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Possibility of Using Thermal Decomposition of Hydrogen Peroxide For Low Thrust Propulsion System Application

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Abstract
Precise positioning of a satellite or a space probe is crucial for many missions. The simplicity, reliability and efficiency are the most desirable features of attitude control system (ACS). One of the most commonly used ACS are based on simple monopropellant thrusters which use a single substance that decomposes to a hot gas. The gas is delivered into the nozzle producing the thrust.
Nowadays a widely used propellant in monopropellant systems is hydrazine. It can deliver good performance but it is also extremely toxic, inflammable and carcinogenic what makes the testing and ground handling dangerous and expensive. Those problems result in constant searching for alternative solutions.
One of the most promising alternative for hydrazine is highly concentrated hydrogen peroxide (H2O2). It is known as a green propellant – completely safe for environment, it's stable, easy to obtain, the ground handling is relatively safe and is able to deliver reasonable specific impulse (1600-1700 m/s). All those features make the hydrogen peroxide strong competition for hydrazine in future satellite application. In this case, many research indicates problems with catalyst pack. Lower grade H2O2 with stabilizers can poison the catalyst pack lowering its performances. Higher grade (ab. 98%) generates extremely high temperature (about 1200 K) which is able to melt the metallic catalyst (e.g silver) or increase the temperature gradients in ceramic one causing it to crack. But there is a way to overcomes those problems. Hydrogen peroxide decomposition can be also started and maintained by the temperature source.
In this paper authors would like to present the research on possibility of using thermal decomposition of highly concentrated hydrogen peroxide (98%+) for low thrust propulsion system application. The research stand for thruster parameters measurements was built and will be presented followed by the experimental results, discussion of problems encountered and authors' conclusions and future plans.

1. Introduction

Most of the satellites require some kind of attitude control system (ACS) to fulfil their missions. There are many techniques to control and stabilize an attitude of a spacecraft e.g. momentum wheels, magnetic torquers (MTQ), passive stabilization methods. The choice depends on mission objectives, required accuracy and also funding issues. One commonly used solution for ACS application is a system based on low thrust electrical or chemical rocket thrusters. When the mission requires a thrust on level of single newtons the first choice is a monopropellant thruster. It uses a single substance in liquid state which is delivered into decomposition chamber and decomposes into hot, gaseous products which are then delivered into the nozzle producing thrust. Due to the simple construction and well known technology they are also characterised by high reliability. Very widely used propellant for today's monopropellant systems is hydrazine [1], [2] which is able to deliver a specific impulse on the level of 2300 m/s [3]. Despite good performance of hydrazine there are many research all over the world focused on finding its replacement. It is strictly connected with the problematic testing, ground handling and environmental protection issues due to its toxicity, flammability and carcinogenic effects [4], [5]. Many so called green propellants are under investigation [6]–[12] and one very important is hydrogen peroxide. Discovered by Louis-Jacques Thenard in 1818 [13] hydrogen peroxide (H_2O_2) decomposes into hot mixture of oxygen and steam what makes it completely save for environment. It is also stable, accessible and easy to use. All those features together with reasonable specific impulse on the level of

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1600-1700 m/s [6] and relatively high density (1.431g/cm^3 at 25^{O}C for 98% High Test Peroxide [14]) makes it a strong competitor for hydrazine. To use the hydrogen peroxide as a propellant in an effective way, the knowledge about the mechanisms and processes during the decomposition and initiation, is required.

