Multiphase fluid dynamics simulation of electric expansion valves for refrigeration and air conditioning applications

Evaluating the ability of numerical methods to replace experimental testing to calculate the capacities of expansion valves

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Standards compliance requires expansion valve producers to supply detailed user manuals that accurately specific the refrigerant capacity of their valves. This article details a study that was undertaken by Castel, a producer of refrigeration and air conditioning components, to compare the results of an experimental method for testing expansion valves with a numerical method using Ansys.

Expansion valves for refrigeration and air conditioning applications are used to take the refrigerant fluid from its condensation pressure to its evaporation pressure. This pressure drop is achieved by a shutter and an orifice, both of which must be appropriately designed to ensure that the whole system functions correctly, in particular to maintain a constant set-point temperature in the cold room. The other important purpose of this device relates to the superheating parameter which must be regulated and kept constant for the compressor to function correctly.

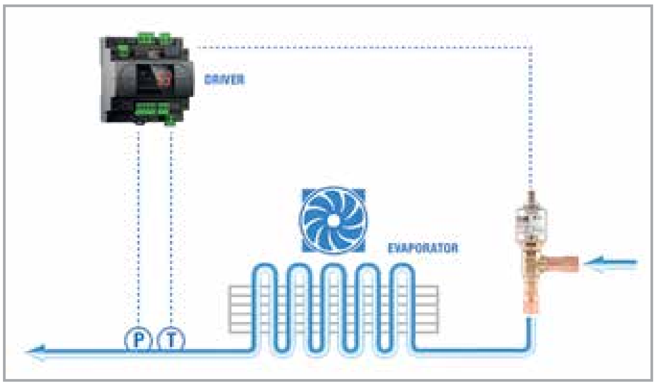

Fig. 1 – General schematic outline of an EEV

Electric expansion valves (EEV) are the most reliable and efficient of all expansion valves. Technologically, they are based on a stepper motor that provides precise regulation of the valve shutter position, allowing it to respond accurately to variations in the thermal load in the cold room. They require a driver and two sensors, one to control pressure and one for temperature. (Fig. 1).

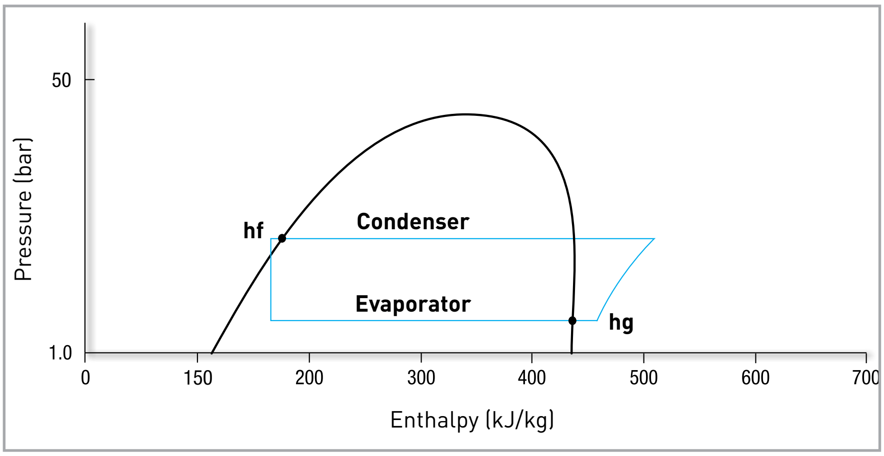

Fig. 3 – Refrigeration cycle - ph. diagram

All expansion valves must be supplied with a manual, an important document that must specify their refrigerant capacity. Castel's EEV portfolio includes several valve models that differ mainly in their geometrical dimensions and in the expressed mass flow rates, which depend on the pressure drop through the valve and on the refrigerant fluid, since each refrigerant has a unique capacity to transfer heat.


Fig. 2 – EEV Models

The company therefore needed a precise method to obtain the capacity values for all its EEV models in order to compile the EEV manuals so that refrigeration equipment manufacturers could select the most suitable components for their applications.

Standard

In view of the fact that the EEVs were studied in the company's own R&D department, a considerable challenge lay in how to calculate the capacity of all the models designed. The ASHRAE Standard 17 offers an experimental method for testing expansion valves and provides the measurement system on a testing machine.

The capacity is calculated with a well-known formula:

$\dot{m}$ (hg – hf)

$\dot{m}$ = mass flow rate [kg/s]

hg = enthalpy of saturated refrigerant vapor [kJ/kg]

hf = enthalpy of saturated refrigerant liquid [kJ/kg]

It became clear at the outset that in order to implement an Ashrae-compliant experimental test it would be necessary to build a number of testing machines, each equipped with a flowmeter capable of measuring the mass flow rates from the lowest to the highest.

Given the nominal capacity of our valves, some of these testing machines would have been very large in size, requiring a significant investment and considerable time, as well as the need to produce many prototypes, resulting in a delay in commercializing the products.

Computational fluid dynamics vs the traditional approach

Before Ansys was used, the only way to provide the refrigerant capacity for each valve (except for building the testing machines) was to calculate the flow coefficient (Cv) in combination with

Shutter angle [deg]	Seat diameter [mm]	Rated capacity [KW]
18	4,3	58
20	4,1	50
22	3,9	45

Table 1 – Relationship between geometry and capacity

About CASTEL

Castel, a leading supplier of refrigeration and air conditioning components, is a 100% Italian-owned, family-run company which has grown and established a name for itself since 1961. Our aim is to increase our customer base by providing reliable, durable, high quality, technologically advanced products, manufactured in an environmentally friendly manner, that are supported and enhanced by service levels that exceed industry standards.

