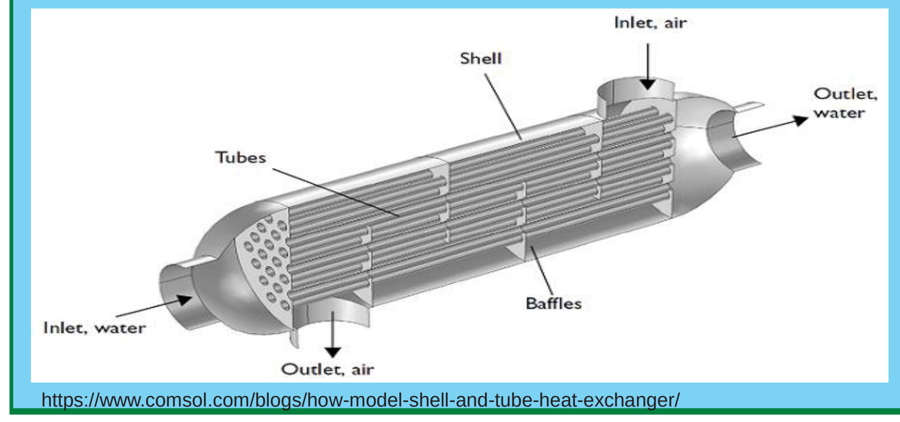

https://www.comsol.com/blogs/how-model-shell-and-tube-heat-exchanger/

Homebrewing: Obtaining an efficient Cold Break

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http://romebeerfest.com/2015/06/the-home-brew-competition-is-back/

Background

My research focused upon the development of an alternative method for heat transfer to chill hot wort in the brewing process. Efficient heat transfer is necessary to ensure an adequate cold break for a clear and flavorful product. The cold break is a group of proteins that must be thermally shocked to precipitate out of solution[2]. An ice bath is not sufficient to obtain an efficient cold break, so alternative methods must be explored.

Commercially, there are three types of chillers readily available. There are immersion chillers, plate chillers, and counter-flow chillers[2]. The term chiller is used, but in reality these are types of heat exchangers.

A MATLAB code was developed to aid in the design of a shell and tube (S&T) heat exchanger. Construction of the (S&T) heat exchanger was done with Polyvinyl Chloride (PVC) pipe, Chlorinated Polyvinyl Chloride (CPVC) pipe, and copper tube, and brass sheeting.

Types of Heat Exchangers Examined

The two types of heat exchangers used here to compare performance were chosen due to their cooling ability being predicted to be either better or worse than the S&T exchanger to be designed in this study. An immersion chiller and a plate chiller were chosen for comparison. The immersion chiller was constructed as well, but the plate chiller was purchased as the facilities for machining stainless steel were not available.

Copper Immersion Chiller
Heat Transfer Area: 2.62 ft^2

Plate Heat Exchanger
Heat Transfer Area: 5.17 ft^2

S&T Chiller
Heat Transfer Area: 10.97 ft^2

Shell and Tube Design

To design the S&T heat exchanger, a design method was chosen. The Bell-Delaware Method[5] was examined to determine the validity of its use in the design of the exchanger. This method utilizes a log mean temperature difference and various correction factors to predict the overall heat transfer coefficient and pressure drop within the exchanger. The tube heat transfer and pressure drop were predicted as follows[5]:

$$h_i = \frac{1.86k_c}{D_i}\left(\frac{Re_{tube}Pr_cD_i}{L}\right)^{\frac{1}{3}}\left(\frac{\mu_c}{\mu_w}\right)^{0.14} \qquad Re_{tube} < 2100$$

$$h_i = 0.116Cp_c\dot{m}_{tube}k_c\left(\frac{Re_{tube}^{0.66}-125}{Re_{tube}}\right)\left(1+\left(\frac{D_i}{L}\right)^{\frac{2}{3}}\right)Pr_c^{\left(-\frac{2}{3}\right)}\left(\frac{\mu_c}{\mu_w}\right)^{0.14} \qquad 2100 < Re_{tube} < 10000$$

$$h_i = \frac{0.023k_c}{D_i}\left(\frac{Re_{tube}^{0.8}Pr_cD_i}{L}\right)^{\frac{1}{3}}\left(\frac{\mu_c}{\mu_w}\right)^{0.14} \qquad Re_{tube} < 10000$$

$$h_{int} = h_i\left(\frac{D_i}{D_o}\right)$$

$$\Delta p_i = \frac{4f_iLn\dot{m}_{tube}{}^2}{2}\frac{\rho_c}{D_i}$$

The shell side heat transfer and pressure drop were predicted as follows:

$$h_o = j_ICp_h\dot{m}_{shell}Pr_h^{\left(-\frac{2}{3}\right)}$$

$$h_{ext} = J_CJ_LJ_BJ_RJ_SJ_\mu h_o$$

$$\Delta p_o = \Delta p_c + \Delta p_w + \Delta p_e$$

In the above equations:

$Pr_{c,h}$ = hot or cold fluid Prandtl number
$Re_{tube,shell}$ = tube side or shell side Reynolds number
$h_{i,o}$ = internal or external heat transfer coefficient
$D_{i,o}$ = internal or external tube diameter
k_c = cold fluid thermal conductivity
L = length of tube
$\mu_{c,w}$ = viscosity of cold side fluid or at the wall interface
$\Delta p_{i,o}$ = pressure drop in the tube side or shell side
$\dot{m}_{tube,shell}$ = mass flow rate in the tube side or shell side