Decomposition process of hydrogen peroxide may be started catalytically or thermally. Catalytic decomposition requires a catalyst bed which may absorb some heat during the initiation of the process and lower the dynamic of propulsion system. Catalyst packs are working in very high temperatures which may cause them to melt – e.g. silver and using a high temperature resistant materials such as platinum is very expensive. Ceramic based catalyst with the active phase of e.g. manganese oxides are vulnerable to cracking due to the high thermal shock and mechanical loads. Both types are also at risk of poisoning by H_2O_2 stabilizers. Extensive research on the catalyst for hydrogen peroxide has been conducted all over the world [15]–[21]. Thermal initiation and decomposition is less popular and understood. It might however solve the problem with catalyst packs. Different research, both experimental and modelling, on thermal decomposition of pure hydrogen peroxide, with additions and also in the presence of other substances, has been conducted over the years [22]–[25]. Most of them are very important from the storage and safety point of view but only few try to use a thermal decomposition for propulsion application. In [26][27] authors described a research on addition of liquid H_2O_2 spray into the stream of products of decomposition at a rocket type conditions. They indicate an influence of residence time, mass flow rate and H_2O_2 concentration on decomposition efficiency. In the following paper authors try to use a pure thermal decomposition of hydrogen peroxide for thruster application. It means that all the materials used for manufacturing models are compatible with highly concentrated (98%) hydrogen peroxide of HTP class in the room temperature. No catalytic materials were used for initiation of decomposition process. Catalytic effects of different materials, even relatively inert [28], are clear for authors and have been knowingly omitted. Focusing on the effect, not a process itself, the basic question to answer is if the decomposition of 98% HTP is possible and effective to be initiated and maintained without a presence of catalyst pack – using only the heat source.

Presented work is a part of the project supported by the National Science Center of Poland aiming at the research on thermal decomposition in three different configurations. First stage was dedicated to investigate the effect of slow heating of the vessel containing a hydrogen peroxide and was described in [29]. Following paper partially reported the work done during the second phase – thermal decomposition in a flow regime simulating the rocket thruster. Third part will be dedicated to investigate the initiation and dynamic of decomposition after rapid contact with hot surface.

2. Experimental setup

To investigate the phenomenon, the research stand was built. The major parameters were measured – temperatures, pressure and thrust. Measurement points are described below.

Hydrogen peroxide was stored in cylindrical, low volume tank made of passivated stainless steel. It was equipped with filling valve and safety valve in the case of an undesirable decomposition. Also due to the safety reasons the stored amount of HTP was very low – required only for few experiments at most. To deliver the medium to the decomposition chamber, the pressure fed system was used. Gaseous nitrogen was used as pressurizer delivered to the HTP tank through the valve, pressure regulator (redactor) and low pressure tank (LPT). LPT was used to lower the pressure oscillation in the system during the experiments - as a buffer tank with the pressure of 10 bars. Liquid hydrogen peroxide is delivered through the filter and electromagnetic valve to the decomposition chamber where it heats up and decomposes. Temperature was measured by the K-type thermocouple in two spots: heater area (T_1) and nozzle inlet (T_2). Pressure sensor Kistler 601A together with 5015 charge meter (P_1) measured the pressure inside the decomposition chamber. The thrust was measured by the Kister 9205 sensor also with 5015 charge meter, using an impulse method with baffle plate (F). Acquisition and archiving the data is made by computer NI PXIe-8108. In-house software allows on fully automatic control over the stand to increase the safety level and repeatability of the results. General scheme of research stand is shown in Figure 1.

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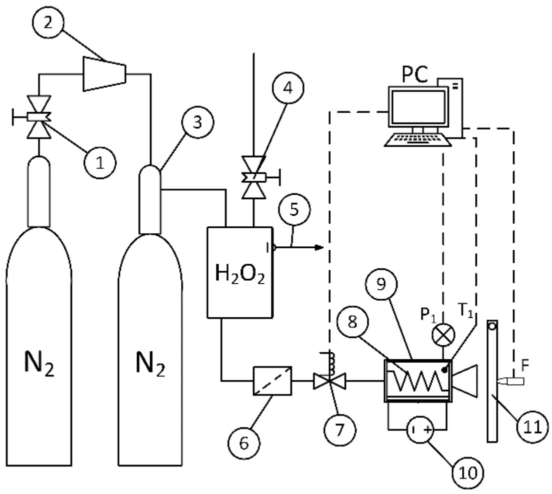

Figure 1. General scheme of the research stand: 1-Nitrogen valve, 2-Pressure reductor, 3-Low pressure nitrogen tank; 4-HTP filling valve, 5-Safety valve; 6-HTP filter, 7-Injection valve, 8-Heater, 9-Decomposition chamber, 10 Power supply, 11-Thrust measurement system;The main element of the stand is a heating chamber which task is to deliver the required amount of energy to increase the temperature of HTP and start the decomposition process. The chamber consist of few parts: injector head, heating element, internal insulation, decomposition chamber and two-piece case with the nozzle.

