Low Pressure Counter Current Heat Exchanger

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Abstract. A low pressure counterflow heat exchanger was designed to reduce the electricity bill of a manufacturer by $2000 per annum. Waste heat is recovered from a hot waste water stream and used to preheat a cold incoming stream. The exchanger measures 2.5m x 0.5m x 3.3m, and contains 135m of exchanger length. The exchanger is a plastic copper annulus of 5.08cm outer diameter and 2.54cm inner diameter. Over ten years the exchanger will save 4.7 times the initial investment. The associated payback period is 13 months.

Key words: Industrial energy recovery, heat exchanger, low pressure, waste heat recovery

Introduction

The team was contracted by the Linamar CAMTAC plant to reduce energy consumption of the manufacturer. Yearly savings are attained by preheating fresh wash water using waste wash water. Subsequent site visitations and discussions with management and floor workers defined the problem further. The plant has 11 washers, each containing a volume of 5300 L at 60°C. They are exchanged once per month at a rate of approximately 2.2L/s. The waste wash water is left to settle and cool before being disposed off site. The Guelph main water line has an approximate temperature of 10°C at 415 kPa. Electricity costs to plant are significant because of a low power factor (0.821) in the resistive washer heaters, and the cold mains water(10°C). Electricity cost are approximately 0.05 $/kWh. The design is seen in Fig. 1.

The key innovation was using a simple and robust technology (annulus heat exchanger), combined with a mathematical optimization to produce a design solution which maximizes ROI, and therefore value to the company. The secondary innovation was realizing that low quality heat flows necessitated a low technology solution, one that could be built by trade persons on site.

Optimization

The selected counter flow annulus heat exchanger was subsequently modeled to return a function expressing the return on investment. This function was subsequently maximized over several different pipe diameters, thicknesses, materials, and required pumps. The following equations summarize the model:

\[
ROI = \frac{Savings - Cost}{Cost} \tag{1}
\]

\[
S = fn(P_E, N_{wash}, C_p, N_{exch}, mass, T_{c2} - T_{c1}, PF) \tag{2}
\]

\[
L_{pipe} = fn(\frac{\partial m}{\partial t}, D_1, D_2, T_{h1}, T_{h2}, T_{c1}, T_{c2}) \tag{3}
\]

\[
ROI = \frac{S - (C_{pump} + (a + b + c + d)[\frac{L_{pipe}}{3}])}{(C_{pump} + (a + b + c + d)[\frac{L_{pipe}}{3}])} \tag{4}
\]

Where \( P_E = 0.058/kWh \), \( N_{wash} = 11 \) is the number of washers on site, \( C_p = 4.3 \frac{J}{g\circ C} \) is the heat capacity of
water, $N_{exch} = 12$ is the number of times the water is exchanged per year, $mass = 5300\text{kg}$ is the mass of washer water, $\frac{2m}{\partial t} = 2.2\text{kg/s}$ is the mass flowrate of water, $D_1 = 0.0254m$ is the inner copper tube diameter, $D_2 = 0.0508m$ is the outer CPVC tube diameter, $T_{h1} = 60^\circ C$ is the temperature of the waste hot water, $T_{h2} = 15^\circ C$ is the final wash water temperature, $T_{c1} = 10^\circ C$ is the Guelph mains temperature, and finally $C_{pump} = 700$ is the cost of the chosen pump.

a, b, c, and d are the costs of components, a is the 1 inch copper piping, b is the 2 inch CPVC piping, c is the 2 inch end caps, and d is the rubber nipple joining two tubes.

Holding everything constant except for $T_{c2}$ allows for an analysis based on recovered heat in the cold stream. The first year ROI is negative (figure 2), so a net present value was calculated at an interest rate of 15%. There are no significant maintenance costs for the heat exchanger, the pump is expected to cost 30$ per annum to run and the energy savings are assumed to be constant each year.

![ROI Sensitivity analysis](image)

**Fig. 2.** Sensitivity analysis of Annulus Heat Exchanger

As can be seen in figure 2, a $T_{c2}$ between 40$^\circ C$ and 50$^\circ C$ yields the greatest ROI. The actual ROI equation is not continuous because a straight run length of 3m was decided upon, and therefore all components multiples were rounded according to the nearest 3m of length for the design. The capital payback period is 13 months.

**Discussion**

The design was acceptable given the constraints. It can be fabricated by Linamar and therefore if the need for excess heat exchanger capacity is required the unit can be modified or altered to suit their needs. The design is optimal for the specific conditions and can easily be applied in other situations, the solution is not unique to the Linamar plant. Simplicity is another significant advantage. Should an individual component wear out with this design, the components can easily be replaced due to their simple nature. The exchanger operates on easily understood principals and operators will find it easy to use. The non continuous nature of its use will allow it to be used in other heat exchange applications as the plant expands. A maximum of about $2000 is expected, and it will not have a perceivable effect upon the overall ROI of the plant. More favourable investments will take precedence over this project and it may not be constructed. Increasing energy prices will make this investment more favourable in the future.

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**Final Design**

The final design is seen in figure 1. The basic design is a tube in tube exchanger of straight length 135m. Heat exchange occurs between the fluids in the inner tube and the annulus space across the thickness of the inner tube. The tube pairing rotates back onto itself in 180 degree turns to conserve floor space, after 15 of these changes the pairing is turned a perpendicular 90 degrees. The exchanger is composed of 45 lengths of 3 m tube pairs. A scaffolding of 1/2 inch square steel tubing was constructed to support the apparatus. The measurements of the assembly are 3.300m x 2.5m x 0.5m. Tube centers are 160mm apart horizontally and vertically in a square pattern. Tubing is run from the inlet and outlet valves to chest height, 1.25m, ensuring an easy connection.