Heat Exchanger Design Parameters Effect on Low Pressure Side Maximum Pressures during a Tube Failure

Dustin Smith, P.E. & John Burgess, P.E. & Zubin Kumana, P.E.

Introduction

This poster looks at the following variations in design parameters and how they affect the maximum pressures in various components of the system.

1. ***Cooling water lateral diameter:***
   For each model, the exchanger was assumed to be attached to a 24" main cooling water supply and return header, and a 4", 6" and 8" diameter cooling water lateral was used to connect the exchanger to the main headers.

2. ***Cooling water lateral lengths:***
   For each of the different lateral diameters that were investigated, lengths of 45', 75', and 150' were used to connect the exchanger to the main headers.

2a. ***Cooling water lateral flow resistance:***
   For one of the cooling water lateral systems (6" diameter and 75' length), the effect of varying the fitting resistances (K values) was investigated.

3. ***Asymmetric lateral diameters:***
   The effects of having different inlet and outlet lateral diameters were investigated for 75' of lateral piping.

4. ***Effect of a rupture on exchangers in series:***
   A system with three heat exchangers in series was investigated to see the effects of a tube rupture in one exchanger on the other two.

5. ***Effect of a rupture on exchangers in parallel:***
   A system with three heat exchangers in parallel was investigated to see the effects of a tube rupture in one exchanger on the other two.

Description of Model

The model is an implementation of the one presented by Sumaria et al. [1], consisting of a defined network of control volumes connected via inertial segments. The pressure within each control volume is defined by a single average value across the control volume. One or more segments are identified as the location where a tube rupture occurs.

The flow entering the system via the ruptured tube is modeled based on an orifice flow calculation using the tube internal diameter, upstream pressure and physical properties, and the pressure in the control volume in which the rupture occurs. Flow from a single orifice was introduced to the both inlet and outlet channels; thus, from an overpressure protection standpoint the system was modeled with high pressure vapor inlet flow from 2 orifices.

The differential equation governing a control volume is: **Eq. 1**

$$\left(\frac{V_l}{B_l} + \frac{V_g}{kP} + \frac{VD}{TE}(1-u^2) \right) \frac{dP}{dt} = \frac{W_i - W_o}{P_l} + \frac{W_g}{P_g}$$

V_l = Liquid phase volume	k = Isentropic coefficient	u = Poisson ratio	P = Pressure
V_g = Vapor phase volume	D = Diameter	W_i = Flow into control volume	P_l = Liquid density
V = Liquid phase volume	T = Material Thickness	W_o = Flow out of control volume	P_g = Vapor density
B_l = Bulk modulus	E = Modulus of elasticity	W_g = Gas flow into control volume	t = Time

The differential equation governing an inertial segment is: **Eq. 2**

$$\frac{L}{Ag_c}\frac{dw}{dt} = P_i + P_o - \Delta P_{flow}$$

L = Actual length of fluid mass
A = Cross - sectional area of fluid mass
g_c = Gravitation conversion constant
P_o = Pressure at time zero
P_i = Pressure at time step i

The pressure nodes, associated control volumes, and linking inertial segments were chosen to suit the layout of the system under analysis. The main cooling water supply and return headers were treated as infinite reservoirs at the stated supply and return pressures. Each segment was solved to obtain a steady state prior to the introduction of the tube rupture. The resulting system of differential equations was solved using a classical fourth-order Runge-Kutta method.

Results Single Exchanger Modeling

This section of describes the results of the items investigated for changing the parameters for a system with a single heat exchanger. For single exchanger systems, the following parameters were used:

1. ***High pressure gas:***
   A Natural Gas with a MW of 18.4 at 200 °F. The gas pressure upstream of the rupture was varied from 250 psig to 5,000 psig.

2. ***Heat exchanger:***
   The heat exchanger channel was 1.5' long by 25" in diameter with 250 36' long ¾ BWG 16 u-tubes.

3. ***Cooling water system:***
   The cooling water system consisted of a supply pressure of 75 psia and a return pressure of 60 psia. The main headers were 24" diameter.

