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## Design, Build and Test A 5 N Green Monopropellant Thruster using Potassium Iodide Catalyst

AH. Deif<sup>1</sup>, A.M. ElZahaby<sup>2</sup>, Ah. El-S. Makled<sup>3</sup>, Mohamed K. Khalil<sup>4+</sup>

Ph.D. Candidate Space Technology Centre, Cairo, Egypt<sup>1</sup>

Professor, Faculty of Engineering, Tanta University, Tanta, Egypt.<sup>2</sup>

Associate Professor, Faculty of Engineering, Zagazig University, Zagazig, Egypt.<sup>3</sup>

Associate Professor, Military Technical College, Cairo, Egypt.<sup>4</sup>

**ABSTRACT:** The objective of this article is to develop a 5N Hydrogen Peroxide( $H_2O_2$ ) monopropellant thruster (MPT) using newly developed Potassium iodide Catalyst. It is used in remote sensing satellites for attitude control and orbit correction. The thruster uses inhouse prepared high test peroxide (HTP) of 85 % concentration. Firstly,  $H_2O_2 \approx 85\%$  by weight is prepared in laboratory. The thruster is designed based on a mathematical model utilizing NASA CEA rocket performance code. The test facility is developed which consists of the thruster, the feeding system, static test stand and a measurement system. A test bench is designed and fabricated with Pendulum thrust mechanism to measure the thrust. Finally, Potassium iodide (KI) Catalyst loaded on  $Al_2O_3$  high surface catalyst support pellets is manufactured and packed inside the thruster. The thruster testing without heating are not completely successful. The analysis of the results shows that the thruster has a thrust range from 4.2-4.3N. The specific impulse is evaluated to be 101s while the theoretical is to  $\approx 111.5s$ . The decomposition efficiency  $\approx 90\%$  at chamber pressure of  $\approx 10$  bars and mass flow rate  $\approx 4.18$  g/s.

**KEYWORDS:**Spacecraft Propulsion, Monopropellant, Hydrogen Peroxide, Catalyst Bed.

### INTRODUCTION

High test hydrogen peroxide (HTP) has been utilized as a monopropellant and an oxidizer with propulsion systems many years ago. It has been used in many manned and unmanned space systems since 1930s up to the present time [1]. NASA has performed a lot of work on  $H_2O_2$  decomposition as a monopropellant[2]. A need for a higher  $I_s$  gradually led to the replacement of  $H_2O_2$  with Hydrazine( $N_2H_4$ ). Moreover, the development of a superior catalyst bed for  $N_2H_4$  (Shell 405) tilted the balance in favor of  $N_2H_4$ . Also, dinitrogen tetroxide ( $N_2O_4$ ) replaced  $H_2O_2$  for use as a storable oxidizer. On the other hand, the Russian Soyuz launch vehicle, which has been in active service for over forty years, continues to depend on  $H_2O_2$  in its gas generator to drive the main turbine pump and in the reaction control system (RCS)thrusters used for the descent phase of the re-entry capsule of the Soyuz spacecraft[3][4]. The performance of  $H_2O_2$  as a monopropellant is around 20% lower than  $N_2H_4$ , but the volume specific impulse achievable with 90%  $H_2O_2$  is higher than for most other propellants due to its high density. This is particularly useful for systems with significant aerodynamic drag losses or firm volume constraints, as is often the case for small satellites[5]. the development of active, dependable, restartable and durable catalytic beds which have fast, and reproducible performance is a real challenge. The catalyst beds must resist poisoning by stabilizers and impurities exist in the propellant which decrease the reactivity of  $H_2O_2$  such as pyrophosphate ions. In addition, such thrusters need to be capable of performing the large number of operation cycles designed by mission scenarios Nowadays the most popular catalyst material for  $H_2O_2$  is metallic silver [2]. The main defect of the catalytic silver is the low melting temperature limitation and poisoning [6] that is why it was decided to develop a new catalyst bed which could support high decomposition temperatures of hydrogen peroxide As the  $H_2O_2$  flows through Potassium iodide (KI) Catalyst loaded on  $Al_2O_3$  high surface catalyst support pellets, the decomposition takes place in an exothermic reaction producing oxygen and water steam.

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## II. RELATED WORK

Ceramic supports contributed greatly in catalyst development to decompose hydrogen peroxide (>90%). concentration due to their high temperature of melting. They also possess high surface area, above 200m<sup>2</sup>/g, and resist high thermal shocks. They have two main different forms; pellets and monoliths. ALTA S.p.A. (Italy) and DELTACAT Ltd. (United Kingdom) jointly examined the usage of catalytic materials loaded on ceramic substrates as a cheaper substitute to metallic gauze catalysts to decompose HTP in small monopropellant thrusters. ALTA S.p.A.[7]. Rusek [8] assessed chemically a variety of high surface area ceramic substrates in form of cylinder and sphere. Romeo et al [9] investigated with two different ceramic catalyst supports; 0.6 mm diameter alumina-silica (70:30 wt.%) spheres ( $S_{BET} = 401 \text{ m}^2/\text{g}$ ) and 0.6mm diameter alumina spheres ( $S_{BET} = 170 \text{ m}^2/\text{g}$ ). Fernanda F.M. et al [10] developed new bulk catalysts composed of mixed oxides of cobalt and manganese by impregnation for decomposing of HTP.

