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MATHEMATICAL MODELING OF REAL GAS COMPRESSION IN A PISTON COMPRESSOR

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Abstract: The paper explores an approach to mathematical modeling of the compression process of a real gas or vapor in the cylinder piston compressor with possible phase transitions, heat transfer of the compressible body with structural elements and leaks through the seals.

Efficient realization of technological processes, including compression of gases and vapors, and those in high-pressure area, is impossible without full consideration of numerous factors related to the process.

The process of compressing the working fluid in a piston compressor in the real conditions is accompanied by a set of interrelated phenomena. These include the change in volume, pressure and temperature of the working fluid; the change in mass of the working fluid due to leakage through the seals; the change of phase composition and mass of the gas phase during compression of wet vapor; the influence of thermal effects of phase transitions; heat transfer of the working fluid with the structural elements.

The complexity of the mathematical modeling of the compression process due to the necessity of taking into account a large number of interrelated processes occurring simultaneously with different physical nature and include a significant number of physical parameters that are difficult for analytical evaluation.

The authors have developed an approach, which underlies the calculation algorithm, it allows calculating the change in the parameters of a real gas or vaporing in time during the compression process in the cylinder piston compressor.

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Using of the developed algorithm allows us to estimate the costs of implementing a given process, the structure of losses, time to steady state, peak loads, and other mode parameters depending on the organization of the compression process.

In developing the mathematical model the following assumptions were accepted:

– within a short time interval the thermo physical characteristics of the working fluid, temperature of structural components which are in contact with the working fluid and the surface area of contact remains constant;

– coefficient of heat transfer from a structural element to the working fluid does not depend on the shape of the surface and its orientation in space;

– the compression process is considered as a sequence of time intervals during each of them the volume of working fluid is changed at a constant value ΔV;

– liquid fraction of the working fluid is incompressible.

The method used mathematical modeling of unsteady processes interrelated heat and mass transfer is described in detail in [1].

Consider the compression of wet vapor in the current time interval.

The work expended for the compression of the working fluid

$$A_p = (P + \Delta P)(V_g - \Delta V)(m_g - m_f - m_u) - P V_g m_g . \quad (1)$$

Change in heat content of the gas fraction of the working fluid

$$Q_g = C_v(T, P)\big((T + \Delta T)(m_g - m_f - m_u) - T m_g\big). \quad (2)$$

Change in heat content of the liquid fraction of the working fluid

$$Q_l = C_l(T, P)\big((T + \Delta T)(m_l + m_f - m_{lu}) - T m_l\big). \quad (3)$$

Heat of phase transition

$$Q_f = r(T)\, m_f . \quad (4)$$

Heat transfer to structural elements

$$Q_t = \alpha F (T - T_k) \Delta\tau, \quad (5)$$

where P, V_g, T – respectively the current pressure, Pa, the volume of the gas fraction, m^3, and temperature, K, of the working fluid; ΔP, ΔT – respectively pressure, Pa, and temperature, K, changes caused by the change in volume ΔV; m_g, m_f, m_u, m_l, m_{lu} – respectively the current masses of: gas fraction; the working fluid, which has committed the phase transition; the gaseous working fluid displaced through the seals; the liquid fraction; the liquid fraction displaced through the seals, kg; $C_v(T,P)$, $C_l(T,P)$ – respectively isochoric heat capacity of the gas fraction and the heat capacity of the liquid fraction, J/(kg·K), as a function of temperature T, K, and pressure P, Pa; $r(T)$ – specific heat of phase transition as a function of temperature, J/kg; α – coefficient of convective heat transfer from the structural elements to the working fluid, J/(m^2·K); T_k – the temperature of structural elements at the end of the previous time interval, K; F – the total surface area of contact of structural elements with the working fluid, m^2; $\Delta\tau$ – the duration of the current time interval, s.

The balance equation for the current time interval includes listed components:

$$A_p - Q_f + Q_g + Q_l + Q_t = 0. \quad (6)$$

This equation contains three unknown quantities: the change in pressure ΔP, the change in temperature ΔT of the working fluid and the mass of the working fluid m_f, committed the phase transition.

We need to add two new equations.

The working fluid at the end of the current interval should be in a state of saturation

$$T + \Delta T = T_s(P + \Delta P). \quad (7)$$

We also require the equation of Clapeyron–Mendeleev at the end of the current interval, taking into account the compressibility factor

$$(P + \Delta P)(V_g - \Delta V) = z\, m_g \frac{R}{\mu}(T + \Delta T), \quad (8)$$

here z – the compressibility factor; μ – molecular mass of working fluid, g/mol; R – universal gas constant.

Thus, the solution of (6) – (8) for successive time intervals allows determining the estimated change in the parameters of wet vapor in the process of compression in the cylinder piston compressor.

Thermo physical characteristics, used to calculate the process parameters in the current interval are defined for the start of the current interval corresponding to the end of the previous one.

For the mathematical modeling of the compression of gas or superheated vapor, using the same ratio (1) – (3) and (5), (6), (8), in which the values of Q_f, m_f, m_l, m_{lu} assumed to be zero.

Heat transfer coefficient of the structural elements to the working fluid can be determined by the Eidelberg formula [2]

$$\alpha = 7{,}8(PT)^{0,5} W^{-0,33},$$

where W – the average velocity of the piston compressor, m/s; P – pressure in atmospheres; T – temperature, K.

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Математическое моделирование процесса сжатия реального газа в поршневом компрессоре

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Ключевые слова и фразы: математическое моделирование; реальные газы; сжатие газов и паров.

Аннотация: Представлен подход к математическому моделированию процесса сжатия реального газа или пара в цилиндре поршневого компрессора с учетом возможных фазовых переходов, теплообмена сжимаемого тела с конструкционными элементами и утечек через уплотнения.