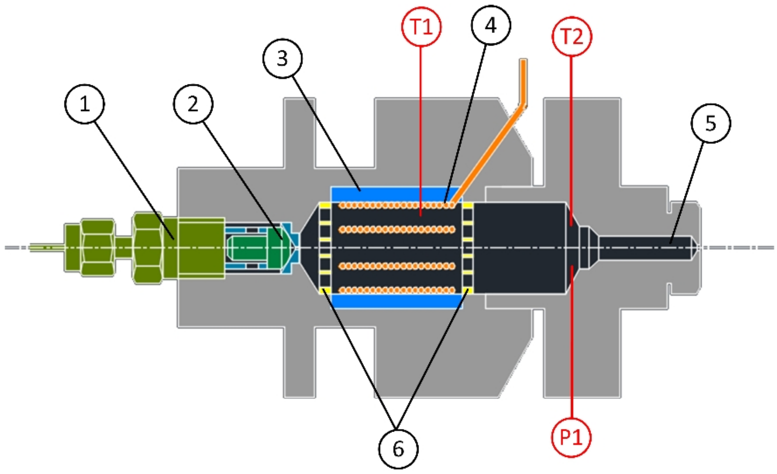

Figure 2Thermal decomposition chamber scheme: 1-HTP connector, 2-injector, 3-ceramic insulator, 4-heating coil, 5-nozzle, 6-holding plates, T1- temperature in the heater area, T2-temperature in the nozzle inlet, P1-chamber pressure.

A heating wire formed to double coil was used to initiate the decomposition. The wire consist of a resistive element surrounded by the electrical insulation and enclosed in a casing made of Inconel. External diameter of a wire is 1mm and the resistance is 9 Ω/m. Authors decided to use such a solution because it gives a flexibility in heater shape and resistance. Additionally it is able to withstand the temperature of 1000 ^{O}C and heating dynamic is high due to the low mass. The scheme of the wire is shown in Figure 3.

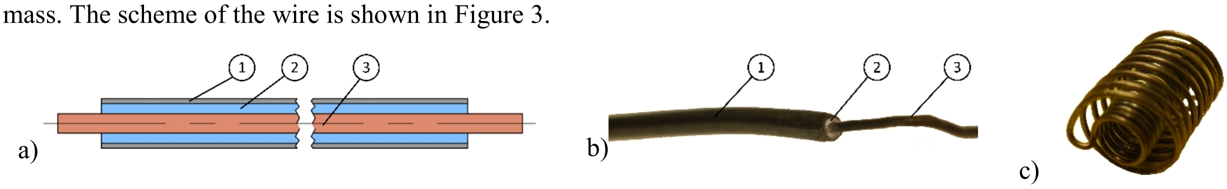

Figure 3. Heating wire: a) model, b) picture, c) example of a double coil: 1-Inconel case; 2-Electric insulator (MgO); 3-resistive wire;

The heating coil was placed in the chamber together with insulator made of ceramic material which limits the heat loss to the chambers wall. Heater was powered by controllable laboratory power supply (Digimess SM10010 model). Hydrogen peroxide was delivered into the heater area through orifice limiting the flow and swirler which form the flow in shape on cone spray. It allows rapid vaporisation of HTP and also fast initiation of the process. Decomposition products are delivered into the nozzle and expand to the atmospheric conditions producing thrust. First model of a thruster was prepared to produce about 1 N of thrust. To limit the flow the orifice with a diameter of 0.3 mm was used.

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Using a pressure system with 10 bars, during the calibration process of injector system, the mass flow rate on the level of 1.3 g/s was obtained.
Thrust measurement has been done using an impulse method with baffle plate. This method using a flat plate which task is to collect all the gaseous products released from the nozzle. By changing the velocity vector of 90^{O} it measure the impinging force of a gases which equals to thrust of the engine (Figure 4). Then the force is transferred to the transducer and recorded by the measuring system. The plate is hanging freely on an axis of revolution supported by low friction bearing. To lower the signal oscillations, an initial force is introduced to the transducer.

