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The comparison of real gas and ideal gas models for compressor design

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1. Introduction

This paper is focused on the comparison of the real and ideal gas models for the case of the compressor for the secondary cooling circuit for gas-cooled nuclear reactor developed in the frame of KOBRA project. Real gas model is defined by polynomial model from Baehr and Schwier [1]. Both models are compared and used for the stage design of the axial compressor. The comparison is performed for the case of the isentropic compression corresponding to the parameters of the KOBRA compressor for the secondary cooling circuit. The dependence of the real gas parameters on the temperature is presented and relative error in comparison with the ideal gas model is determined.

2. Methods

Following functions were programmed in the MATLAB environment with the mathematical model from [1]:

- $h\,(T,v)$,
- $s\,(T,v)$,
- $c_p\,(T,v)$,
- $c_v\,(T,v)$,
- $p\,(T,v)$,
- $v\,(T,p)$,
- $T\,(p,v)$,

where h [J.kg^{-1}] is the enthalpy, T [K] is the temperature, v [m^3.kg^{-1}] is the specific volume, s [J.K^{-1}] is the entropy, c_p [J.kg^{-1}.K^{-1}] is the specific heat capacity at constant pressure, c_v [J.kg^{-1}.K^{-1}] is the specific heat capacity at constant volume and p [Pa] is the pressure. The accuracy of these functions was tested, see [2]. These functions are used as the base for the other functions needed. Following functions are needed for the case of the isentropic compression:

- $T\,(p,s)$,
- $v\,(p,s)$,

- $h\,(p, s)$,
- $c_p\,(p, s)$,
- $c_v\,(p, s)$,
- $\kappa\,(p, s) = \frac{c_p}{c_v}$,
- $r\,(p, s) = c_p - c_v$,

where r [J.kg^{-1}.K^{-1}] is the specific gas constant and κ [$-$] is the isentropic coefficient, i.e., c_p/c_v. An iterative numerical approach is used for the calculation of all these variables. The Newton-Rapson method is used, ideal gas values are used as the initial guess. Ideal gas and real gas results are compared for the case of isentropic compression both for the single stage (i.e., the first compressor stage) and the whole compressor. Basic parameters for both cases are in Table 1.

Table 1. Compressor parameters

parameter	compressor	the first stage
input pressure p_1 [MPa]	7.5	7.5
input total temperature T_1 [K]	333.15	333.15
pressure ratio Π [$-$]	3	1.246
number of stages	5	1

3. Results

Dependence of real gas parameters on the pressure are presented for the case of the KOBRA secondary cooling circuit compressor, i.e., the specific gas constant r in Fig. 1, the isentropic coefficient (ratio of specific heats) κ in Fig. 2, the heat capacity at constant pressure c_p in Fig. 3 and the heat capacity at constant volume c_v in Fig. 4.

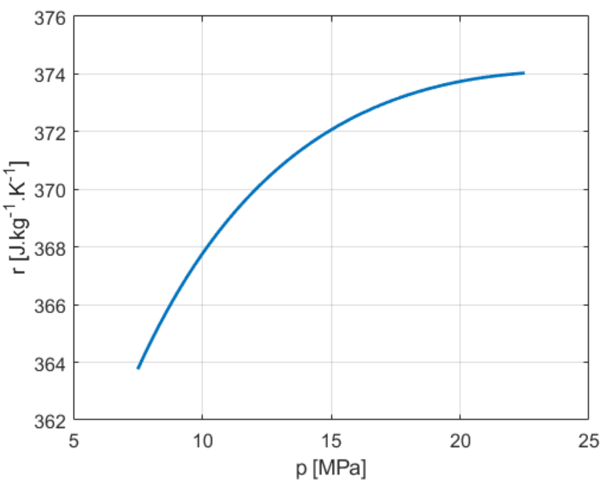

Fig. 1. Specific gas constant r constant on pressure p for the KOBRA compressor

Comparison of the results for the real and ideal gas ($r = 287\,$J.kg^{-1}.K^{-1}, $\kappa = 1.4$) are presented in following tables for the case of the whole compressor (see Table 2) and for the single stage (see Table 3). Ideal gas values are used as reference for the computation of the relative error.

