlet temperature	80 ºC
Thermal (Tubes)	
inlet temperature	300 ºC
unknown flow rate and outlet temperature	
Requirements	
tube length	12 ft
fouling resistance	0.002 h.ft^2.ºF/BTU
maximum pressure drop	10 psi

The exercise can be considered correct if the considerations done for the design of the heat exchanger is coherent and if the operational parameters such as the pressure drop and the fouling resistance be near to the recommended ones.

Expected Results

Thermal 159	
flow rate	161.5 ton/h
inlet temperature	300 ºC
outlet temperature	250 ºC
Heat Exchanger	
shell diameter	19.25 in
tube external diameter	0.75 in
tube pitch	1.0 in
number of tubes	256
tube length	12 ft
number of passes in the tubes	2
number of baffles	23
baffle cut	0.25
Other Results	
fouling resistance	0.0081 h.ft^2.ºF/BTU
shell pressure drop	9.3 psi
tube pressure drop	3.3 psi

❖ Heat Transfer Fluid [Exercise 3]

In this exercise the student should choose the best heat transfer fluid for a given process, among a list of heat transfer fluids.

Problem

Cooling of Acetone with Heat Transfer Fluid or Water	
Acetone	
flow rate	650 ton/h
inlet temperature	100 ºC
outlet temperature	80 ºC
Heat Transfer Fluids	
available fluids	Thermal 155, 120TX, 100N, 166, Water
inlet temperature	30 ºC
outlet temperature	60 ºC
Requirements	
fouling resistance	0.005 $h.ft^2.ºF/BTU$
maximum pressure drop	10 psi

Testing the fluids, it will be observed that the fluids Thermal 155 and 120TX could be used. The fluids Thermal 100N and 166 exceeds the maximum pressure drop and the Water presents a fouling resistance higher that the maximum required for the process.

Expected Results

Thermal 155 – best choice	
flow rate	366.4 ton/h
fouling resistance	0.0038 $h.ft^2.ºF/BTU$
shell pressure drop	8.3 psi
Thermal 120TX	
flow rate	426.5 ton/h
fouling resistance	0.0049 $h.ft^2.ºF/BTU$
shell pressure drop	8.6 psi
Thermal 100N	
flow rate	376.8 ton/h
fouling resistance	0.0006 $h.ft^2.ºF/BTU$
shell pressure drop	13.9 psi
Thermal 166	
flow rate	530.8 ton/h
fouling resistance	0.0043 $h.ft^2.ºF/BTU$
shell pressure drop	14.5 psi

Water	
flow rate	176.4 ton/h
fouling resistance	0.0063 h.ft^2.ºF/BTU
shell pressure drop	1.5 psi

❖ Liquid Wax Process [Exercise 4]

In this exercise the student should adjust the flow rate and outlet temperature of the heat transfer fluid in order to optimize the process.

Problem

Heating of Triethylamine solution with Thermal 159	
Triethylamine	
load a reactor with 100 m^3 of triethylamine in 30 minutes	
inlet temperature	25 ºC
outlet temperature	85 ºC
Thermal 159	
flow rate	unknown – should be determined
inlet temperature	200 ºC
outlet temperature	unknown – should be set
What is the minimum loading time of the reactor?	
Knowing that the main pumps support up to 25 psi	
If the main pumps fail, what will be the loading time of the reactor?	
Knowing that the auxiliary pumps support up to 10 psi	

Expected Results

Operational Conditions for Reactor Loading Time of 30 minutes	
Thermal 159 (Shell)	
flow rate	456.6 ton/h
inlet temperature	200 ºC
outlet temperature	150 ºC
Heat Exchanger	
tube side pressure drop	19.1 psi
shell side pressure drop	17.1 psi
fouling resistance	0.00056 h.ft^2.ºF/BTU
Operational Conditions for Maximum Pressure Drop of 25 psi	
Thermal 159 flow rate	560 ton/h
Triethylamine flow rate	230 ton/h
loading time	26 min

Operational Conditions for Maximum Pressure Drop of 10 psi	
Thermal 159 flow rate	350 ton/h
Triethylamine flow rate	145 ton/h
loading time	41 min

Obs: loading time and flow rate may change depending on the outlet temperature of Thermal 159 that is set.

