19.2: Joule-Thomson Coefficient

One remarkable difference between flow of condensate (or liquid) and natural gases through a pipeline is that of the effect of pressure drop on temperature changes along the pipeline. This is especially true when heat losses to the environment do not control these temperature variations. Natural gas pipelines usually cool with distance (effect commonly called ‘Joule–Thomson cooling’), while oil lines heat. The reason for such dissimilarity pertains to the different effect that pressure drop has on the entropy of a natural gas than on the entropy of an oil mixture. Katz (1972) and Katz and Lee (1990) presented a very enlightening discussion on this regard.

Whether or not a gas cools upon expansion or compression — that is, when subjected to pressure changes — depends on the value of its Joule–Thomson coefficient. This is not only important for natural gas pipeline flow, but also for the recovery of condensate from wet natural gases. In the cryogenic industry, turboexpanders are used to subject a wet gas to a sudden expansion (sharp pressure drop) in order to cool the gas stream beyond its dew point and recover the liquid dropout.

Thermodynamically, the Joule–Thomson coefficient is defined as the isenthalpic change in temperature in a fluid caused by a unitary pressure drop, as shown:

$$\eta = \left( \frac{\partial T}{\partial P} \right)_H \quad \text{(19.18)}$$

Using thermodynamic relationships, alternative expressions can be written. For example, using the cycling rule we may write:

$$\left( \frac{\partial H}{\partial P} \right)_T \left( \frac{\partial P}{\partial T} \right)_H \left( \frac{\partial T}{\partial H} \right)_P = -1 \quad \text{(19.19)}$$

or
\[
\left(\frac{\partial H}{\partial P}\right)_T = -\left(\frac{\partial H}{\partial T}\right)_P \left(\frac{\partial T}{\partial P}\right)_H \tag{19.20}
\]

We have also seen that we can express enthalpy changes in terms of pressure, temperature and volume changes:

\[
\left(\frac{\partial H}{\partial P}\right)_T = \tilde{v} - T \left(\frac{\partial \tilde{v}}{\partial T}\right)_P \tag{19.22}
\]

Additionally, the following identity can be derived:

\[
\eta = \frac{R T^2}{P c_P} \left(\frac{\partial Z}{\partial T}\right)_P \tag{19.23}
\]

All together, we have several ways of calculating the Joule–Thompson coefficient for a fluid, as shown next:

\[
\eta = \left(\frac{\partial T}{\partial P}\right)_H = \frac{1}{c_P} \left[ T \left(\frac{\partial \tilde{v}}{\partial T}\right)_P - \tilde{v} \right] = -\frac{1}{c_P} \left(\frac{\partial H}{\partial P}\right)_T = \frac{R T^2}{P c_P} \left(\frac{\partial Z}{\partial T}\right)_P \tag{19.24}
\]

Once the constant pressure specific heat “cₚ” is calculated as discussed in the previous lecture, all the entries in the previous expression are known and the Joule–Thomson coefficient can be analytically calculated. An interesting observation from all above expressions for "Contact your instructor if you are unable to see or interpret this graphic." is that the Joule–Thompson coefficient of an ideal gas is identically equal to zero. However, real fluids take positive or negative Joule–Thompson values.

Contributors and Attributions

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