Memorandum

To: Professor Pershing
From: Josh Whitehead
Date: 22 Nov 2021
Subject: Ch En 3453 Heat Exchanger Design

Problem

Our company is in need of a shell and tube heat exchanger that can use steam at 338°F to heat 5,000 lb/hr of milk from 90°C to 135°C with a maximum pressure drop of 20psi. The milk must not stay above 100°C for longer than 10 seconds.

Fixed Conditions

The inlet pressure of the milk is 85 psia and that of steam is 95 psia. The steam condenses at 320°F. Milk and steam have fouling factors of 0.0025 and 0.001 respectively. Tubes must be ½" OD, 12 BWG, 316 stainless steel. The vendor provided specifications regarding the maximum number of tubes in a given shell and these tubes are set on a 1.0" triangular pitch at 30°.

Considerations

While considering the best design for this heat exchanger, I decided that the milk should be the fluid in the tube because it has a higher fouling factor so whichever surface it comes into contact with will need to be cleaned more frequently than the surfaces touched by the steam. I decided that 1 tube pass is better than 2 because with 2 passes, the tube length would have to be such that the available area is larger than it would be with 1 pass, making it more expensive than if it had only 1 pass. The driving factors for determining the best design were total cost and efficiency, which is related to pressure drop. The proposed design is the cheapest overall, and has a milk side pressure drop closest to the maximum which makes it the most efficient.

Alternative Designs

I considered a design with a 7.25 in shell ID, 5 in central baffle spacing, 20 tubes of 20 ft and 2 passes. While this design fulfills the necessary requirements and has a similar tube side pressure drop, the final cost is estimated to be almost $26,000 more than the proposed design above. Another design I considered has 5.25 in shell ID, 5 in central baffle spacing, 9 tubes of 40 ft and 1 tube pass. This design fulfills all necessary requirements but is almost $7,000 more expensive. It also has a milk side pressure drop of about 8.15 psi which is almost half that of the proposed design so this design would be more expensive and less efficient.

Solution

I propose the purchase of a heat exchanger with a 7.25 in shell ID, 5 in central baffle spacing, 7 tubes of 50 ft and 1 tube pass. In this exchanger the milk would flow through the tubes and the steam through the shell. The milk pressure drop would be about 15.8 psi and the steam pressure drop would be about 0.063 psi. The milk would stay above 100°C for about 5 seconds. This exchanger requires about 42.52 ft^2 of area with 45.7 ft^2 available and has an overdesign factor of about 7.48%. This design also includes the specified fixed conditions and fulfills the requirements previously mentioned. I estimate the purchasing and installation price to be $19,119 and $61,181 respectively with a total cost just over $80,000. A more complete summary of this design is attached at the end of this memo.

Design Summary Sheet

1. Tube Side

a. Tube fluid: Milk
b. Tube length: 50 ft
c. Outlet temperature: 275°F
d. No. of tube passes: 1
e. Fluid flow rate: 5,000 lb/hr
f. No. of tubes: 7
g. Tube wall thickness (BWG): 12
h. Tube material: 316 Stainless steel
i. Tube fouling factor: 0.0025
j. Tube pressure drop: 15.8 psi

2. Shell Side

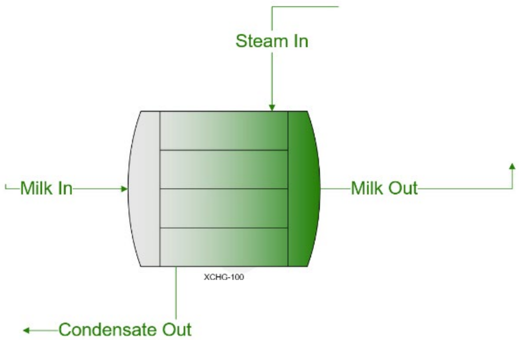
a. Shell fluid: Steam
b. Outlet temperature: 320°F
c. Shell ID: 7.25 in
d. Central baffle spacing: 5 in
e. Shell fouling factor: 0.001
f. Shell pressure drop: 0.063 psi

3. Overall Considerations

a. Area required: 42.52 ft^2
b. Area available: 45.7 ft^2
c. Percent overdesign: 7.48 %
d. Seconds above 100 °C.: 4.84 s
e. Purchase price: $ 19,119
f. Installation cost: $ 61,182
g. Total project costs: $ 80,301

Memorandum

Heat exchanger base design



Stream info

Stream		Milk In	Steam In	Milk Out	Condensate Out
From Block				XCHG-100	XCHG-100
To Block		XCHG-100	XCHG-100		
Temperature	°F	194	338	275	320
Pressure	psia	85	95	65	89.5317
Mole Fraction Vapor	%	0	100	0	0
Mole Fraction Light Liquid	%	100	0	100	100
Mole Fraction Heavy Liquid	%	0	0	0	0
Molecular Weight	lb/lbmol	18.0153	18.0153	18.0153	18.0153
Mass Density	lb/ft^3	60.2832	0.207382	58.1261	56.6675
Molar Flow	lbmol/h	277.542	24.6614	277.542	24.6614
Mass Flow	lb/h	5000	444.283	5000	444.283
Vapor Volumetric Flow	ft^3/h	82.9418	2142.34	86.0199	7.84016
Liquid Volumetric Flow	gpm	10.3408	267.097	10.7246	0.977475
Std Vapor Volumetric Flow	MMSCFD	2.52775	0.224607	2.52775	0.224607
Std Liquid Volumetric Flow	sgpm	9.99536	0.888153	9.99536	0.888153
Compressibility		0.00362111	0.964066	0.00255521	0.0034018
Specific Gravity		0.966561	0.622021	0.931975	0.908588
API Gravity		9.98972		9.99215	9.98918
Enthalpy	Btu/h	-3.35296e+07	-2.51506e+06	-3.31223e+07	-2.92236e+06
Mass Enthalpy	Btu/lb	-6705.93	-5660.95	-6624.47	-6577.71

