INVESTIGATION OF THE PROCESS SUBLIMATION FOR SOLID HYDROCARBONS IN PERMANENT SECTION CHANNELS

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Abstract

At present, the development of the gas generators for solid hydrocarbons sublimation (based on polyethylene, paraffin, urotropin, etc.) is becoming significant for stream generation with low temperature and high content of combustible components. Such gas generators are considered to be the sources of gaseous fuel for sustainable power plants of short-term and periodic action. This paper is devoted to the numerical and experimental research of the solid hydrocarbons sublimation process under the high-temperature gas stream. A one-dimensional mathematical model was developed and validated based on known results of laboratory research. A model experimental set-up was designed, which made it possible to investigate the solid hydrocarbons sublimation in a wide range of operating conditions. The obtained data can be used to develop the fundamentals of controlled sublimation technology for solid hydrocarbons in gas generators of short-term and periodic action.

1 General Introduction

One of the promising methods and topical solution of cold gases (700…800 K) production problem is the development of gas generators for solid hydrocarbons sublimation under the high-enthalpy and high-temperature flow [1]. Sublimation products in this case should have low temperature and high mass fraction of combustible components. Hereby the paraffin is considered as solid hydrocarbon. Temperature decrease of the sublimation products can be achieved by implementation of the two-chamber gas generator.

During the decomposition (or combustion) of the active material, high-temperature combustion products are produced in the first chamber, the flow of which coats the surface of the solid hydrocarbon filler. It is important that solid hydrocarbons are not capable of self-burning. Under the influence of high-temperature combustion products, the solid hydrocarbon filler gasifies and undergoes partial destruction, the result of which is low temperature flow of sublimation products enriched with combustible components.

The lack of empirical data leads to the need to study the dependence of the sublimation rate of solid hydrocarbons in a wide range of pressures, temperatures and heat fluxes. This paper is devoted to a numerical and experimental study of the sublimation of solid hydrocarbon in a high-temperature gas flow in a model experimental set-up.

Sublimation process of solid hydrocarbon based on paraffin is investigated. It should be noted that in general the thermophysical characteristics of such a solid hydrocarbon depend on the polymerization degree and other conditions. To generalize the results of the simulation, the averaged values of the characteristics of the solid hydrocarbon are used in this paper. As an active material high-temperature air stream is considered, which temperature and thermophysical properties are determined by the results of thermodynamic calculations using the TERRA software package [2] for given pressures and enthalpies.

2 One-dimensional mathematical model

2.1 Description

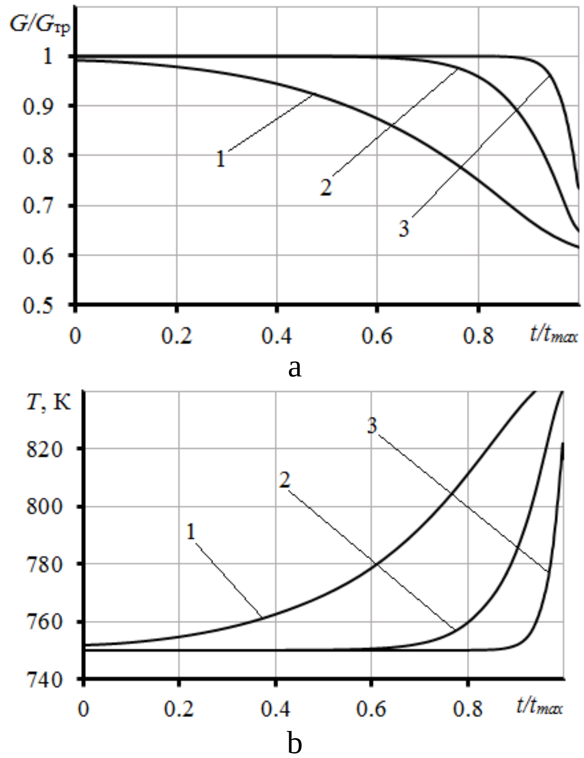
A large number of parametric research are required to estimate the efficiency and basic configuration of the gas generator, which ensures the generation of cold gas with high mass fraction of combustible components. The use of multidimensional mathematical models is associated with significant computational and time costs.

The authors proposed a one-dimensional mathematical model of the process of solid hydrocarbon sublimation under the conditions of blowing it with a stream of high-temperature combustion products of the active material. Evaporation of hydrocarbons was taken from the mathematical model presented in [3].

2.2 The results of parametric research

A parametric study of the influence of geometric and regime parameters on the efficiency of the sublimation of solid hydrocarbon filler in a two-chamber gas generator is carried out for different operating times t_1 = 20 sec, t_2 = 100 sec and t_3 = 500 sec and pressures p_{gg1} = 1 MPa, p_{gg2} = 3 MPa and p_{gg3} = 5 MPa.

