THERMODYNAMICS OF LIQUID-VAPOUR TWO-PHASE DRAFT TUBES FOR LIQUEFIED GAS EXPANDERS

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Abstract

In modern refrigeration process plants the liquefaction of gases is achieved at high pressure to improve the overall efficiency of the cryogenic process. After the condensation of the refrigerated gas the pressurized liquefied gas is expanded across a liquid-vapour two-phase expander to a lower pressure suitable for storage and transportation of the liquefied gas. The expansion process generates a certain amount of vapour and the remaining liquid is cooled down.

The objective is to increase the amount of liquid and to decrease the amount of vapour at the outlet of the two-phase expander. By employing a two-phase draft tube at the exit of the two-phase expander an increase in the amount of liquid is accomplished. The fluid dynamic operation and the thermodynamic performance of two-phase draft tubes is presented and analyzed.

Two-Phase Expansion Process

By expanding saturated liquefied gas to a lower pressure, vapour is evaporating from the liquefied gas. Figure 1 shows the expansion process for saturated liquefied gases. At the pressure p_1 the point 1 is on the saturated curve. The mass ratio between vapour and liquid portion is defined as x. At the point 1 the value of x_1 is zero, because no vapour occurs at this point.

Using a Joule-Thomson valve to expand the saturated liquid from pressure p_1 to the lower pressure p_2 as the specified outlet pressure, the enthalpy h of the two-phase fluid remains constant, $h_1 = h_2$. The amount of vapour at the point 2 is given by x_2. The expansion across a Joule-Thomson valve is approximately isenthalpic.

Expanding the saturated liquid across a two-phase expander with power generation from p_1 to the lower specified outlet pressure p_2 to the point 3, the enthalpy of the fluid is reduced from h_2 to h_3 by the amount of the generated power ($h_2 - h_3$). The vapour-liquid ratio x_3 is smaller than the ratio x_2, hence producing a higher liquid portion than in the case of a Joule-Thomson expansion.

Two-phase expanders with two-phase draft tubes are of the type of radial outflow turbines or of similar designs and the expanded fluid exits with a certain amount of remaining rotational or translatory kinetic energy. By employing a two-phase draft tube at the exit of the two-phase expander the fluid is expanded to a pressure p_4 below the specified pressure p_2 and the power generation increases. The increased power generation reduces the enthalpy from h_2 to h_4 at the point 4. The vapour-liquid ratio x_4 is smaller than the ratio x_3 producing more liquid at point 4 than at point 3.

Because the specified outlet pressure for the expander is p_2 and not p_4 a certain portion of the remaining kinetic energy of the fluid has to be converted into static energy in form of pressure using a two-phase draft tube. The two-phase draft tube is a diffuser that increases the fluid pressure from p_4 to the specified pressure p_2 at the point 5 with a partial re-condensation of the vapour. The vapour portion x_5 at the point 5 is smaller than the vapour portion x_4 at the point 4. The enthalpy of the fluid across the draft tube remains constant with $h_4 = h_5$. The liquid portion at point 5 is larger than at point 4, and the liquid portion at point 4 is larger than at point 3.