Tube info

Tubes

Service	Demand	
Material of Construction	HA Steel|A213|TP3	
Type	Plain	
Length	50	ft
Layout	30 Triangle	
Outside Diameter	0.5	in
Pitch	1	in
Pitch Ratio	2	
Tube Count	7	
Max. Tube Count	39	
Max. Tube Count with Imp. Plate	38	
Thickness	0.109	in
Gauge Thickness (BWG)	12	
Inside Diameter	0.282	in
Passes	1	
First Tubepass Flow	Counter	
Inlet Nozzle Diameter	2.41667	in
Outlet Nozzle Diameter	2.41667	in
Roughness	0	in
Inside Corrosion Allowance	0	in

Shell info

Shell

Inside Diameter	7.25	in
Front Type	A	
Shell Type	E	
Rear Type	N	
Shells in Parallel	1	
Shells in Series	1	
Inlet Nozzle Diameter	2.41667	in
Outlet Nozzle Diameter	2.41667	in
Shell Orientation Angle	0	°
Tube Side Entry Type	Radial	
Bundle Diameter	6.81693	in
Bundle Clearance	0.433071	in
Tubesheet Thickness	0.725	in
Sealing Strips	0	
Impingement Control Device	TEMA Required	
TEMA Imp. Plate Calculation Suggests		
Phases at Entrance	1	
rho v^2 at Entrance	72.3804	lb/(ft*s^2)
Baffle Window Correction J_c	0.654983	
Baffle Leakage Correction J_l	0.926847	

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Shell side info (steam)

Side for XCHG-100 - B

Fluid Flow Path	Shell Side	
Service	Supply	
Average h	2309.18	Btu/(h*ft^2*°F)
Fouling Resistance	0.001	(h*ft^2*°F)/Btu
Flow Area	0.123147	ft^2
Flow Length	57.8263	ft
Equivalent Diameter (dP)	0.5	in
Equivalent Diameter (HT)	0.5	in
Specified Pressure Drop	5.46834	psi
Calculated Pressure Drop	0.062858	psi

Side Increment	Fluid Temperature	Heat Transfer Regime	Incremental h	Length	Velocity	Reynolds Number	Pressure Drop	Mass Flux
	°F		Btu/(h*ft^2*°F)	ft	ft/s		psi	lb/(ft^2*s)
0	338	Vapor Phase	11.8984	0	4.83238	4088.64	0	1.00215
1	324.192	Condensation	3057.66	6.53267	4.74174	4165.28	0.00116629	1.00215
2	323.808	Condensation	3057.66	7.28671	4.32051		0.000739271	1.00215
3	323.393	Condensation	2647.31	6.93112	3.86211		0.000207911	1.00215
4	322.976	Condensation	2583.83	6.18828	3.39898		0.000136721	1.00215
5	322.557	Condensation	2527.81	5.57805	2.93104		7.91605e-05	1.00215

General | Detail

Tube side info (milk)

Overall
Results
Shell
Baffles
Tubes
Fins
Internals
Notes
XCHG-100 - A
Side
Pipes
XCHG-100 - B
Side
Pipes
Solve

Side for XCHG-100 - A

Fluid Flow Path	Tube Side	
Service	Demand	
Average h	3337.14	Btu/(h*ft^2*°F)
Fouling Resistance	0.0025	(h*ft^2*°F)/Btu
Flow Area	0.00303615	ft^2
Flow Length	50	ft
Equivalent Diameter (dP)	0.282	in
Equivalent Diameter (HT)	0.282	in
Specified Pressure Drop	20	psi
Calculated Pressure Drop	15.7967	psi

Side Increment	Fluid Temperature	Heat Transfer Regime	Incremental h	Length	Velocity	Reynolds Number	Pressure Drop	Mass Flux
	°C		Btu/(h*ft^2*°F)	ft	ft/s		psi	lb/(ft^2*s)
0	90	Liquid Phase	2970.09	0	7.58835	50978	0	457.45
1	94.5584	Liquid Phase	3036.26	3.03768	7.61229	53786.3	0.932715	457.45
2	99.1063	Liquid Phase	3101.12	3.2369	7.63718	56620.8	0.991432	457.45
3	103.643	Liquid Phase	3164.46	3.46345	7.66301	59475.5	1.05857	457.45
4	108.167	Liquid Phase	3226.25	3.72502	7.68978	62344.8	1.13649	457.45
5	112.678	Liquid Phase	3286.48	4.03022	7.71748	65223.2	1.22782	457.45

General | Detail

Final results

Results

Fraction Over Design	7.47844	%
Area Available	45.7042	ft^2
Area Required	42.524	ft^2
Overall U	117.376	Btu/(h*ft^2*°F)
Clean U	314.253	Btu/(h*ft^2*°F)
Bare U	117.376	Btu/(h*ft^2*°F)
Service U	109.209	Btu/(h*ft^2*°F)
Effective Overall UA	5364.59	Btu/(h*°F)
End Point UA	4816.39	Btu/(h*°F)
Duty	407301	Btu/h