Guidance page for practical work 10: ejector refrigeration cycles

1) Objectives of the practical work

The objective is to study ejector refrigeration cycles and show how they can be modeled realistically with Thermoptim, and compare the results to those without ejector cycles.

An ejector or injector (Figure 1) receives as input two fluids normally gaseous but which may also be liquid or two-phase:

- the high pressure fluid called primary fluid or motive;
- the low pressure fluid, called secondary fluid or aspirated.

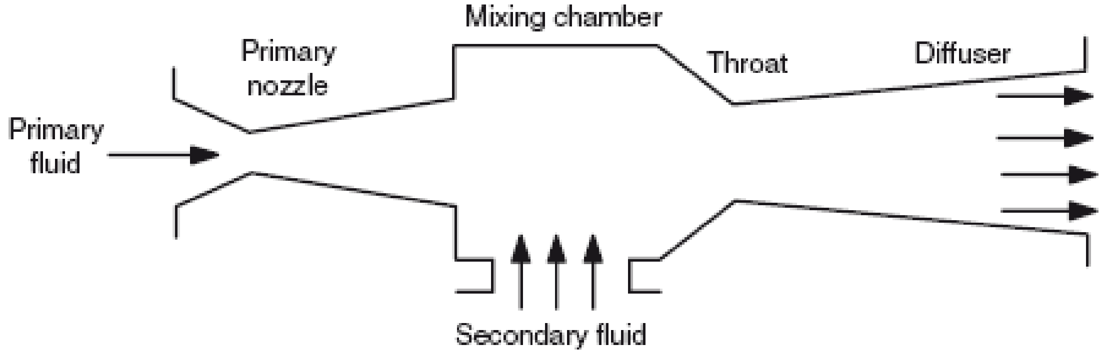

Figure 1: Cross section of an ejector

The primary fluid is accelerated in a converging-diverging nozzle, creating a pressure drop in the mixing chamber, which has the effect of drawing the secondary fluid. The two fluids are then mixed and a shock wave may take place in the following zone (throat in Figure 1). This results in an increase in pressure of the mixture and reduction of its velocity which becomes subsonic. The diffuser then converts the residual velocity into increased pressure.

The ejector thus achieves a compression of the secondary fluid at the expense of a decrease in enthalpy of the primary fluid.

We have built an ejector[1] model that has been implemented in a Thermoptim external class to simulate cycles including refrigeration, involving the component model.

The advantage in introducing an ejector refrigeration cycle is mainly to reduce, or even eliminate, the compression work, relatively large when the compressed fluid is in a gaseous state.

This document is an excerpt from the guidance page with complete results, which is reserved for teachers. For this reason, the numbering of figures is flawed.

2) References

D.W. SUN, I.W. EAMES, *Performance characteristics of HCFC-123 ejector refrigeration cycle*, Int. J. Energy Res. 20 (1996) 871–885.

[1] You will find the corresponding documentation, the class code and extUser.zip file at: http://www.thermoptim.org/sections/logiciels/thermoptim/modelotheque/modele-ejecteur

A.A. KORNHAUSER, *The use of an ejector as a refrigerant expander*. Proceedings of the 1990 USNC/IIR—Purdue refrigeration conference, Purdue University, West Lafayette, IN, USA, 1990, p. 10–19.

D. LI, A. GROLL, *Transcritical CO2 refrigeration cycle with ejector-expansion device*, International Journal of Refrigeration 28 (2005) 766–773

3) Main practical work

3.1 Setting out

An ejector refrigeration cycle without compressor (Figure 2) is as follows:

- at the condenser outlet, part of the flow is directed to a pump that compresses the liquid, at the price of a very low work;
- the liquid under pressure is vaporized in a generator at a relatively high temperature (about 100 °C), and possibly superheated, the temperature depending on fluid thermodynamic properties. Heat supplied to the generator is a purchased energy;
- this superheated vapor is then used in the ejector as motive fluid;
- the part of the liquid that was not taken up by the pump is expanded in the evaporator, then headed to the ejector as secondary fluid;
- the mixture leaving the ejector is condensed in the condenser and the cycle is complete.

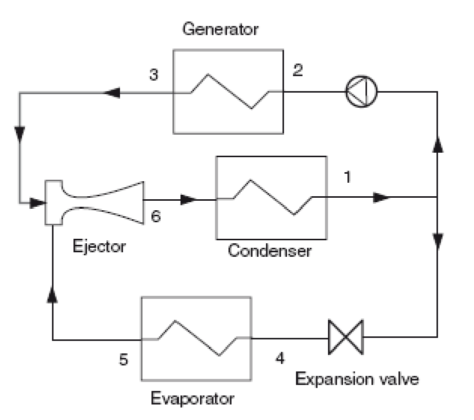

Figure 2: Ejector refrigeration cycle

The advantage of this cycle is to replace compressor work by a much smaller work consumed by the pump and by heat supplied by a generator at medium or high temperature, which can be done using thermal effluents or solar collectors.