❖ Caustic Soda Process [Exercise 5]

In this exercise the student should design a heat exchanger using the heat provided by a stream of a given process. The selection of the heat exchanger is free from any restriction on the configuration of the exchanger. Therefore this is the most complex exercise for the student.

Problem

Heating of Heat transfer fluid with Steam	
Thermal 155	
flow rate	600 ton/h
inlet temperature	145 ºC
outlet temperature	150 ºC
Steam	
inlet temperature	450 ºC
Requirement	
fouling resistance	0.02 h.ft^2.ºF/BTU
maximum pressure drop	10 psi

The exercise can be considered correct if the considerations done for the design of the heat exchanger is coherent and if the operational parameters such as the pressure drop and the fouling resistance be near to the recommended ones.

The exercise can have multiple answers depending on the chosen tube length, tube diameter and number of passes in the tubes.

Expected Results

Steam (Shell)	
flow rate	1.95 ton/h
inlet temperature	450 ºC
outlet temperature	300 ºC
Heat Exchanger	
shell diameter	31 in
tube external diameter	0.75 in
tube pitch	0.9375 in

number of tubes	766
tube length	8 ft
number of passes in the tubes	4
number of baffles	6
baffle cut	0.25
Other Results	
fouling resistance	0.054 $h.ft^2.°F/BTU$
shell side pressure drop	8.6 psi
tube side pressure drop	5.1 psi

Obs: It should be observed that only the steam sensible heat should be used, not been allowed the use of the steam latent heat (phase change). Therefore it is desirable that the outlet temperature of the steam be higher than 290ºC.

Double Tube Heat Exchanger

❖ Ethanol [Exercise 1]

In this exercise the student should design a double tube heat exchanger, operating in series, for a process that has to cool down ethanol with water. The student should design the best heat exchanger and the kind of flow (cocurrent and countercurrent).

Problem

Cooling of Ethanol with Water	
Ethanol (Tube)	
flow rate	3.0 ton/h
inlet temperature	70 ºC
outlet temperature	30 ºC
Water (Shell)	
inlet temperature	23 ºC
outlet temperature	27 ºC
flow rate not set	
Requirements	
maximum velocity	2.5 m/s
fouling resistance	0.005 ft^2.h.ºF/BTU
hairpin length	4 ft

The exercise can have multiple answers depending on the considerations that have been made. A good result is shown below.

Expected Result

Heat Exchanger	
shell diameter	3.5 in
tube diameter	1.9 in
number of hairpins	6 – countercurrent flow
	8 – cocurrent flow

❖ Cocoa Fermentation [Exercise 2]

In this exercise the student should design a double tube heat exchanger to heat up a heat transfer fluid used to maintain the temperature of a reactor at constant temperature. The student should also study how the water flow rate should vary throughout the year, knowing that the fouling resistance increases linearly with time.

Problem

Heating of Thermal 166 using Water	
Thermal 166 (Shell)	
flow rate	100 ton/h
inlet temperature	45 ºC
outlet temperature	47 ºC
Water (Tube)	
inlet temperature	97 ºC
outlet temperature	60 ºC
flow rate not set	
Requirements	
exchanger operating in series / countercurrent flow	
fouling resistance	0.01 ft^2.h.ºF/BTU
hairpin length	8 ft

Expected Result

Water	
flow rate	1.8 ton/h
Exchanger	
shell diameter	4.5 in
tube diameter	1.0 in
number of hairpins	3
shell velocity (Thermal 166)	3.8 m/s
tube velocity (Water)	1.8 m/s
exchange area	158 ft^2
overall heat transfer coef. (clean)	92.7 BTU/ft^2.h.ºF

❖ Titanium Dioxide Process [Exercise 3]

In this exercise the student should design a double tube heat exchanger to heat up sulfuric acid using a heat transfer fluid. The design should be based on operational conditions only, been the only requirements the maximum pressure drop and the fouling resistance.

