Analysis of Coke Gas Properties at Operation of its Metering Systems

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Abstract – The generalization and analysis of coke oven gas composition using the data of literary sources and coke enterprises are carried out in the paper. The range of pressure and temperature of coke gas during transportation is defined. The physical properties of coke gas (density, compressibility factor, adiabatic index, dynamic viscosity) that are the part of the equation of gas flowrate by method of variable differential pressure are investigated in the defined range of pressure and temperature. 25 gas mixtures with different composition were synthesized in order to make the analysis of dependency of physical properties versus pressure, temperature and composition of the mixtures. According to the results of the research the recommendations for the development of simplified methods for calculating the physical properties of coke oven gas are made.

Key words – mixture, coke gas, physical properties, density, compressibility factor, adiabatic index, dynamic viscosity.

I. Introduction

Coke oven gas is the result of coal carbonization and contains a lot of combustible components. Since the coke oven gas is a valuable energy resource and is used in various manufacturing processes it is necessary to meter its flowrate. In order to calculate the flow and volume of coke oven gas it is necessary to know its physical parameters (density at operating conditions, compressibility factor, adiabatic index, dynamic viscosity). However, the measuring process the instruments for measuring the properties of coke oven gas are expensive. Therefore physical parameters are calculated using the measured values of temperature, pressure and component composition of coke oven gas. Complex methods of calculating the properties of coke oven gas that require full information about its composition could not always be realized in algorithms of calculators of flowrate. Hence we have the problem of the development of simplified methods for calculating the physical properties of coke oven gas.

II. Analysis of coke oven gas properties

According to the analysis of literary sources such as [1, 2] and based on laboratory data of coke enterprises we analyzed the composition of coke oven gas. The range of content of each component of coke oven gas (see. table 1) was defined based on the results of this analysis.

Methods for calculating the properties of moderately compressed gas mixture of variable composition [3] are applied to calculate the physical properties of coke oven gas (density ρ, compressibility factor z, adiabatic index κ, coefficient of dynamic viscosity μ). These substances such as methane, ethane, propane, normal- and isobutane, normal- and isopentane, hexane, nitrogen, carbon dioxide, hydrogen, oxygen, argon, carbon monoxide, ethylene, helium-4, hydrogen sulfide and ammonia imitate components coke oven gas in various combinations. Number of components of the mixture (N) can vary in the range of $1 \le N \le 18$.

TABLE 1

COMPOSITION OF COKE OVEN GAS

The components content Mol%.	Data source				Limits of components content
	JSK «AMK»	JSK «YKKHZ»	PC «Zaporizhstal»	Literary sources	
H_2	55-62	54.2-56.7	56.1-56.8	42-61.2	42-62
CH_4	23-26	23.2-24.5	25.5-26.9	10-32	10-32
C_mH_n	2,5-3	6.6-6.8	2-2.4	2.2-2.5	2-6.8
O_2	0-1	0.7-1.3	1-1.3	0.1-1	0-1.3
CO	6-8,5	4-6.2	6.2-7.2	5-10	4-10
CO_2	2-4	2.3-3.5	2.3-2.5	1.7-5	1.7-5
N_2	2-5	3-6.1	4.3-5.2	1-13	1-13

The method has the limited range of the absolute temperature $200 \le T \le 400$ K and pressure $0.1 \le p \le 1$ MPa. The density of the mixture $\rho(T, p)$ should not exceed half of pseudo critical density ρ_{pc}.

This methodology is based on theoretically grounded virial equation of state for calculating the density, compressibility factor and adiabatic index. For the calculation of dynamic viscosity in the state of rarefied gas are used the classic expression of molecular-kinetic theory. To calculate the viscosity at the working pressure used decomposition on degrees of density, the similar virial equation.

We formed 25 gas mixtures with different composition for analyzing coke oven gas properties. The content of each component must be within the values that presented in Table 1. The sum of all the individual components of the mixture equals 100 %. The mixtures are formed so that to cover the whole range of the molar proportion of each component.

The values of density, compressibility factor, adiabatic index and dynamic viscosity coefficient for synthesized mixtures at standard conditions ($P_S = 0.101325$ MPa, $T_S = 293.15$ K) are calculated using the methodology for calculating of properties of moderately compressed gas mixture [3]. Minimum, maximum and average values for each parameter of physical properties of coke gas are defined. The deviation from the average value is also calculated by formulas 1 and 2.

$$\delta_{min} = [(\rho_{min} - \rho_{mid}) / \rho_{mid}] \cdot 100\ \%; \quad (1)$$

$$\delta_{max} = [(\rho_{max} - \rho_{mid}) / \rho_{mid}] \cdot 100\ \%, \quad (2)$$

where ρ_{min}, ρ_{max}, ρ_{mid} are the minimum, the maximum and the average value of density of coke oven gas, calculated according to the methodology [3].

