Design of the Evaporator for the Methanol/Water Mixture

Introduction

In order to design an evaporator or a heat exchanger, various things need to be considered. The first task is always to determine the area needed to facilitate the desired amount of heat transfer. In order to do so, we need to know the temperature difference as well as the flow rates. In addition, we need to estimate the heat transfer coefficients at all interfaces and determine the overall heat transfer coefficient. In many cases, this can greatly simplify the first design iteration. Care has to be taken that the first design is of conservative nature, i.e. the lowest possible heat transfer coefficient and the lowest possible temperature differences should be taken into account.

The overall amount of heat transferred in a heat exchanger can be calculated using the following equation:

\[ Q = UA \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} \]  

(Eq. 1)

where \( Q \) is the overall amount of heat transferred in \( W \), \( U \) is the overall heat transfer coefficient in \( W/m^2K \), \( A \) is the total area and the last term is called the mean logarithmic temperature difference, where \( \Delta T_1 \) is the temperature difference between the hot and the cold fluids at the inlet of the hot side, and \( \Delta T_2 \) is the temperature difference between the fluids at the outlet. If the heat exchanger has been split up in different sections, we need to evaluate the mean logarithmic temperature difference for each section.

In our particular case, we want to evaporate a given amount of methanol/water fuel mix with a given amount of a secondary oil loop. The feed stream enters at around 20 °C and should be superheated to 192 °C, whereas the oil loop only cools down from around 200 °C to 193 °C. Thermodynamic cycle simulations have shown that this is possible because of the high flowrate of the oil and the high heat capacity.

Knowing the temperature difference, we need to estimate an overall heat transfer coefficient \( U \) (again this may be done for the different sections of the heat exchanger). However, in order to do so, we need to determine a basic concept as to what the heat exchanger / evaporator should look like. This will be discussed in the next section.

Using Equation 1, it can also be demonstrated that the counter-flow design yields always a higher temperature difference, which means that the heat exchanger can always be more compact in the counter-flow design. In addition, in this case the outlet temperature of the cold fluid can exceed the outlet temperature of the hot fluid, which is of course impossible for the co-flow design. Textbooks on heat exchange equipment conclude therefore that counter-flow heat exchangers are always to be
preferred over co-flow design, unless there are very compelling reasons for the co-flow concept.

However, if the outlet temperature of the hot fluid should only be slightly higher than the outlet temperature of the cold fluid, the co-flow design may be chosen unless the heat transfer rates in every section of the heat exchanger is very well known so that the equipment can be properly sized.

**Basic Design of the Evaporator**

**General Remarks**

There is a large range of possible designs for this kind of evaporator, and it is difficult to decide, which particular design we wanted to use. In any case the following criteria should be met:

- Compact design. Because of the particular application, we want the final design to be as small as possible, yet supplying the surface needed to facilitate the desired heat transfer rate. A compact design will also help reducing any undesirable heat losses to the environment.

- Simple design. Heat transfer equipment can easily become very elaborate, and thus we want to start simple in the beginning. Care must be taken that the evaporator can be assembled and dismantled with standard tools, probably avoiding welding altogether.

- Reasonable pressure drops. This criterium might be less strict than the above ones, particularly at the oil-side. The work needed to pump the liquid oil is relatively small. However, it appears difficult to control the pressure of the superheated steam, *i.e.* we need to think about a solution that allows us to control the rate of flow of the water and methanol steam and the pressure inside the evaporator.

- Controlable flow rates. This might become a problem particularly on the fuel side. Obviously, under steady-state conditions the incoming liquid fuel must be the same as the flow rate of the vapour leaving the evaporator.

- Sealing is very important, because we want to avoid any traces of oil getting into the fuel cell and reducing the performance.

- Cost and weight must be considered, *i.e.* we should use ”standard” materials and take care not to oversize the equipment, particularly in the co-flow mode. In order to do so, we need to make an effort to well understand the heat transfer rates inside the heat exchanger.
As was mentioned above, there is a large variety of possible designs for our equipment. In addition, various companies sell heat exchangers in all different sizes. However, because we will need to do a detailed calculation in term of the needed heat transfer area anyway, which can vary a lot with different designs, we finally decided to design and build our own equipment.

The basic design was resulted out of a discussion with Prof. Hallvard Svendsen from the Department of Chemical Engineering at NTNU, and it is shown in Figure 1.

The oil is passed through numerous tubes, and the methanol/water mixture is fed into the bottom of the vessel. The design shown above is operating in the counter-flow mode, but the direction of the oil can be easily changed in order to operate in co-flow fashion. Because it will enter in the liquid phase, we will have a certain amount of boiling liquid inside the vessel, above which we will have steam rising and leaving the evaporator, driven by the pressure that has build up inside the vessel. On the other hand, the vessel pressure will result out of the added pressure losses for the anode gas when it is passed through the steam reformer, fuel cell, catalytic burner and the heat exchangers. This particular design was suggested by Prof. Svendsen and it has the advantage that it can be easily manufactured.

Now that the design was chosen, we needed to size the vapourizer. In order to do so, we have to calculate the overall amount of heat that is to be transferred. In addition,
we need to get an understanding of the heat transfer coefficients and limitations in the different parts of the system.

Figure 2: Conceptual design of the oil manifolder and tubing. The shaded area are for the vapour to leave the vessel. The total number of oil tubes is 76.
Appendix – Drawings
1.) Top plate
2.) Top manifold - upper plate
3.) Top manifold - lower plate
4.) 8 steam pipes
5.) 5 distance holder tubes
6.) Upper manifold - upper plate
7.) Upper manifold - lower plate
8.) 76 oil pipes
9.) 5 distance holders
10.) Vessel
11.) Lower manifold - upper plate
12.) Lower manifold - lower plate
13.) Bottom plate
14.) Aluminium Funnel

O-Ring 115 x 4
O-Ring 115 x 3
O-Ring 115 x 3
O-Ring 115 x 3
2.) Top manifold - upper plate
3.) Top manifolder - lower plate
6.) Upper manifold - upper plate
7.) Upper manifold - lower plate
11.) Lower manifolder - upper plate
12.) Lower manifolder - lower plate
9. Distance holder tubes
13.) Bottom plate
1.) Top plate
14. Aluminium Funnel