Utilizing the above equations, the overall heat transfer coefficient was calculated:

$$UA = \left(\frac{1}{h_{ext}A_o} + \frac{\log_{10}\frac{D_o}{D_i}}{2\pi Lk_{tube}} + \frac{1}{h_{int}A_i} + \frac{F_i}{A_i} + \frac{F_o}{A_o}\right)^{-1}$$

$$\dot{q} = UA\Delta T_{LM}$$

MATLAB was utilized to minimize the difference between the guessed wall temperature and calculated wall temperature with a nonlinear multivariate Interior Point method subject to given bounds and constraints[1].
For the chosen design, it was predicted:

$$\Delta p_i = 0.065\ psi$$

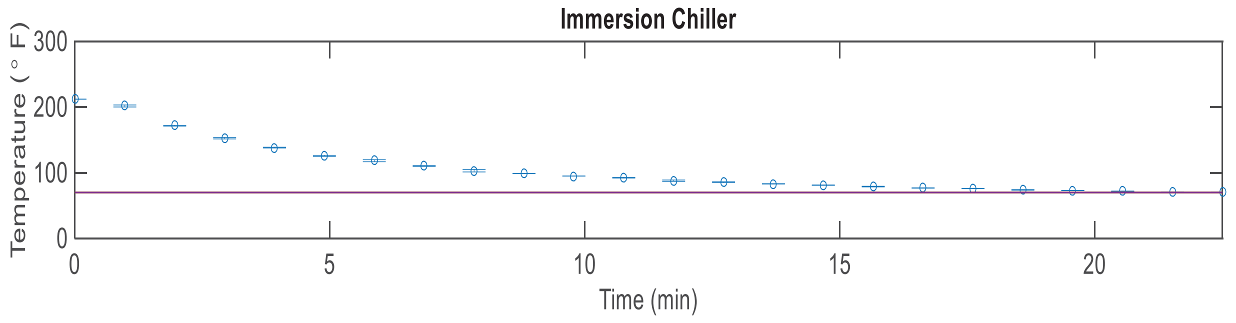
$$\Delta p_o = 0.10\ psi$$

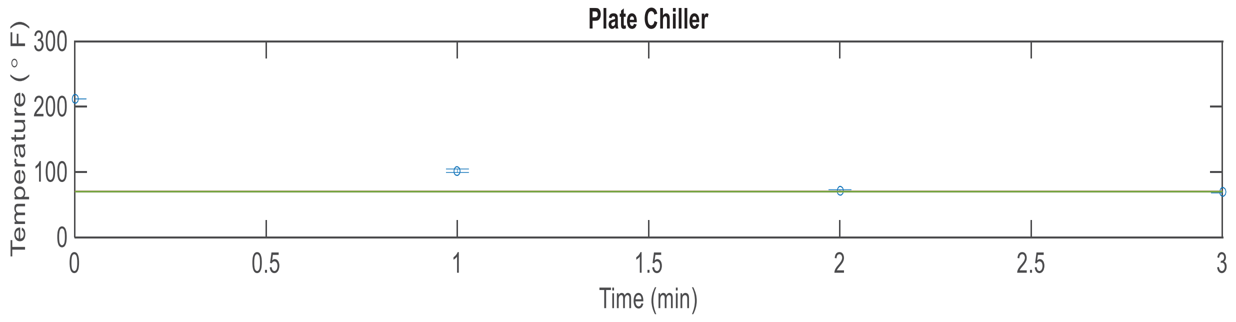
$$UA = 1029.2\,\frac{\mathrm{W}}{\mathrm{K}}$$

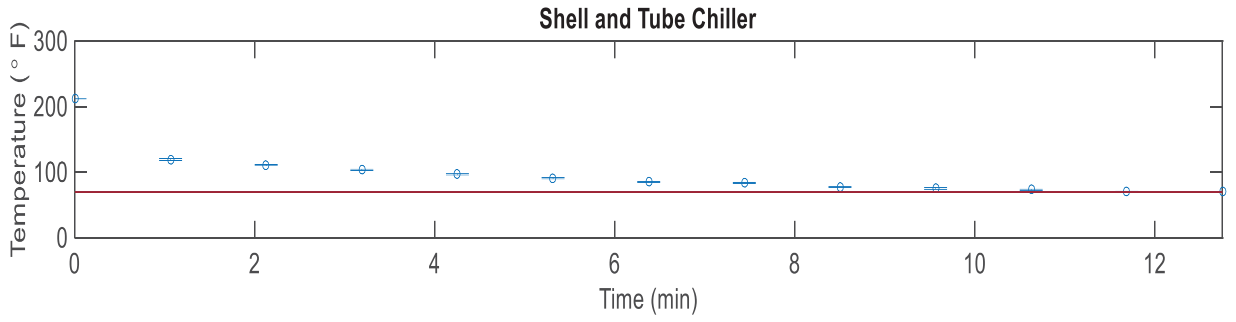
Model Validation & Results

In order to test the performance of the S&T heat exchanger that was designed, a comparison was done between the three. To keep performance as similar as possible, flow rate of cooling water was kept constant at 3.5 gallons per minute (gpm) through all with an initial temperature of 56˚F. For the S&T and plate exchanger, the hot fluid flow rate was kept at a constant 2 gpm. Hot fluid cooling and water usage is shown in the following plots. Three trials were run on each to ensure standard error could be achieved. Five gallons of water was used as the hot media with an initial temperature of 212˚F.

Test Results







Findings

- Plate Chiller is the most efficient
- S&T Heat Exchanger cools roughly twice as fast as the immersion chiller
- Water usage:

Model	Trial 1 (gal)	Trial 2 (gal)	Trial 3 (gal)
Immersion	97.1	98.0	97.5
Plate	19.2	19.5	20.1
S&T	54.3	56.1	55.4

Future Work

- Conduct more trials with varying flow rates in S&T to maximize heat transfer
- Explore more efficient shell and tube designs to improve heat transfer

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