

Heat Exchanger Calculations

Ethylene from a pipeline (50 t/h, 70 bar, 5 °C) passes a heat exchanger and is heated up to 45 °C. The pressure drop is negligible. As usual, in the data sheet of the heat exchanger the c_p values at inlet and outlet are given as,

$$C_p(5\text{ °C}, 70\text{ bar}) = 3.984\text{ J/g.K} \quad C_p(45\text{ °C}, 70\text{ bar}) = 3.783\text{ J/g.K}$$

In order to calculate the heat to be exchanged within the exchanger most engineers would adopt a standard approach and use the average value of C_p in their calculations. Especially, as the two temperatures are not far apart, the quoted C_p are similar and ethylene is supercritical at 70 bar ($P_c = 50.4\text{ bar}$). Hence, with C_p values at 5 °C and 45 °C the average value, $C_{p,av}$ can be determined to be,

$$C_{p,av} = (3.984 + 3.783)/2 = 3.8835\text{ J/g.K}$$
$$Q = m \cdot C_{p,av} \cdot \Delta T = 2.157\text{ MW}$$

However, if the calculation is performed using a high-precision equation of state then the enthalpies at two temperatures are,

$$h(5\text{ °C}, 70\text{ bar}) = -356.825\text{ J/g} \quad h(45\text{ °C}, 70\text{ bar}) = -108.907\text{ J/g}$$
$$Q = m \cdot \Delta h = 3.443\text{ MW}$$

There is a large difference between the two results. Which one is to be preferred?

Although the C_p values are correct, the first approach does not yield a reasonable result. The problem is that C_p exhibits a strong critical enhancement in the vicinity of the critical point, resulting in a sharp maximum, as Figure 1 illustrates.

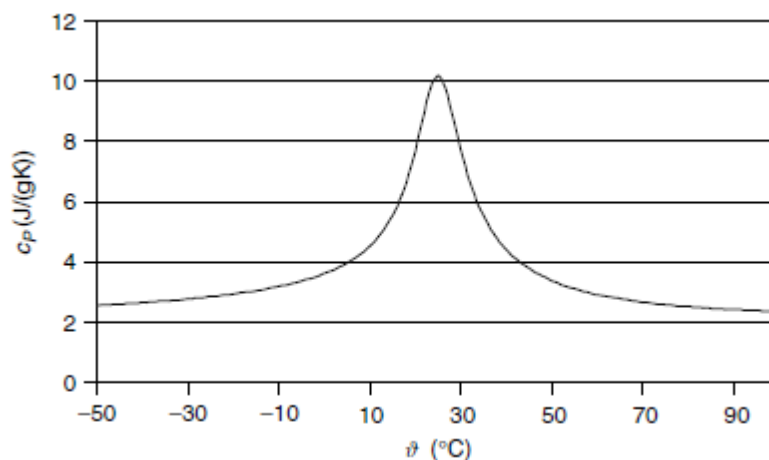


Figure 1 Specific heat capacity c_p of ethylene at $P = 70\text{ bar}$ as a function of temperature.

This example actually occurred in a practical application and caused a lot of confusion, as it is a common procedure to take the C_p values at inlet and outlet for the calculation of the heat duty and for the design of the heat exchanger.

Hence, if the process operates anywhere near the critical point, it is important to use accurate EoS that take into account the critical enhancement of thermodynamic properties. The same is true of transport properties where thermal conductivity and to a smaller extent viscosity display analogous behavior.

Reference:

Jürgen Gmehling, Bärbel Kolbe, Michael Kleiber, and Jürgen Rarey, *Chemical Thermodynamics: for Process Simulation*, First Edition. © 2012 Wiley-VCH Verlag GmbH & Co. KGaA. Published 2012 by Wiley-VCH Verlag GmbH & Co. KGaA.