4. ***Overpressure protection:***
   The exchangers were modeled without any overpressure protection other than the normal cooling water flow paths to the tower (which are presumed to remain open).

5. ***Cooling water flow:***
   The flow of the cooling water was not restricted. There were no check valves on the supply side to prevent flow reversal of the cooling water during the high pressure transient.

   Some of the parameters such as resistance of fittings in the lateral and additional flows in the main header and differences in header lengths and lateral resistances were further investigated in the various sections.

Variation of Cooling Water Lateral Diameters and Lengths

For all of these models, the exchangers were assumed to be attached to a 24" main cooling water supply and return header, and a 4", 6" and 8" diameter cooling water lateral was used to connect the exchanger to the main headers.

Figure 1 shows the results for the variation in inlet diameter and lengths for laterals. The 45'x4" in the legend is shorthand for a 4" cooling water lateral that is 45' on the inlet and outlet. The peak pressures shown in Figure 1 are the highest pressure predicted in the cooling water lateral and/or inlet and outlet exchanger tube side channel. Figure 2 shows the peak pressures are higher in the inlet and outlet piping than the exchanger. This was representative of a majority of the cases investigated in this study.

The results shown in the Figures 1 & 2 suggest that the most important parameter for limiting pressure to the cooling water system is the diameter of the lateral piping. While it was not investigated, it could be presumed that at some point the diameter of the header piping would also be an important factor.

Figure 3 shows the maximum pressures in the systems with 75' of lateral piping for cases with asymmetric inlet and outlet lateral diameters. The results shown in Figure 3 indicate that the peak pressures predicted for asymmetric piping are between the larger and smaller lateral diameters (as contrasted to being similar to the peak pressures predicted for either the smaller or larger diameter lateral).

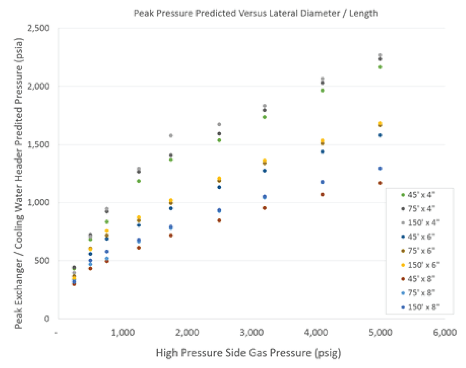

Figure 1. *Comparison of Lateral Diameters and Lengths*

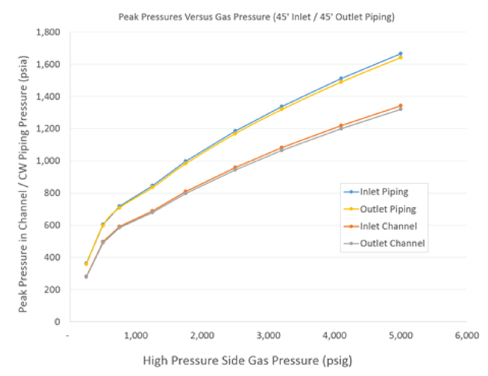

Figure 2. *Comparison of Peak Pressures for a Single Exchanger Run*

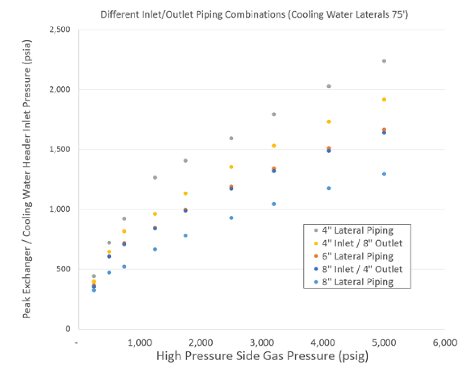

Figure 3. *Comparison of Asymmetric Lateral Diameters*

Variation of Cooling Water Header Lengths and Lateral Resistances

The length of the cooling water header supply and return piping was increased some (quadrupled) and then increased significantly (ten times) to determine the effect on the maximum predicted pressure in the exchanger and lateral piping. In addition, the flow resistance was increased (doubled) and then increased significantly (six times) to determine the effect on the maximum predicted pressure in the exchanger and lateral piping. The base case (Figure 2) that was used for comparison was the one with 75' of 6" lateral piping connected to the heat exchanger.