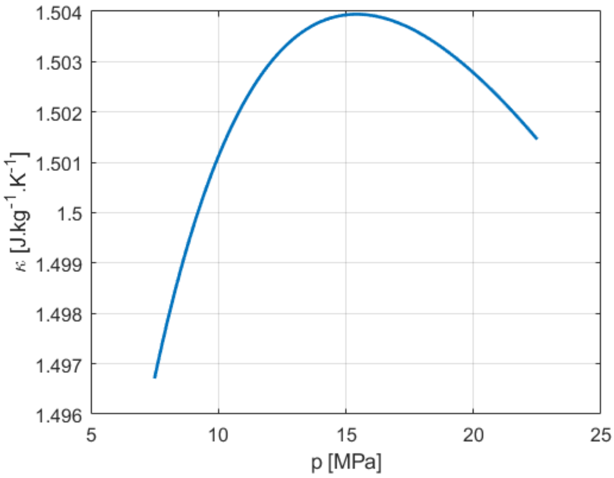

Fig. 2. Isentropic coefficient κ constant on pressure p for the KOBRA compressor

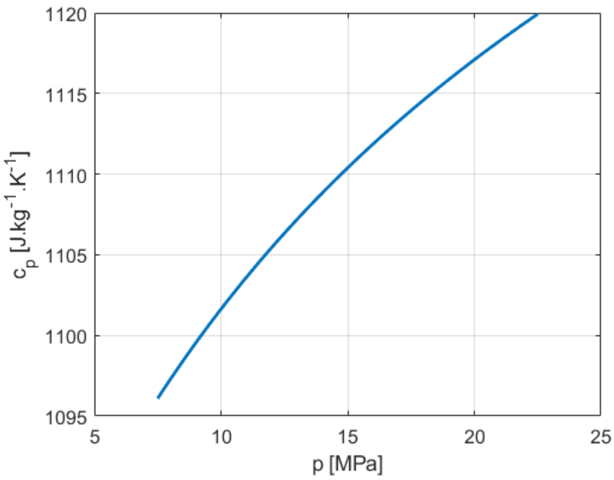

Fig. 3. Specific heat capacity at constant pressure c_p constant on pressure p for the KOBRA compressor

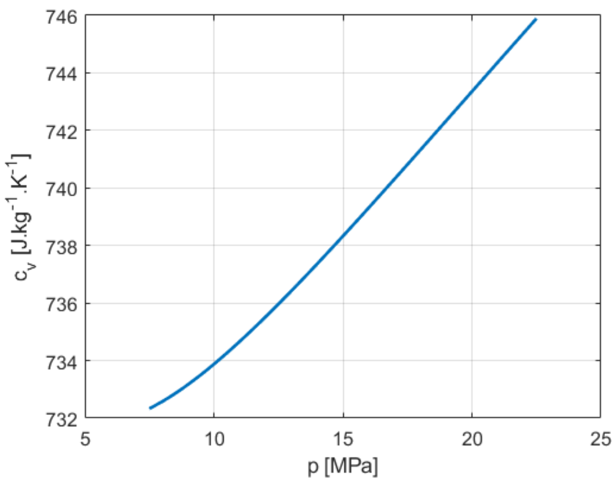

Fig. 4. Specific heat capacity at constant volume c_v constant on pressure p for the KOBRA compressor

Table 2. Comparison real vs. ideal gas for the compressor outlet

parameter	real gas	ideal gas	relative error [%]
T_2 [K]	459.099	455.995	0.68
v_2 [m^3.kg^{-1}]	0.0064	0.0058	10.02
Δh [kJ.kg^{-1}]	129.656	123.398	5.07

Table 3. Comparison real vs. ideal gas for the first stage outlet

parameter	real gas	ideal gas	relative error [%]
T_2 [K]	355.3521	354.757	0.17
v_2 [m^3.kg^{-1}]	0.0111	0.0110	1.36
Δh [kJ.kg^{-1}]	21.960	21.704	1.18

4. Conclusions and future Work

The comparison of the ideal and the real gas models based on the work of Baehr and Schwier [1] is presented for the case of the compressor for the secondary cooling circuit of the KOBRA project. It is shown that the gas parameters change quite strongly with the pressure for this case. The results will be used for the improvement of the compressor design and possibly also for the implementation to the CFD simulation model.

Acknowledgement

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References

[1] Baehr, H. D., Schwier, K., The thermodynamic properties of air, Springer, Berlin – Göttingen – Heidelberg, 1961. (in German)

[2] Fukuchi, M.,Thermodynamic air modelling, internship report, 2022.