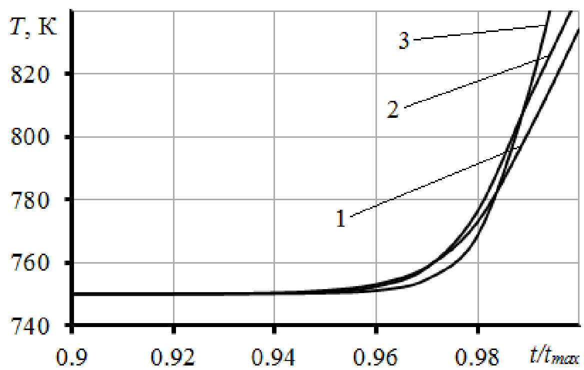
Fig.1 shows the graphs of the mass flow rate and temperature change in time at the outlet of the model gas generator. The mass flow rate is presented in dimensionless form as the ratio of the current mass flow rate G to its required value G_{tr}. The dimensionless time is the ratio of the current time t to the maximum t_{max} for the considered problem. In general, the operational time of the low-temperature gas generator depends on a large number of factors, and the obtained data characterize the possibility of ensuring the constancy of the parameters during the operating time.



‘Fig.1. Mass flow rate (a) and temperature (b) in the outlet over time: 1 - t_{max} = 20 sec; 2 - t_{max} = 100 sec; 3 - t_{max} = 500 sec’

As can be seen at Fig. 1, with an increase in the operating time of the low-temperature gas generator, it is possible to obtain a relatively constant flow rate and temperature of the gases in the outlet.

Fig.2 shows the graphs of the gasification products temperature change in the outlet section of the gas generator at various pressures p_{gg}.



‘Fig.2. Temperature in the outlet over time: 1 – p_{gg} =1 MPa; 2 – p_{gg} =3 MPa; 3 – p_{gg} =5 MPa’

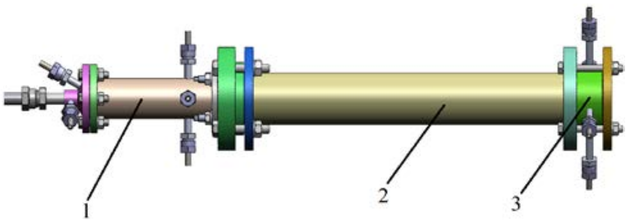
The effect of pressure in the gas generator on the physical aspects of the temperature change is insignificant and manifests itself only at the end of the work.

3 Experimental research

3.1 Experimental set-up

Preliminary studies have shown that the heat and mass exchange between the combustion products of the active material and the solid hydrocarbon filler, gas-dynamic and physicochemical processes in the duct of the considered gas generator, have a significant effect on the sublimation efficiency. The authors created an experimental set-up for conducting experimental studies of sublimation of solid hydrocarbons for the formulation of the scientific and theoretical foundations for the technology of generation of low-temperature gas flows.

The 3D model and photo of created experimental set-up are shown at Fig. 3.



a

b

'Fig.3. 3D model (a) and photo (b) of the experimental set-up: 1 – high-enthalpy flow generator, 2 – channel with filler, 3 – nozzle'

The design of the model experimental set-up allows to carry out measurements of the main parameters during fire testing. At the outlet of the gas-dynamic channel, the pressure and temperature for sublimation products flow are recorded by the corresponding sensors.

3.2 Experimental results

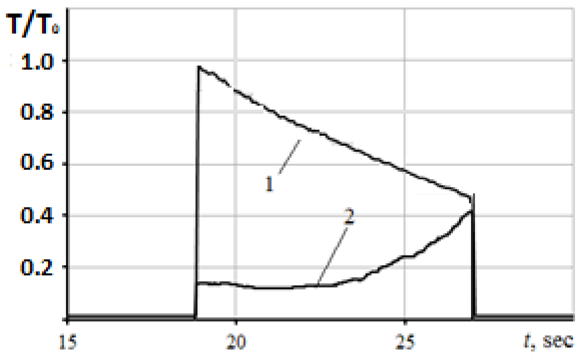
Test item (channel with the solid hydrocarbon filler) before and after the fire testing is shown at Fig. 4.

a b

'Fig.4. Test item before (a) and after (b) the fire testing'

During the fire testing of the sublimation process of the paraffin charge (Fig. 4a) with the mass flow rates of components (air – $G = 0.038$ kg / s, hydrogen – $G_H = 1.65*10^{-3}$ kg / s), the temperatures at the exit from the chamber were recorded $T = 2262$ K and at the outlet from the gas-dynamic cylindrical channel $T = 600$-1000 K (Fig. 5). The pressure in the second chamber is $p = 0.57$ MPa.

The weight of the test object, determined on the Sartorius CPA34001S scales, was 4941.7 g, after the experiment was 4429.2 g. The visual inspection of the cylindrical channel showed almost complete removal of the paraffin filler (Fig.4b) from the duct during the test. The average mass flow rate is 50-65 g/s.



'Fig.5. Flow temperature during the experimental research: 1 – prior the filler; 2 – after the filler'

4 Conclusion

1. One-dimensional mathematical model for calculating the characteristics of the sublimation process in a gas generator on solid hydrocarbons is developed. As the result of parametric study for model solid hydrocarbon, mass flow rate and temperature low-temperature gas at the output of the gas generator are obtained as the function operating time and pressure in the gas generator.

2. The model experimental set-up has been developed to study the intensification of the sublimation process for solid hydrocarbons by exciting high-frequency acoustic pulsations in the channels.

3. Experiments on sublimation of paraffin filler in a model set-up have been carried out. As the result, the gas temperature at the outlet of 600-1000 K was obtained at mass flow for solid hydrocarbon of 50-65 g/s.

References

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