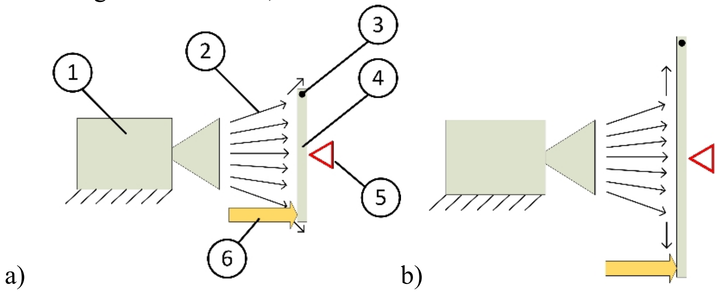

Figure 4. The scheme of thrust measurement: a) in-correct measurements – plate is to small and does not collect all the gases, b)correct measurement; 1-supported thruster, 2-gas stream, 3-axis of revolution, 4-measuring plate, 5-force transducer, 6-initial force;

Complete research facility is shown in Figure 5.

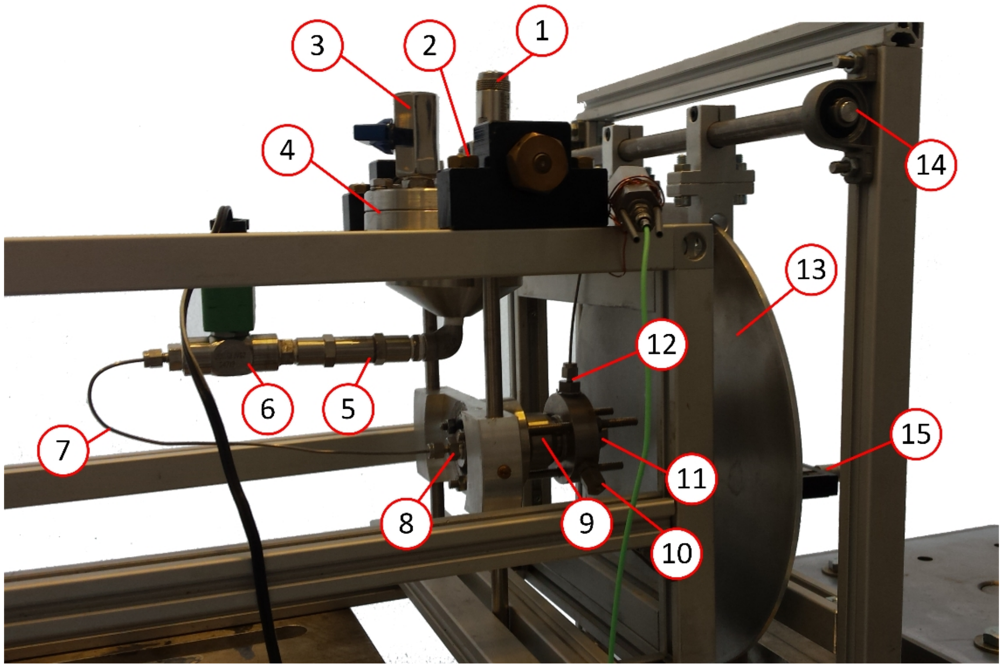

Figure 5. Research facility:1-safety valve, 2-presurant valve (not visible), 3-HTP filling valve, 4-HTP tank,5-filter, 6-electromagnetic valve, 7-feeding line, 8-injection system, 9-decomposition chamber, 10-thermocouple port, 11-nozzle, 12-pressure transducer port, 13-baffle plate, 14-plates axis of revolution, 15-support of force transducer.

Experiments

Experiments were conducted for different initial temperature of a heater, controlled by the power level, set on the power supply. Temperature of a heater was measured and after obtaining the steady state an experiment was started. At t=0s an acquisition system start collecting data. After 500 ms injection valve was opened and HTP was deliver into the heater area for 15 seconds. The whole experiment (acquisition) lasted 18s to observe the drop of a pressure after closing the valve. Recorded results from exemplary experiment ($T_{initial}$=600^{O}C) are shown in Figure 6.

