Problems of Microthruster Development


*Moscow Aviation Institute (Technical University), Moscow, Russia

bAstrium ST, Möckmühl, Germany

Received October 21, 2009

Abstract— A description of a microthruster operating on the single-component propellant-hydrazine with the Shell-405 catalyst is presented. The hydrazine decomposition reaction at the specified parameters occurs on the surface. The gas temperature entering the nozzle actually depends on the catalyst temperature. It is established that if the temperature of hydrazine decomposition products at the catalyst outlet is lower than 400 K, ammonia condensation takes place in the supersonic nozzle part. The temperature distribution in the working chamber microchannel is calculated, the microthruster thrust and specific impulse are evaluated on the basis of a physico-mathematical model. A fundamental possibility of obtaining $10^{-3}$–$10^{-2}$ N level thrust is shown.

DOI: 10.3103/S1068799810020121

Key words: microthruster, mathematical modeling, catalyst, nozzle, hydrazine.

In recent decades an intensive development of space micro-and-nanosatellite platforms of a new generation is under way. In this case, one of the most important problems is the creation of a microthruster of about $10^3$ N in thrust for orientation systems; as a result, there arises a necessity of mathematical modeling of working processes in a microthruster as well as of developing the technology of microthruster manufacture and tests and a fuel supply system.

The purpose of this investigation is the determination of the microthruster appearance and mathematical modeling of a working process in the structure elements.

A general view of a microthruster developed at OOO Astrium ST is shown in Fig. 1.

![Microthruster on a single-component fuel](image)

*Fig. 1. Microthruster on a single-component fuel (at the left—exponent against the background of a one-kopeck coin, at the right—catalyst and nozzle)*

The overall dimensions of the microthruster working chamber are the following: length $2.5 \times 10^{-3}$ m, width $1 \times 10^{-3}$ m, height $7 \times 10^{-5}$ m, area of two-dimensional contoured nozzle exit $F_d = 8.88 \times 10^{-8}$ m$^2$. 
Silicon is used as a structural material. The flow part was formed by the lithographic etching method. After the Shell-450 catalyst was applied on the substrate, the chamber and nozzle were diffusely connected with the cover.

Hydrazine used as a fuel is supplied by means of the pressure-feed system through the feeding capillary into the distribution system, comes in contact with the catalyst and is decomposed releasing heat [1]. The hydrazine decomposition products enter the nozzle part and escape into space. The microthruster is characterized by the pulsed operation with working pulse duration 0.01–0.1 s.

At the initial moment after the valve connecting the hydrazine feeding manifold with the prereactor cavity is opened, the cavitation processes take place at the valve outlet section. As a result of cavitation, the prereactor area and inlet sections of the catalyst channels prove to be filled with a two-phase mixture consisting of vapors and small droplets of liquid hydrazine [2].

According to [1], the hydrazine decomposition on the Shell-450 catalyst occurs by the reaction

\[ 3N_2H_4 = 4NH_3 + N_2. \]

In its turn ammonia gas is decomposed according to the reaction

\[ 2NH_3 = N_2 + 3H_2. \]

A possible nozzle expansion ratio is limited by the process of condensation products reaction. The basic hydrazine decomposition product is ammonia gas (NH₃) that at the pressure \( p = 0.1 \text{ MPa} \) has the condensation temperature 240 K. Under conditions of nonequilibrium efflux from the nozzle at a lowered pressure the temperature of the ammonia gas condensation will be lower than 240 K; as a result, a possible ammonia gas condensation in the nozzle will restrict a permissible gas expansion ratio and the specific thrust of microthruster.

The mathematical modeling of working processes in the microthruster was made under the following assumptions.

— the working fluid flow in the microthruster path is laminar;
— the catalyst temperature is not varied in a time of one working pulse, the catalyst is heated gradually during a series of working pulses;
— hydrazine is decomposed both on the active catalytic surface and in the volume [3];
— the reactions of the catalytic and thermal hydrazine vapor decomposition are considered as chemical first-order reactions described by the Arrenius law [4];
— the microthruster is considered to be a non-deformable rigid body.

The microthruster processes were calculated with the use of the mathematical model consisting of the nonstationary Navier-Stokes equations, three-dimensional equation of heat conduction, equations of hydrazine decomposition kinetics and equations of state of fuel decomposition products. In the one-dimensional approximation the working chamber was presented as a combination of 16 channels with the equivalent diameter \( d_e = 24 \times 10^{-6} \text{ m} \). The wall temperature was taken to be equal to 273, 473, and 673 K, hydrazine flowrate in all channels was assumed to be the same and equal to 3.44×10⁻⁸ kg/s.

The calculation results are presented in Fig. 2, where we can see the variations of the fluid temperature \( T_f \), dryness factor \( \chi \), degree of hydrazine decomposition \( Z \), and heat flux density \( q \) along the channel \( \bar{x} = x/d_e \). The heat flux magnitude is considered to be positive in the direction from the chamber wall to the working fluid. The calculation showed that it is possible to separate four characteristic regions which are denoted by Roman numerals.

In region I the two-phase mixture entering the inlet is heated. The catalytic reaction of hydrazine decomposition starts when the two-phase medium comes in contact with the channel walls. The heat released in this case is spent for heating the medium that fills the channel. In addition, the medium can be further heated at the expense of heat transfer from the catalyst if the temperature of the latter exceeds the