Energy Balances the Process Thermal Decomposition Methane in Cooling Conditions High-Temperature Technological Installations

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Abstract. A mathematical model the energy balances the process thermal decomposition methane under cooling conditions high-temperature installations is proposed. The model under study allows us to evaluate the possibility using regenerative heat use, in order to reduce heat losses through the fence a high-temperature installation by utilizing the heat of the liquid coolant, allowing to increase the productivity the high-temperature process.

Natural gas as an energy carrier has a lot advantages and in comparison with other types fuel can be fully used, since it is easy to organize complete combustion with minimal heat loss. It is worth noting that natural gas does not contain ballast and harmful impurities, it also has a high calorific value and high temperatures develop during combustion.

All high-temperature installations have the main task ensuring the continuity the process with minimal fuel consumption, using energy from both primary and secondary energy resources (SER). Under pyrolysis conditions, methane is most thermally stable, since thermal degradation methane is thermodynamically possible at temperatures above 560°C. However, when methane reaches significant speeds, it decomposes at temperatures about 900°C, and at temperatures above 1400°C it completely decomposes into carbon and hydrogen.

The purpose calculations the mathematical model is to determine the heat transfer coefficient and the temperature field methane heating inside a single tube under specified boundary conditions and thermal parameter the system under consideration. Solving this problem will increase the energy efficiency the high-temperature process. Also, the input the calculations was the analysis of existing apparatus for the pyrolysis methane with liquid coolant for steelmaking, is determined depending on the heat transfer regime gas flow (Re≤105), the number Nusselt, the amount heat received and given in the decomposition process, the temperature heating natural gas and represented by a graph fraction carbon and hydrogen inlet the thermal decomposition in terms the cooling high-temperature facilities.

1. Introduction

Industrial high-temperature installations are the main consumers the country's fuel and energy resources. All heat-technological high-temperature schemes are associated with high energy intensity and relatively low energy efficiency. Increasing fuel efficiency in high-temperature installations is achieved in three ways [1, 2, 3]:

- reduction heat waste;
– regeneration waste heat;
– the external use waste heat in the energy or industrial purposes.

For most high-temperature reactors, the fuel utilization indicators are affected by heat losses through masonry and with cooling individual elements the fence, to the environment.

Considering the heat losses lost through the fence, the method thermochemical regeneration using a perforated fence will further reduce the fuel consumption for the technological process.

The perforated fence is a wall with evenly blown holes, which allows you to take heat from the wall a high-temperature reactor and return heat losses to the technological process [4, 5]. This gas is considered to be a gaseous fuel-natural gas.

When natural gas is heated above 1400°C, the process thermal decomposition methane into carbon and hydrogen is carried out [6]. There are many devices for pyrolysis methane in a liquid coolant that can reduce heat losses through the walls a high-temperature reactor by utilizing the heat the spent gaseous coolant, which leads to an increase in the efficiency the installation [7, 8, 9]. When preheating hydrocarbon raw materials in the methane supply pipe due to the utilization the heat the spent gaseous coolant, it reduces heat losses to the environment, which leads to an increase in the productivity the apparatus for pyrolysis natural gas in a liquid coolant [9, 10].

2. Thermal decomposition of methane

The aim the study is to determine the convective heat transfer inside an opening with a moving flow hydrocarbon raw materials, where the process thermal decomposition methane is carried out during heating under cooling conditions high-temperature installations.

2.1. Problem statement

The hole is located in the enclosure a high-temperature installation and is exposed to high temperatures from the material processing zone, where a certain amount heat is also applied to the hole. The outer walls the hole are not forced to cool down and are exposed to an ambient temperature that is lower than the temperature the inner walls the hole.

Natural gas enters the hole (Fig.1) with a diameter \( d = 0.1 \text{ m} \), with an ambient temperature \( t_{nach} = 0 \degree \text{C} \) and a speed movement \( w_{CH4} = 3 \text{ m/s} \), the temperature inside the high-temperature installation \( t_{kon} = 1500 \degree \text{C} \).

![Figure 1. Statement of the problem of holes with a heat carrier](image)

While moving inside the tube, natural gas begins to gradually heat up from the oppositely moving heat flow from the liquid coolant, acquiring a certain amount energy for C-H (1) dissociation, thereby the acquired energy by natural gas is returned back to the high-temperature process [11, 12]:

\[
2CH_4 \xrightarrow{t_{CH4}} 2 \cdot d_{CH_4} \cdot CH_4 + 2 \cdot d_{H_2} \cdot H_2. \tag{1}
\]

2.2. Solving the problem

The problem relates to the equation non-stationary thermal conductivity, since the temperature natural gas at each section the pipe changes over time, where the amount supplied \( Q_1 \text{ kJ/m}^3 \) and the amount
heat removed $Q_2 \text{kJ/m}^3$ also changes. The flow this process inside the tube is considered relative to the x coordinate plane.