The relative deviation from the average value for compressibility factor, adiabatic index and dynamic viscosity coefficient are calculated similarly. The results of the analysis of physical properties of coke oven gas at standard conditions are presented in table 2.

TABLE 2

THE RESULTS OF ANALYSIS OF PHYSICAL PROPERTIES OF GAS MIXTURES (COKE OVEN GAS)

Parameter	The value of the parameter			Deviation from average	
	Min.	Mid.	Max.	δ_{min}, %	δ_{max}, %
ρ_c, кг/m^3	0.4184	0.51	0.597	-17.96	17.07
z_c	0.9996	1	1.0002	-0.04	0.02
κ_c	1.3241	1.356	1.3709	-2.35	1.1
μ_c, μPa·s	11.9266	12.9593	13.8376	-7.97	6.78

The analysis of physical properties (density, compressibility factor, adiabatic index and coefficient of dynamic viscosity) for a pressure range from 0.1 to 0.12 MPa and temperature range from -50 to +50 °C is carried out for the mixture №13 because its density at standard conditions is the nearest to the average density of all formed mixtures. Such ranges of pressure and temperature are obtained by analyzing the data from coke enterprises JSK «AMK», JSK «YKKHZ» and PC «Zaporizhstal». These ranges of temperature and pressure of coke oven gas cover the conditions of its transportation through pipelines which are laid in open areas and inside the buildings of coke enterprises. The results of the analysis are presented in table 3 and figure 1.

TABLE 3

THE RESULTS OF ANALYSIS OF PHYSICAL PROPERTIES OF COKE GAS (MIXTURE 13) AT PRESSURE AND TEMPERATURE CHANGES

Parameter	The value of the parameter			Deviation from average	
	Min.	Mid.	Max.	δ_{min}, %	δ_{max}, %
ρ, кг/m^3	0.4617	0.6017	0.7847	-23.27	30.41
z	0.9992	0.9998	1.0002	-0.06	0.04
κ	1.3542	1.3681	1.3829	-1.02	1.08
μ, μPa·s	10.6054	12.4587	14.2202	-14.88	14.14

Analysis of the results makes it possible to identify common approaches and principles for the development of simplified methods for calculating the properties of coke oven gas.

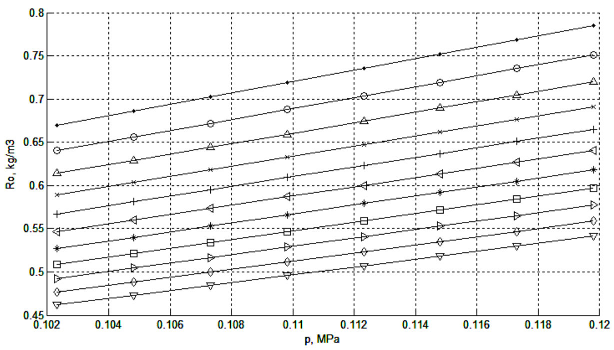

Fig.1. Dependence of coke gas density versus temperature and pressure (· – T=-50°C; ○ – T=-40°C; Δ – T=-30°C; × – T=-20°C; + – T=-10°C; ⊲ – T=0°C; ∗ – T=10°C; □ – T=20°C; ⊳ – T=30°C; ◊ – T=40°C; ∇ – T=50°C)

Conclusion

Based on the results of analysis of physical properties of coke oven gas presented in Tables 2 and 3 the following conclusions are made:

1) The changes of the coke gas density in the range of pressure and temperature at conditions of its manufacturing and transportation is significant (35 %). Therefore it is necessary to develop simplified relations for calculating the density of coke oven gas which will take into account the pressure, temperature and its composition.

2) The deviation of the compressibility factor from its average value is insignificant both for the change of composition of coke gas and for the change of pressure and temperature (does not exceed 5 %). According to the research the change of compressibility factor is larger when the temperature of mixture changes. Therefore it is necessary to develop a simplified dependence for calculation the compressibility factor of coke oven gas from its temperature and composition.

3) Changes of adiabatic index from its average value for the pressure is insignificant. Therefore it is enough to develop the dependence for calculating adiabatic index of coke oven gas from its temperature and composition.

4) Deviation of dynamic viscosity of coke gas in the range of pressure is insignificant. It was found that changes of the dynamic viscosity is larger when the temperature of the mixture changes. Therefore it is necessary to develop the simplified dependences for calculating the dynamic viscosity of coke oven gas that will take into account the temperature and composition of the mixture.

On the base of the presented recommendations we plan to develop the simplified methods for calculation of physical properties of coke oven gas for application in the calculators of flowrate and volume of coke oven gas.

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