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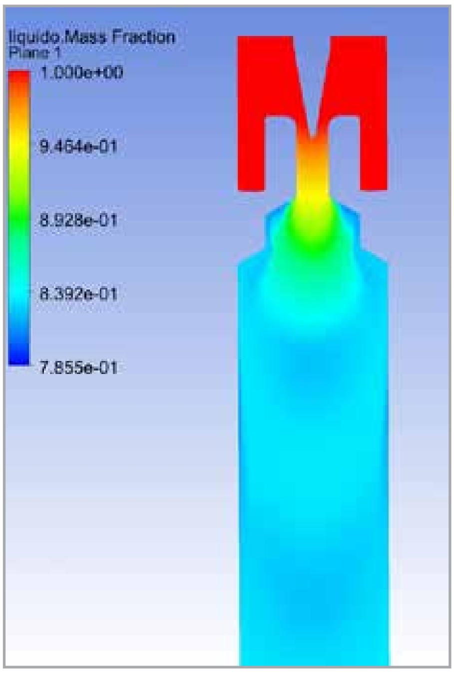

Fig. 4 – Mass fraction: seat canal

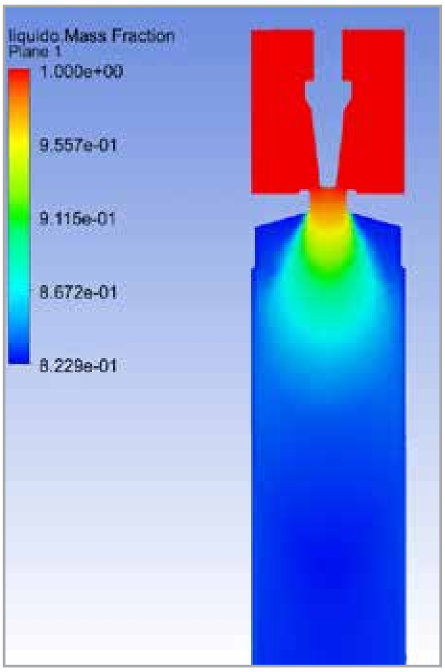

Fig. 5 – Mass fraction: reduced seat canal

the boundary conditions. More specifically, we measured the Cv experimentally in our testing room which required lengthy set-up times.

It therefore seemed very obvious to use a numerical method to solve our problem, and even though Castel's first approach was to calculate the Cv with Ansys, the objective for calculating the EEV capacity was to directly evaluate the mass flow rate for all valve models and therefore their capacity. The mass flow rate calculation, rather than the Cv, was fundamental to comply with Ashrae.

The first challenge we faced was the management of a multi-phase analysis: the refrigerant fluid at the valve inlet is subcooled liquid, while at the valve outlet there is a liquid-vapor mixture. The earliest reliable results obtained with the numerical method showed that the EEV model capacities overlapped slightly and that a few were over-estimated. It was therefore necessary to modify the internal geometries in order to standardize the capacity values; the starting point for this was the results obtained from the simulations.

This approach confirmed that there is a close correlation between the shutter angle and the seat diameter because it changes the amount of vapor at the seat's outlet; the post-processing of the initial simulations focused on these two values in order to improve the internal geometries and obtain the target capacities. Table 1 shows three cases in which the relationship between the geometry and the capacity is evident.

All simulations were conducted with one of the most common refrigerants contained in the Ansys fluid library. Moreover, by means of a specially designed conversion method, it was possible to calculate the capacities for all the refrigerant fluids at each inlet/outlet pressure condition, and so we were able to compile our manual with a variety of data very quickly.

Results

The most important result obtained was the relationship between cavitation and internal geometry, which helped to adequately review the EEV design. Due to machining requirements, some of the models had a small canal below the valve seat (Fig. 4 vs Fig. 5) that caused the pressure to drop below the liquid's vapor pressure.

The presence of this vapor in the "seat canal" resulted in a choked liquid condition because the vapor build-up occupied additional space. As a result of this fluid dynamic phenomenon, the theoretical capacity of some valves was exceeded. This hypothesis was demonstrated by correctly setting the cavitation model.

Conclusions

Finally, we compared the numerical results with the experimental tests in order to validate our numerical approach for calculating the mass flow. As previously noted, since mass flow meters would have been unable to measure the majority of our valve's mass flows, the smallest valve was tested with a refrigeration testing system owned by Castel's laboratory. The simulated mass flow rate values proved to be reliable (see Table 2).

	Temperature [°C]	Pressure [bar]	Enthalpy saturated Liq/Vap [KJ/kg]	Vapor Quality [%]	Density [Kg/m3]	Velocity [m/s]	Mass flow [kg/s]
INLET	28	8,15	244,69	0	1177	1,04	0,095
OUTLET	5	3,55	401,67	0,18	95	12,65	0,095

SIMULATED CAPACITY [KW]	14,91
TEST MACHINE CAPACITY [KW]	15

Table 2 – Simulated vs. experimental capacity, R134a

As this case study has shown, the numerical approach is both convenient and reliable, and enabled us to predict capacity, a key feature of our valves. It is also an excellent tool for designers to predict performance changes between different design configurations.

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