The flow resistances in the laterals were increased by first doubling and then subsequently tripling the doubled K values for the lateral piping in the model. Since the series significantly overlap in Figure 4, it is shown that within the magnitude of the changes reviewed, increasing the header length and/or the lateral resistances does not impact the peak pressures in the system.

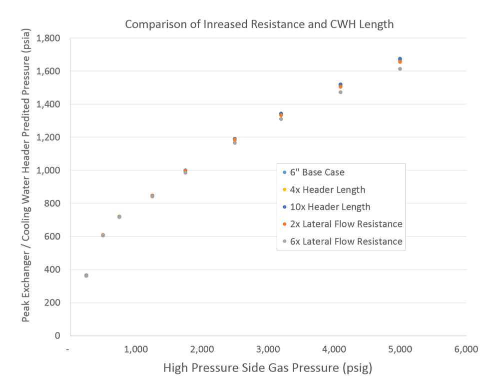

Figure 4. *Comparison of Header and Lateral Flow Resistances*

Multi-Exchanger System - 3 Exchangers in Series

This section of the paper describes the results of the consequences associated with a tube rupture in a system where there are three heat exchangers on a single lateral (as shown in Figure 5). For these runs the same parameters as for the single exchanger plus the following parameters were used:

1. ***Exchanger Layout:***
   The inlet and outlet laterals were modeled as 45' and the cooling water (tube) side of these heat exchangers were assumed to be bolted to each other flange to flange.

2. ***Rupture:***
   Each exchanger was assumed to rupture independently. Thus, it was not assumed that a rupture in one exchanger would cause another in series to also fail.

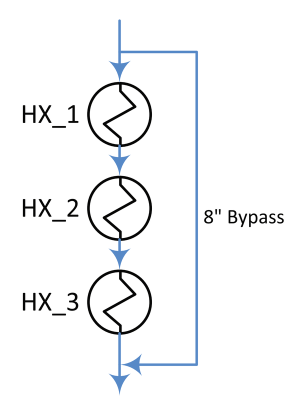

Figure 5. *Arrangement of heat exchanges in series (shown with bypass variant)*

As shown in Figure 6, when one of the exchangers in the series ruptures, the peak pressures in the other exchangers are within 15% difference of each other. Thus, all exchangers in the series need to be designed for the peak pressures.

In Figure 6, Break #1 (Channel) indicates that the pressures reported are the peak pressures for all of the exchangers when there is a tube rupture in Exchanger #1. Inlet shows the pressure in the inlet lateral to the bank of exchangers and outlet shows the pressure in the outlet lateral. A run, similar to those shown in Figure 6, was performed with an 8" bypass around the exchangers connecting the cooling water supply header with the cooling water return header. This was done to estimate the effects of increased cooling water flow rates in headers on the peak pressures. Other than lower peak pressures (15% difference) in the cooling water inlet and outlet headers, the pressures were within 0.1% difference of those in Figure 6. Note that these comparisons were for a break in the middle exchanger. Breaks in the first and last exchanger were not investigated due to the lack of change in the peak pressures from the analysis performed on the middle exchanger.