The boundary conditions for solving the differential equation thermal conductivity are the action the heat flow a liquid coolant on a moving gas flow inside the tube. The distribution the natural gas temperature $t_{CH_4}$ and the heat transfer coefficient $\alpha$ from the surface the tube walls to the moving gas is set by boundary conditions the 3rd kind (2, 3) [11]:

$$\alpha(t_{kon} - t_{nach}) = -\lambda \frac{dt}{dx},$$

(2)

when $\alpha$ – the heat transfer coefficient of the tube wall, W/(m$^2\cdot$°C);

$t_{kon}$ – temperature at the end of the tube, °C;

$t_{nach}$ – initial temperature of the moving heat carrier, °C;

$\lambda$ – thermal conductivity of the tube wall, W/(m·°C);

$t$ – the desired temperature of the moving coolant, °C.

Using the finite difference method, the temperature field is described (Fig. 2) inside a tube with a moving coolant using the equation:

$$\frac{d}{dx} \left( \lambda \frac{dt}{dx} \right) + \frac{d}{dr} \left( \lambda \frac{dt}{dr} \right) = 0.$$  

(3)

![Figure 2](attache.png)

**Figure 2.** One second axis symmetrical to the area of the hole.

Calculations of boundary conditions are supplemented with criteria equations for calculating heat transfer. At laminar movement of the heat carrier in the pipe (3) [11]:

$$Nu = 0,15 \cdot Re^{0.33} \cdot Pr^{0.43} \cdot Gr^{0.1} = 0,15 \cdot Re^{0.33} \cdot Pr^{0.43} \cdot \left( \frac{g \cdot \beta \cdot \Delta t \cdot (\frac{L}{30})^3}{\nu^3} \right)^{0.1}.$$  

(4)

After calculations, the tube was divided into 30 parts to determine the heat transfer coefficient and the heating temperature of the moving coolant at different times, under the condition $Q_1 = Q_2$ (5, 6, 7):

$$Q_1 = \alpha_{CH_4} \cdot (t_{kon} - t_{nach}) \cdot \pi \cdot d \cdot \frac{L}{30},$$  

(5)

$$Q_2 = C \cdot \rho_{CH_4} \cdot V_{CH_4} \cdot (t_{kon} - t_{nach}) \cdot \pi \cdot W_{CH_4} \cdot \frac{d^2}{4},$$  

(6)
\[ \alpha_{\text{CH}_4} \cdot (t_{\text{kon}} - t_{\text{nach}}) \cdot \pi \cdot d \cdot \frac{L}{30} = C \cdot \rho_{\text{CH}_4} \cdot V_{\text{CH}_4} \cdot (t_{\text{kon}} - t_{\text{nach}}) \cdot \pi \cdot w_{\text{CH}_4} \cdot \frac{q^2}{4}. \]  

(7)

At different times, with a constant diameter and speed, methane begins to take heat from the walls the hole and decomposes into carbon and hydrogen in certain proportions, depending on the heating temperature (Fig. 3):

![Figure 3](image)

**Figure 3.** Dependence of methane and hydrogen fractions on the heating temperature.

The graph shows that when the heating temperature methane reaches more than 500°C, the rate decomposition methane increases, and the proportion pure methane becomes smaller, while the proportion hydrogen increases. Also, at 900°C, complete decomposition methane into C-H is observed.

Figure 4 shows the heat flows the moving coolant inside the hole and the flow from the liquid coolant, where at each the sections the hole, methane acquires and gives off approximately the same heat flow and returns it back to the liquid coolant.
Thus, at the 13th section the hole, methane completely decays and is heated to the final temperature the liquid coolant $t_{\text{kon}} = 1500^\circ C$, and the heat flow does not have time to reach the end the hole, which reduces heat losses inside the high-temperature process [13].

Based on the above calculations and the obtained values heat fluxes, the dependences the heat transfer coefficients, thermal conductivity, and the flow criterion the gaseous coolant on the decomposition temperature methane were revealed (Fig. 5).

![Graph showing heat flow](image-url)

**Figure 4. Heat flow.**

a) criterion for the flow a gaseous coolant $\text{CH}_4$
2.3. Research results

Natural gas with a temperature 0°C was considered as a gaseous heat carrier, and the temperature the liquid heat carrier inside the high-temperature installation was 1500°C. The amount heat released from the process thermal decomposition methane is 183.9-207.9 kJ/m³. The maximum average value the heat transfer coefficient natural gas inside the hole was 37.1 W/(m²∙°C), with a diameter 0.1 m the hole and a length 1 m. The thermal conductivity the gas decomposed at 1500°C was 0.37 W/(m∙°C). All the presented calculations are a continuation the study purging perforated fencing to reduce heat losses through the fences high-temperature processes and installations [14, 15, 16].

3. Conclusion

To solve this problem, a mathematical model the energy balances the process thermal decomposition methane in the cooling conditions high-temperature technological installations, where the thermophysical properties methane were obtained when heated from a liquid coolant. The resulting solution makes it possible to evaluate the use natural gas as a gaseous heat carrier inside a perforated fence for heat flow regeneration [17, 18, 19, 20], this will reduce heat losses and increase the process intensifying melting inside a high-temperature installation.
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