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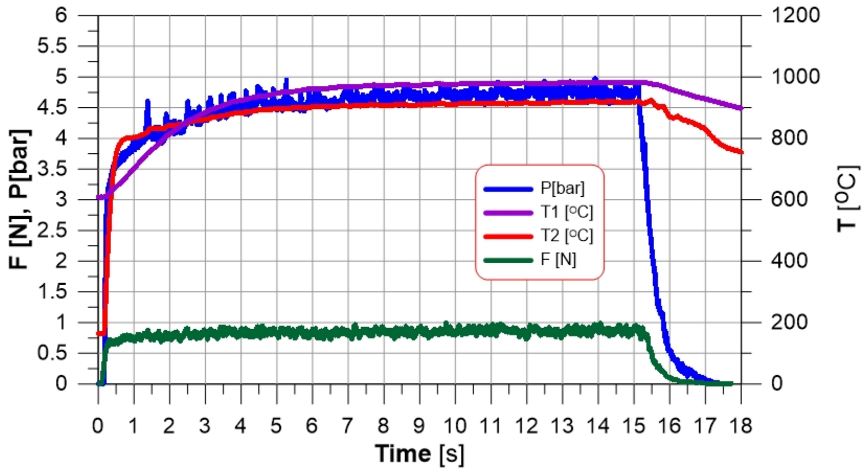

Figure 6. The course of the parameters during exemplary experiment: T1 – temperature in heater area, T2 – temperature in nozzle area, P – chamber pressure, F-measured thrust.

It is clearly visible that all the values rapidly increasing at the HTP injection and are very steady in time. What is more, the beginning of an experiment is very rapid – the dynamic of a system is high. Giving a closer look to the first second, it can be noticed that the pressure sensor reacts after 0.06 s after the injection. Pressure increasing very fast –it reaches 50% of a steady value (4.75 bar in presented case) in about 0.11 s after the injection start. 90% of steady pressure is reached after about 1.9 s after the injection.

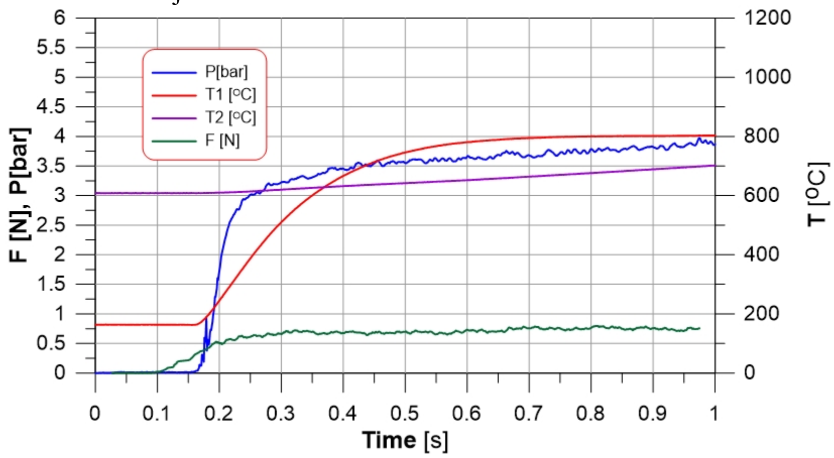

Figure 7. Closer look to the first second of an exemplary experiment.

Also a pressure stability looks fine. Looking at the pressure oscillation in steady region, arbitrarily chosen, between 10s and 15s, it is clear that oscillations are about +/- 4% of mean value.

