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Heat and Mass Transfer in Low-Temperature Gas Generation

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Abstract

The low-temperature gas generator (LTGG) is designed to produce gas with a temperature of 350 to 450K. The main element of LTGG is a cooling chamber with granules of a solid refrigerant. Combustion products have a high temperature which does not allow using them in a whole number of technical devices. Gas cools down while interacting with solid refrigerant granules that take part of the gas' internal energy to decompose. To describe heat and mass transfer processes in LTGG, a mathematical model has been developed based on one-dimensional equations of continuity, momentum, energy, and the integrity of gas mixture components. The gas mixture consists of combustion products, refrigerant decomposition products, and air. The mathematical model takes into account the gas mixture flow in LTGG, heat exchange with the structural elements of LTGG, and kinetics of the refrigerant granule decomposition. To activate the mathematical model, a numerical method has been developed for solving boundary-level problems based on the method of finite differences. The system of equations is approximated by means of implicit differences schemes. Solving nonlinear differential equations involves Newton's method. The boundary-value problem was solved through orthogonal factorization.

Keywords: low-temperature gas generator; mathematical model; numerical method.

1. Introduction

LTGG is used in fire-extinguishing systems [1-5], in spinning turbopump turbines [6-8], and the production of low-temperature gas for supercharging various reservoirs [9-14]. Mathematical models of different levels of complexity were used to describe heat and mass transfer processes in LTGG [12,13]. Mathematical modelling of LTGG allows to reduce the time and cost of designing, and to identify the influence of various factors on work processes. Refrigerant granules usually are cylinders of several millimetres in diameter and length. When filled into

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a cooling chamber, they are arranged randomly, which rules out the use of three-dimensional mathematic models for simulating heat and mass transfer. Instead, it would be more convenient to apply a porous layer model.

Fig.1 shows a schematic diagram of LTGG. Combustion products enter the cooling chamber (1). Gas mixture passes through a layer of refrigerant granules (2). The refrigerant decomposes at high temperature and absorbs heat. The mixture of combustion products and refrigerant decomposition products goes to the consumer.

The granules shrink during decomposition, and their diameter is reduced. Under the impact of dynamic pressure of the gas flow, the granules shift along with the flow. This process is best represented on a one-dimensional model. Granule porosity remains almost unchanged because of not depending on the diameter of the granules; it depends on how granules are arranged. When round and cylindrical granules are filled in an irregular manner, they form a porous layer with an average porosity of 0.32 to 0.39 [15].

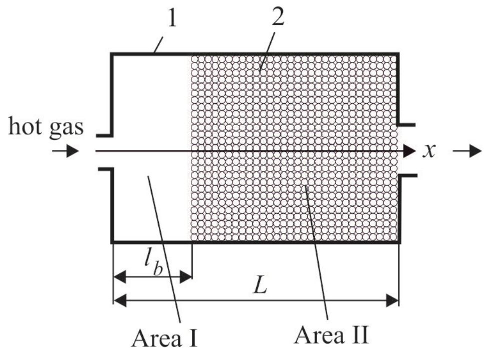

Fig.1. The concept LTGG: 1 – cooling chamber; 2 – granules of the solid refrigerant.

The shifting process creates two areas – one granule-free (I), the other filled with constant-porosity granules (II, see Fig. 1). Estimated shearing friction stress values at those points differ by 2 to 4 digits [16]. During transition from Area I to Area II, the cross-sectional area of the chamber changes abruptly. This results in a significant change in the granular layer's hydraulic resistance and the gas flow rate. This significantly affects also the temperature pattern along the chamber length.

Nomenclature

p	pressure
T	temperature
G	mass flow
x	coordinate
τ	time
ρ	density
w	velocity
g_k	the mass fraction of the k component of gas mixture
R	gas constant
S_0	cross-sectional area of empty cooling chamber
ε	porosity
J_m	mass flux
ξ	coefficient of hydraulic resistance
Π	the perimeter of the granules in the cross section
Q_w	heat flow
h_s	decomposition enthalpy of the refrigerant
k	ratio of specific heats
$\Delta\tau$, h	steps of differences scheme in time and coordinate x, respectively