Problem

Heating of Sulfuric Acid 98% with Thermal 100N	
Sulfuric Acid 98% (Shell)	
flow rate	67 ton/h
inlet temperature	25 ºC
outlet temperature	120 ºC
Thermal 100N (Tube)	
inlet temperature	360 ºC
outlet temperature	335 ºC
flow rate not set	
Requirements	
fouling resistance	0.01 ft^2.h.ºF/BTU
maximum pressure drop	10 psi

Expected Result

Thermal 100N	
flow rate	112.4 ton/h
Exchanger	
flow	parallel / countercurrent
shell diameter	6.5 in
tube diameter	3.5 in
hairpin length	8 ft
number of hairpins	3
shell velocity	0.9 m/s
tube velocity	3.2 m/s
exchange area	552 ft^2
shell pressure drop	0.9 psi
tube pressure drop	1.8 psi
hairpin length	16 ft
number of hairpins	2
shell velocity	0.9 m/s
tube velocity	4.9 m/s
exchange area	1473 ft^2
shell pressure drop	0.5 psi
tube pressure drop	1.8 psi

Pinch Technology

❖ Benzene Process [Exercise 1]

In this exercise the energy integration of a benzene production process should be analyzed. The student should study the effect of the minimum approach temperature on the required hot and cold utilities and on the heat exchanged between the streams.

Initial System

Streams	Inlet Temp [ºC]	Outlet Temp [ºC]	Flow Rate [kg/h]	Cp [J/g.K]
Diphenyl	250	120	526	1.9
Benz + Tol	200	100	1740	2.3
H_2	90	150	205	14.6
Toluene	130	190	2609	2.3

Expected Results

Energy Integration – Delta T = 10ºC	
pinch temperature	135 ºC
required hot utility	70000 kJ/h
required cold utility	60000 kJ/h
heat exchanged between streams	940000 kJ/h
Energy Integration – Delta T = 15ºC	
pinch temperature	137.5 ºC
required hot utility	95000 kJ/h
required cold utility	85000 kJ/h
heat exchanged between streams	890000 kJ/h
Energy Integration – Delta T = 20ºC	
pinch temperature	140.0 ºC
required hot utility	120000 kJ/h
required cold utility	110000 kJ/h
heat exchanged between streams	840000 kJ/h

The results show that the pinch temperature, as well as the quantity of hot and cold utilities required increase with the increase of the minimum approach temperature.

❖ Nitric Acid Process [Exercise 2]

In this exercise the energy integration of a nitric acid production process should be studied. Initially the energy conservation was done between 5 streams, but three more streams should be added to the energy integration system. The student should study the viability of the inclusion of these new streams, and should also analyze the quantity of energy that can be saved with the integration.

Initial System

Streams	Inlet Temp [ºC]	Outlet Temp [ºC]	Flow Rate [ton/h]	Cp [J/g.K]
Air	20	250	16	1.05
NO	350	150	17	1.13
NO_2	150	45	14	1.25
NH_3	20	120	4	2.30
Effluent	50	100	1	1.13

Energy Integration	
pinch temperature	25 ºC
required hot utility	336.3 kJ/h
required cold utility	279.1 kJ/h
heat exchanged between streams	9840.3 kJ/h

System after the Inclusion of the 3 new Streams

Streams	Inlet Temp [ºC]	Outlet Temp [ºC]	Flow Rate [ton/h]	Cp [J/g.K]
Air	20	250	16	1.05
NO	350	150	17	1.13
NO_2	150	45	14	1.25
NH_3	20	120	4	2.30
Effluent	50	100	1	1.13
Air 2	20	130	10	1.05
HNO_3	50	30	20	2.30
NO recycled	50	100	1	1.13

Energy Integration	
pinch temperature	45 ºC
required hot utility	845.9 kJ/h
required cold utility	745.1 kJ/h
heat exchanged between streams	11244.3 kJ/h

The new streams when not integrated to the energy conservation system, needed 1168 kJ/h of cold utility and 1211.5 kJ/h of hot utility. Therefore the system as a hole needed 1504.3

kJ/h of cold utility and 1547.8 kJ/h of hot utility. The student should note that the calculation of these quantities is needed in order not to incur in error.

With the three new streams, the energy integration of the plant requires 845.9 kJ/h of hot utility and 745.1 kJ/h of cold utility, what means a reduction of 45% in hot utility requirement and of 50% of cold utility requirement.

Information

Required System

PC-486 or higher (Pentium is recommended)

8 Mb Ram (16 Mb recommended)

Windows 95 or higher

CD-Rom (for installation)

Support

Contact

EFFTech Engineering Software

e-mail: efftech@yahoo.com

http://efftech.tripod.com