3.2 Plot in a chart

In Figure 3, we have plotted in a (h, ln(P)) chart an example of R123 cycle suggested by Sun and Eames (1996). The plant diagram and the ejector screen are given in Figures 4 and 5.

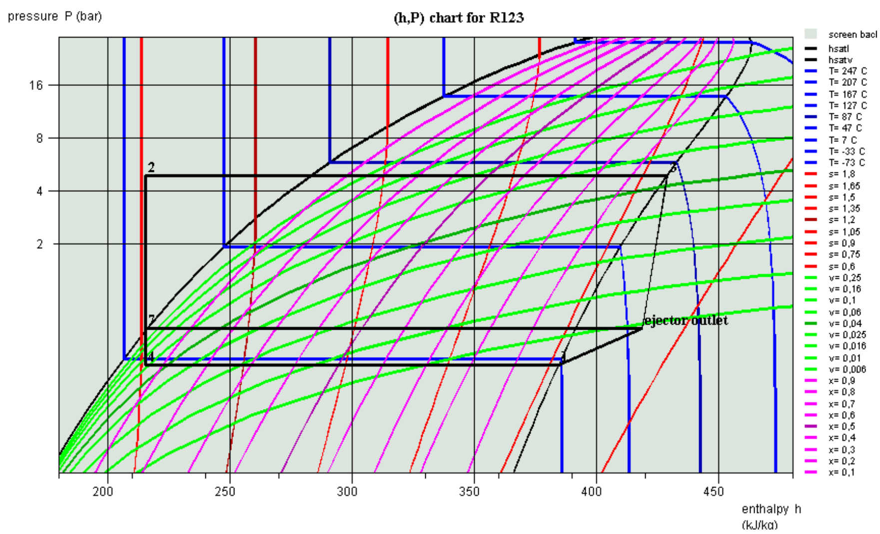

Figure 3: Ejector refrigeration cycle in a (h, ln(P)) chart

Thermoptim model results seem quite close to those (fairly synthetic) provided by the authors.

The efficiency remains very low as compared to that of an absorption[2] cycle, even single-effect, but the system is very simple technologically.

However, one point to consider is that an ejector only works in good conditions if the ratio of internal sections is adapted to boundary conditions it faces. If the ratio of primary to secondary pressures departs from the rated values, there is an important risk that it is not well adapted, the performance of the cycle dropping then.

[2] cf fiche thématique : http://www.thermoptim.org/sections/technologies/systemes/cycles-absorption

Note that the model is quite sensitive to the different parameters that appear on the screen (Figure 5), which are:

- Pe / Pb factor of pressure loss at the inlet of the secondary fluid in the ejector, which sets the minimum pressure in the ejector
- The isentropic efficiency of the two nozzles (motive fluid and aspirated fluid)
- The isentropic efficiency of the outlet diffuser
- The friction factor that may be used to take into account for a pressure drop in the mixing zone .

Sensitivity studies can be conducted on the influence of these parameters on the results.

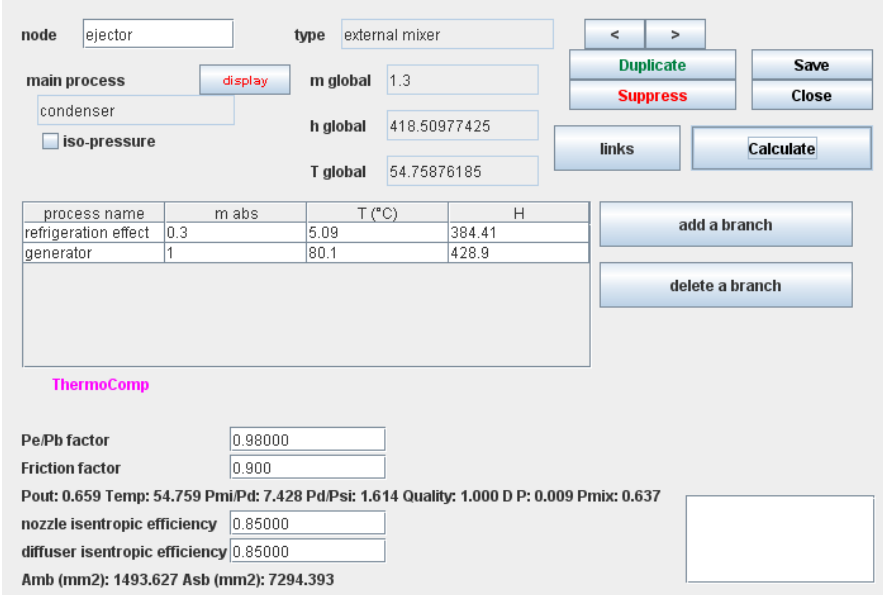

Figure 5: Ejector screen

4) Variants

4.1 Precooler and regenerator

This cycle can be slightly improved by the incorporation of a precooler, which especially allows an increase in the cooling effect, and a regenerator, which reduces heat to provide to the generator (figure 6).