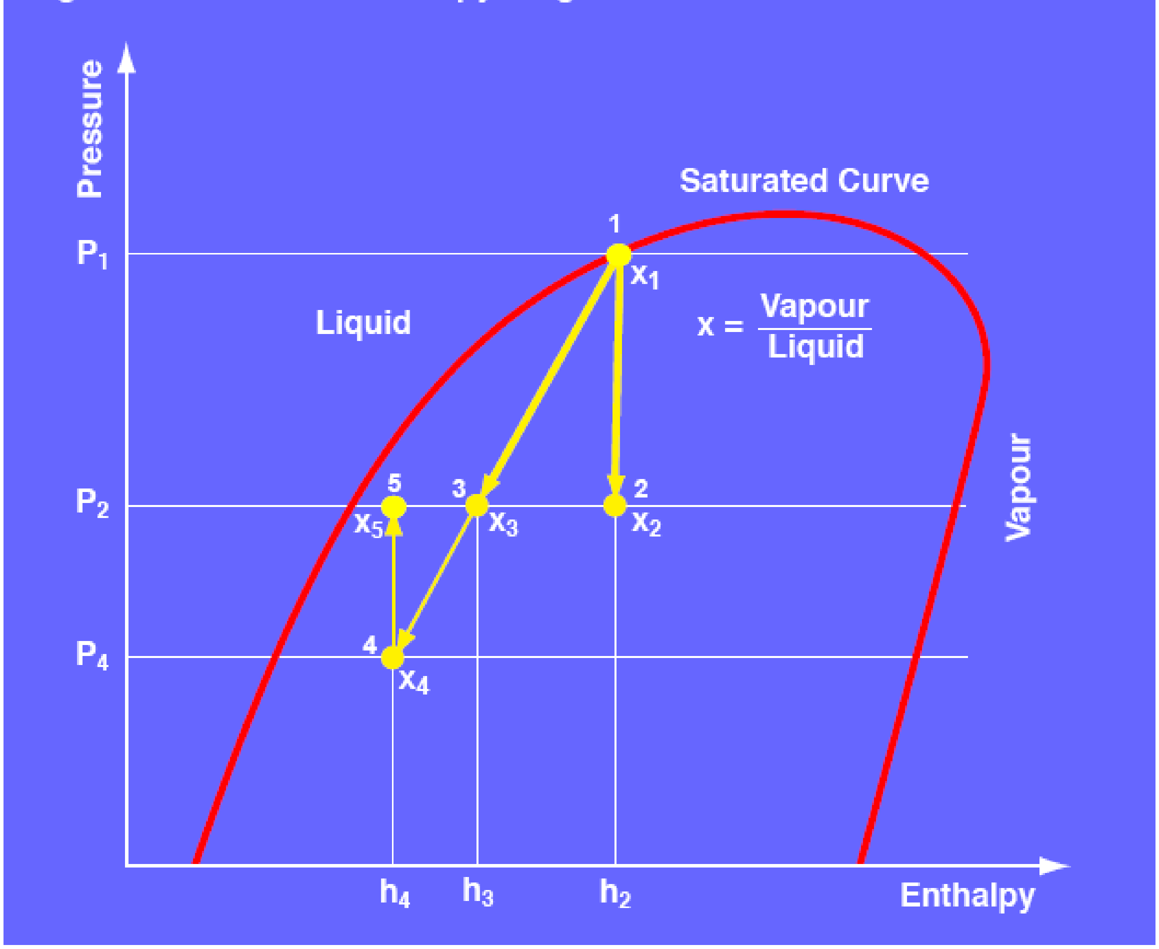

Figure 1: Pressure – Enthalpy Diagram for a Two-Phase Draft Tube

Conceptual Design of a Two-Phase Draft Tube

Figure 2 shows a conceptual design of a two-phase draft tube for radial outflow turbines. The draft tube consists of an inner converging cone and an outer diverging cone, increasing gradually the cross section of the fluid passage. At the inlet of the draft tube the cross section is shaped as a ring and at the outlet as a circle. The ring shaped inlet is designed to fit the ring shaped outlet flow of the radial outflow turbine. Between the inner and the outer cone are vanes shaped to convert the fluid rotation into translatory flow and reducing the kinetic energy of the fluid.

Summary

Using two-phase draft tubes at the outlet of two-phase expanders for the expansion of saturated liquefied gas increases substantially the amount of liquid and decreases the amount of vapour at the outlet of the draft tube.

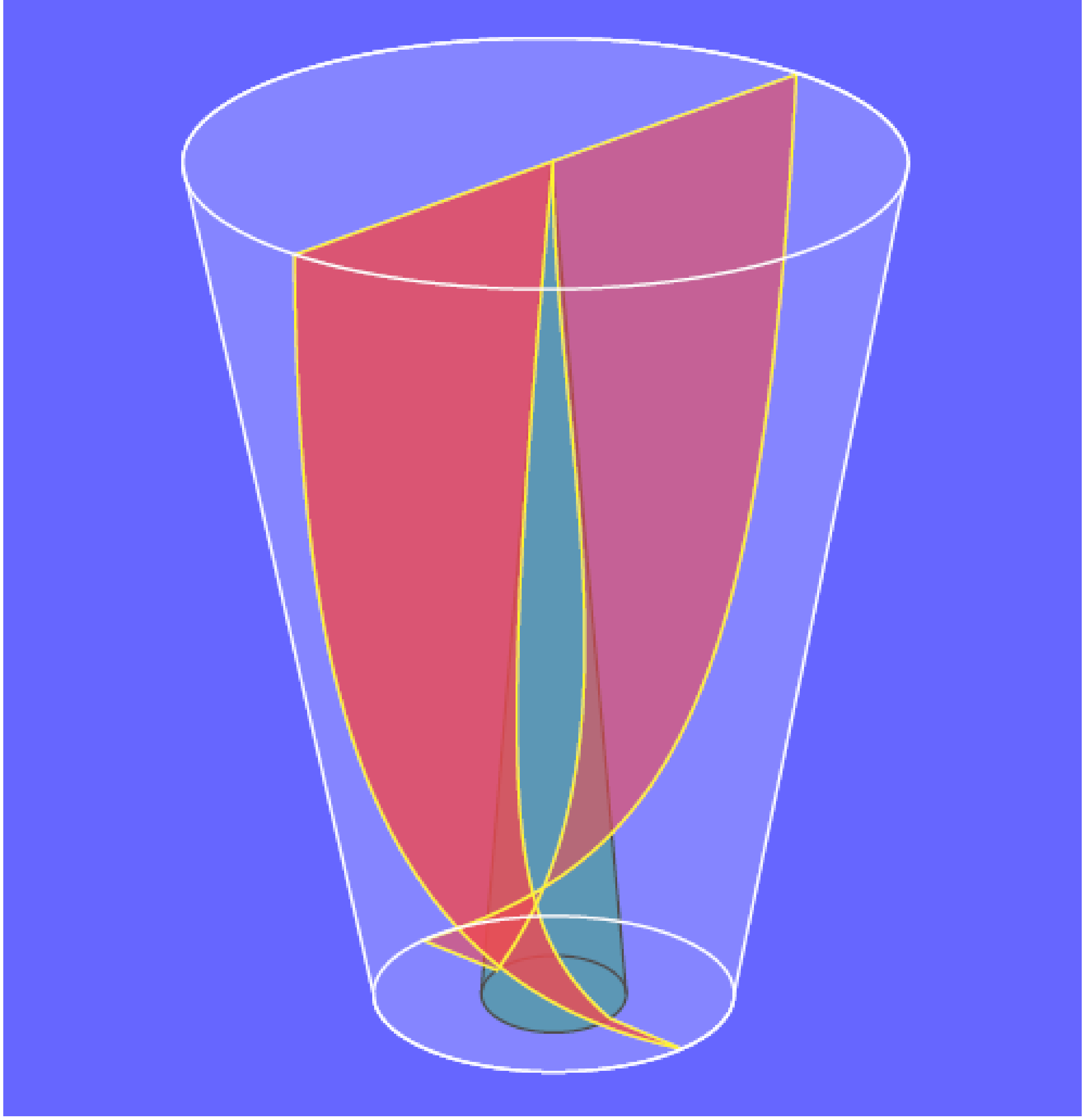

Figure 2: Conceptual Design of a Two-Phase Draft Tube