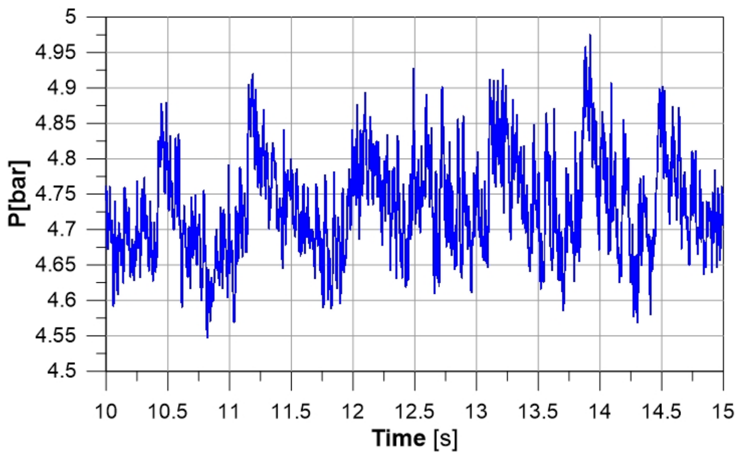

Figure 8. Pressure stability in steady period of thruster operation.

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Several experiments for different temperatures of a heater were carried out. Those were compared by the performance at the last second of the experiments. Mean values of thrust, chamber pressure and temperature at the nozzle area in the function of initial temperature of a heater were presented in …

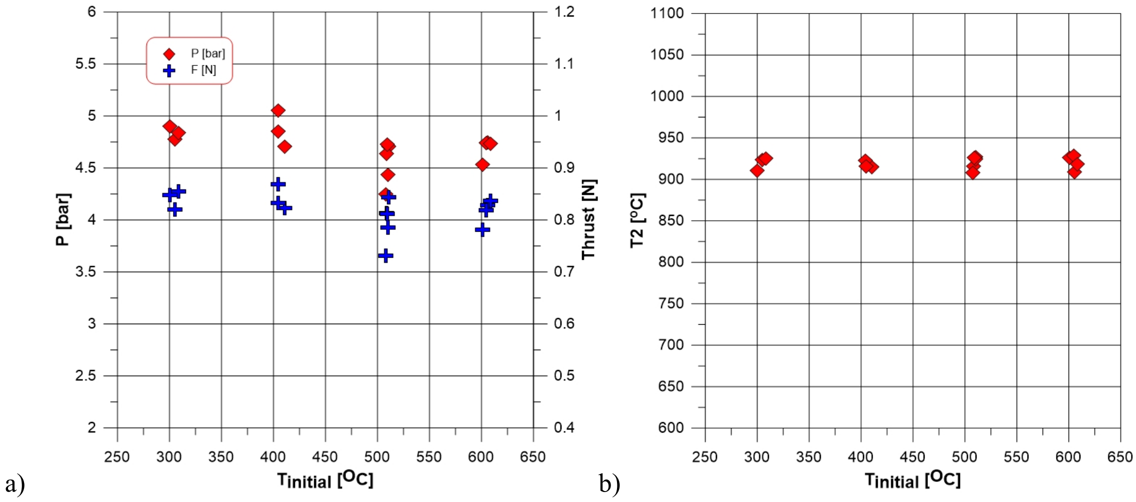

Figure 9. Results for several initial temperatures of a heater: a) Chamber pressure and thrust, b) Temperature in nozzle area

It can be noticed that for conducted experiments, initial temperature of a heater has no influence on temperature after the decomposition. Pressure and thrust seems to be slightly lower with increasing initial temperature of a heater. As mentioned above presented work is a result of an initial phase of the project. Only several experiments have been conducted so far and the research will be greatly extended in a closest future. Results should be taken in a large dose of caution taking their initial character into mind.

Summary and conclusions

The paper presents the initial research on possibility of using thermal decomposition of highly concentrated hydrogen peroxide for low thrust propulsion system applications. The main focus of current task was to investigate the possibility of initialization of stable process of decomposition without a presence of the dedicated catalyst. Authors using the prepared research facility, investigate the decomposition process in thruster-like setup and measure the basic parameters such as chamber temperature, pressure and produced thrust. Initial research revealed that the process in possible to initiate and sustain only by the temperature source. Possibility of removing the catalyst pack from the thruster is very tempting but on that stage of a research, it is too soon to declare that it is possible. Authors recognise many problems to solve and many possibilities to new research. The closest future plans include investigation of influence of an initial heater temperature on dynamic of a thruster, optimization of a thruster model and the heater, power availability considerations and investigation of using supercapacitors as a dedicated power supply for proposed system. The results will be available soon.

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