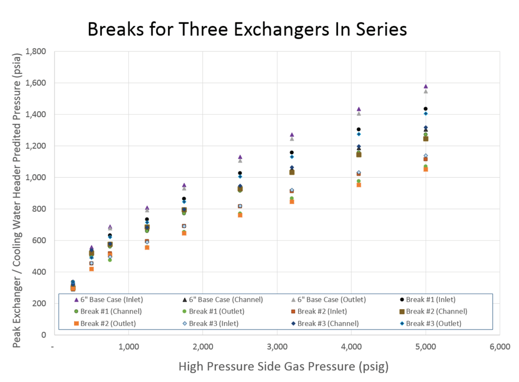

Figure 6. *Comparison of Peak Pressures for Exchangers in Series*

Multi-Exchanger System - 3 Exchangers in Parallel

This section of the paper describes the results of the consequences associated with a tube rupture in a system where there are three heat exchangers connected to a common supply and header in parallel lateral (as shown in Figure 7). For these runs, the same parameters as for the single exchanger plus the following parameters were used:

1. ***Exchanger Layout:***
   The inlet and outlet laterals were modeled as 45 feet and the cooling water (tube) side of these heat exchangers were assumed to be connected to the header 20 feet apart.

2. ***Rupture:***
   Each exchanger was assumed to rupture independently. Thus it was not assumed that a rupture in one exchanger would cause another in series to also fail.

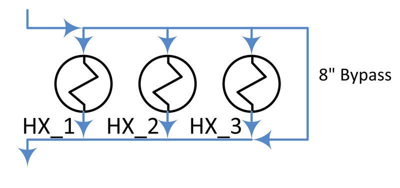

Figure 7. *Arrangement of heat exchanges in parallel (shown with bypass variant)*

In Figure 8, (Oth Ex) is the peak pressure in the non-ruptured exchangers and laterals and (HDR) is the Peak pressure in the supply and/or return headers. The peak pressure of the exchanger that ruptures was not included in Figure 8 as it was similar to the other pressures presented in this paper and made it difficult to see the difference.

As shown by Figure 8, the larger system with higher header flows do not significantly affect peak pressures in the other system exchangers. This is consistent with the results found for the exchangers in series comparison.

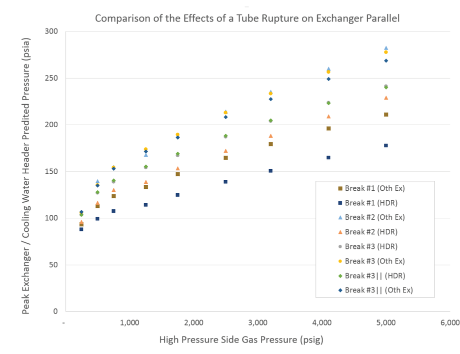

Figure 8. *Comparison of Peak Pressures for Exchangers in Parallel*

Conclusion

When designing a cooling water system, a designer should consider the following parameters.

1. ***Lateral Diameter:***
   The biggest impact as seen throughout the figures in this paper is the diameter of the lateral that leads from the supply header to the exchanger and then back to the return header.

2. ***Lateral Length and/or Resistance:***
   The length of the laterals and the resistance (K) from fittings did not significantly affect the peak pressures observed in this model (as compared to the lateral pipe diameter).

3. ***Header Lengths:***
   Changing the lengths of the cooling water supply and return headers did not increase the system peak pressures appreciably. However, this may not be true for a smaller diameter header (or larger diameter laterals). The smallest ratio explored in this study was a 24" diameter header with 8" laterals.

4. ***Exchangers In Series:***
   The pressure in the exchangers in series were all significantly increased when one ruptured. A system designer should be careful that the combination of any high pressure exchangers with lower pressure exchangers on a single line may overpressure all exchangers on that lateral.

5. ***Exchangers in Parallel:***
   When a system has multiple exchangers hydraulically close, the rupture in one can affect the peak pressures in nearby exchangers. This effect is less severe than when exchangers are in series, but could exceed the design pressure especially dependent on the high pressure side gas pressure.

6. ***Peak Pressures:***
   As seen in many of the figures, the peak pressures seems to be a strong function of the vapor flow through the broken tube. This rate is dependent on the square root of the high side pressure.

References

[1] Sumaria, V.H., Rovnak, A., Heitner, I, Herbert, R.J. Model to Predict transient Consequences of a Heat Exchanger Tube Rupture, API Proceedings – Refining Department, Vol 55. 1976. Pp 631-654.

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