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EXPERIMENTAL VERIFICATION OF CRITICAL FLOW MODEL OF DENSE GASES

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The critical nozzle is necessary to measure the mass flow with only the nozzle supply conditions making use of the flow choking phenomenon at the nozzle throat. Prediction of the mass flow rate and critical flow function is of practical importance since the mass flow rate is essentially associated with the limiting working gas consumption. Critical pressure ratio should be known to establish the operating conditions for safety valves and expansion units. It is simple question only if the fluid behavior undergoes the classical and ideal gas dynamics. Problem of calculation the critical flow (sonic flow) of dense gas or vapour was treated previously by many authors (*Thompson at all., 1977, Leung at all., 1988, Bober at all., 1977*).

Thermodynamic properties of the fluid in superheated vapor area can be obtained by using multi-parameter EOS's and special computer routines. In an engineering practice the most popular and well known EOS's are *Martin-Hou* (MH) and modified *Benedict-Webb-Rubin* (MBWR) EOS. These EOS's have been widely applied and actually used for new pure refrigerants and blends (*Thompson at all, 1977*). Its correctness was confirmed by many authors and can be applied up to high-density region of one component fluid as well as the saturated state analysis.

The aim of the work was an experimental validation of analytical model of the critical dense gas flow. This model was tested for *R-410A* and other refrigerant blends on the special test–bench in the *Refrigeration Engineering Center* (*COCh*) in Krakow. To measure the critical flow conditions two *critical Venturi nozzles* (ISO 9300) for 0,8 and 1,0 mm throat diameter were applied.

In the monograph (*Gorski, 1997*), a unified approach for calculation of thermodynamic properties and generalized process in the dense gases has been proposed. The method of „*Virial Compressibility Derivatives*" (VCD), gave more simple and directly related results to an ideal gas model. The basic relation which allows to find limiting mass flow in a critical section of the conduit A^* for 1D compressible flow is described in the form of critical flow function C^* by

$$C^* = \frac{\dot{m}^* \sqrt{\mathrm{R}T_0}}{A^* p_0} \cong \sqrt{\frac{k}{z_0}} \left(\frac{2}{\chi+1} \right)^{\frac{\chi+1}{2(\chi-1)}} \tag{1}$$

In the eqn. (1) two new parameters appear in the sonic flow of real gases: the generalized isentropic index ($\chi \neq k$) and the compressibility factor ($z \neq 1$). All parameters in eqn. (1) are functions of temperature and pressure and should be averaged between the stagnation (index "$_0$") and critical (index "$_*$") states. A calculation of a process is leading to resolve both stagnation and critical state parameters of the flow at critical condition needs an iterative procedure. It can be much simplified when one assumes initial values for a given stagnation state $\{T_0, p_0\}$. The complete analysis needs an iterative solution of the equation of conservation the energy in a steady isentropic flow of gases

$$h_0 = h + \frac{w^2}{2} = h^* + \frac{a_*^2}{2} = \text{idem.} \tag{2}$$

where at the sonic flow conditions $Ma = 1$, and $w = a_*$. This procedure converges fast to the satisfactory results. Figure 1 depicts a comparison of theoretical and the experimental data for *R-410A* in the critical flow. Experimental results are with closely agreement to the theoretical model based on MH EOS for such refrigerant blends. The average discrepancy between theory and experimental results is less than 1,0% in the wide range of stagnation parameters. It confirms that the suggested theoretical model is valid and is in accordance to real physics.

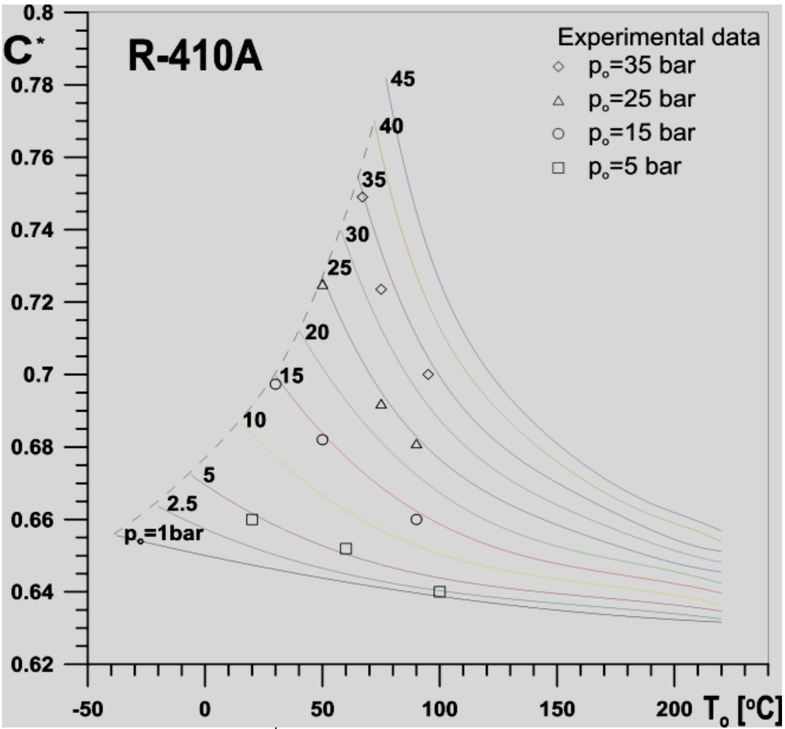

Figure 1. Critical flow function C^*- theoretical and experimental data (*Rabczak, 2007*).

It should be noticed that better result can be obtained from ideal gas correlation for small pressures, up to approximately 5 bars, where an assumption on constant value of isentropic index is still valid. In the high-pressure region (superheated vapour) properly predicted results correspond much closely to real gas behavior. The accurate critical flow conditions and state parameters should be effectively calculated from *Martin–Hou* or MBWR equation of the state.

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