4.2 Cycle with compressor and ejector

The ejector may also simply be used to reduce the throttling irreversibility of a conventional refrigeration cycle, creating a slight pressurization before compression (Figure 7). In this case, the motive fluid is a liquid that expands and becomes diphasic, carrying over and compressing the aspirated fluid. The compression ratio achieved by the ejector is then much lower than in the previous case.

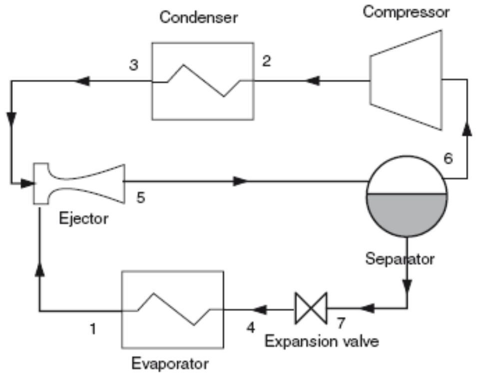

Figure 7: Cycle with compressor

It was considered in this example we had in 3 a flow of 1 kg/s of liquid R134a at 12 bar subcooled by 5 °C, and in 1 at the evaporator outlet R134a at 1 bar in the form of superheated steam at 5 °C. R134a leaving the condenser is expanded in the ejector, which enables it to accelerate the vapor and to slightly recompress it. The two-phase mixture is separated at the ejector outlet and the liquid enters the expander and then the evaporator. The vapor stream is compressed to 12 bar and then condensed in a slightly subcooled liquid state.

The Thermoptim installation synoptic view is given in Figure 8.

For comparison, the synoptic view of a cycle without ejector is given in Figure 9. The gain on the COP is clear.

4.3 Supercritical CO_2 cycle with compressor and ejector

Under certain conditions, especially if the refrigerant is supercritical CO_2, the compressor and ejector cycle has a strong constraint: the flow distribution among the high and low pressure branches must be consistent with the quality of the refrigerant leaving the ejector, which requires the implementation of specific regulations. This is why appear in the diagram of Figure 10 the divisor and the mixer at the separator outlet.

We considered here that we had in 3 a flow of 1 kg/s of supercritical CO_2 at 40 ° C and 100 bar, and in 1 at the evaporator outlet CO_2 vapor at 40 bar and 10 °C, superheated by about 5 ° C .

Supercritical CO_2 is expanded in the ejector, which enables it to accelerate the vapor and to slightly recompress it.

The two-phase mixture is separated at the ejector outlet and the complement to 1 kg/s of the vapor flow is remixed with the liquid before entering the expander and the evaporator. The main vapor stream is compressed to 100 bar and then condensed at 40 °C.

The Thermoptim installation synoptic view is given in Figure 11.

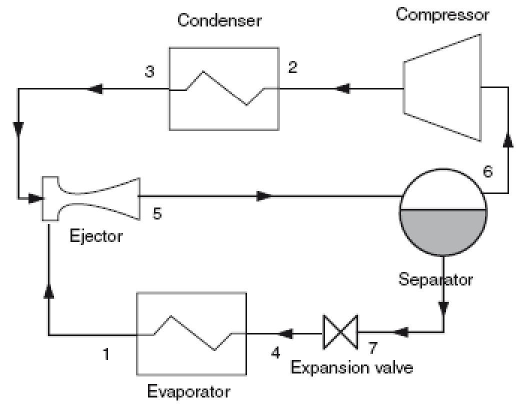

Figure 10: Cycle with ejector and compressor

For comparison, the synoptic view of a cycle without ejector is given in Figure 12. The gain on the COP is clear.

4.3 Exergy Balance

It is also interesting to ask students to build-up the exergy balance of these cycles, if they have enough time.

The Diapason session S06En[3] will if necessary provide them with explanations on how to proceed.

5) Work files

of the external class FluidEjector can be obtained on the Thermoptim -UNIT portal (www.thermoptim.org, see. Footnote on page 1).

[3] Session S06En : http://www.thermoptim.org/SE/sessions/S06En/seance.html