## III. THRUSTER DESIGN

The sequence of the design is performed using NASA CEA rocket performance code[11] is used to calculate the thruster theoretical performance, where a mathematical model is developed to carry out the design of the thruster[12] the design specifications are: 1) The thruster uses H<sub>2</sub>O<sub>2</sub> with concentration of 85% as a propellant, 2) The firing time capability is to exceed 10 seconds, 3) The decomposition chamber stagnated pressure is 1MPa, 4) The exit pressure of the nozzle is the ambient pressure. all these design outcome parameters are listed in table 1

Table (1) Design parameters of the thruster

	parameter	value
Propellant	H <sub>2</sub> O <sub>2</sub>	≈85%
	Mass flow rate, g/s	≈4.20
Catalytic bed	Potassium iodide loaded on Al <sub>2</sub> O <sub>3</sub> Pellets diameter	2-3 mm
	Inner diameter, mm	15
	Length/diameter ratio	4.0
	Loading factor, kg/s m <sup>2</sup>	50.0
Nozzle part	Convergent-divergent nozzle shape	
	Throat diameter, mm	2.25
	Exit diameter, mm	3.32
	Nozzle half angle, deg	14.0°
Injection and retainer plate	Drill injector shape	
	Opening area, %	50
	Diameter, mm	14.6
	Orifice diameter, mm	1.50
	Number of orifices	23
	Thickness, mm	2.0
Thruster performance	Thrust range, N	≤ 5
	Specific impulse, s	≈ 111.49
	Characteristic velocity, m/s	≈ 884.50
	Chamber temperature, K	≈ 907.30
	Thrust coefficient	≈ 1.256

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## IV.EXPERIMENTAL WORK

The concentration process and firing test are done in chemistry and jet propulsion labs respectively. The thruster is fabricated using stainless steel 316 in the AOI Engine Factory based on the mathematical model developed by Ah. Deif et al.[12]. HTP of 85% concentration by weight is used as afuel.

## V.HYDROGEN PEROXIDE PREPARATION

A 50 liters of an industrial  $H_2O_2$  of type HYPROX 500 manufactured in a multinational company called Evonik industries of concentration 50 % by weight is procured from the local market in Egypt **Error! Reference source not found..**It is decided to concentrate the commercial HYPROX 500 to reach the desirable concentration but without removing all the undesirable stabilizers . The concentrated  $H_2O_2$  underwent filtration process to get rid of the undesirable stabilizers which poisons the catalysts.

## VI.THE THRUSTER MANUFACTURE

The Thruster is made of stainless steel 316 to withstand the thermal and mechanical stresses generated during firing based on mathematical model developed by Ah. Deif et al[12]. It is manufactured on modular base where it consists of 3 parts: the injector (1) where the liquid hydrogen is entered and injected, the cylindrical parts which holds the catalyst bed where the hydrogen peroxide is decomposed by flowing through it, and the nozzle (3) where the gaseous products are accelerated into the critical section. The injector plate is designed to distribute the propellant on the surface of the catalyst, the retainer (4) is designed to block the catalyst to go out from the chamber, and an anti-channeling disc to redirect the flow into the core of the catalyst Fig. 1.

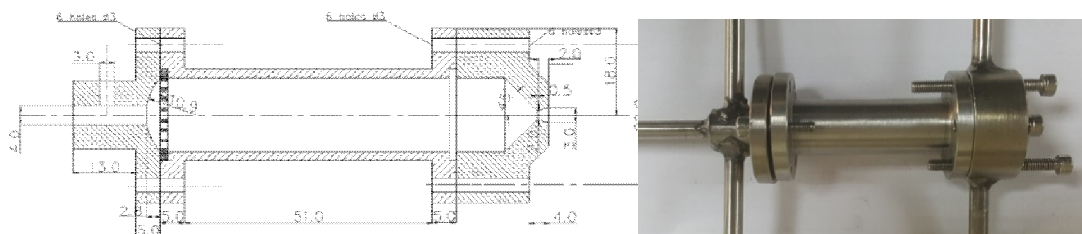


Fig. 1The thruster Drawing

## VII.CATALYST MANUFACTURE

$Al_2O_3$  Aluminum oxide, catalyst support, high surface area was procured from Alfa Aesar undergoing a heat treatment process. It is was known that there were some differences in the size of these substrates; not only with respect to each other but also relative to themselves. The catalysts should be handled with new gloves and washing all the handling equipment using nitric acid bath of 10% concentration for period of 10 minutes then rinsing by a deionized water before usage with the catalyst. the procedure of catalyst development is as follows;

1. Weigh pellets  $Al_2O_3$  Aluminum oxide.
2. Heat pellets  $Al_2O_3$  before loading catalyst at  $550^\circ C$  for 2 hours.
3. Weigh pellets  $Al_2O_3$  Aluminum oxide.
4. Mix Potassium Iodide and distilled water at a ratio of 3:5 by weight. mix the solution mechanically by a magnetic mixer at  $65^\circ C$ , for 1 hour.
5. Put  $Al_2O_3$  in pellets the Potassium Iodide solution.
6. Mix the pellets and solution for one hour by sonication using ultrasonic machine shown in Fig. 2
7. Remove the KI pellets from ultrasonic machine Heat to  $500^\circ C$  for two hours.

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Fig. 2 Ultrasonic machine

8. Weigh pellets and calculate loading factor which was 16% as shown in Fig. 3.



Fig. 3 Weighting pellets before loading of KI

9. Remove any small particles (KI broken pellets, KI powder etc.) Using a sieve Fig. 4.
10. Pack in a plastic container with the loading factor and date of manufacture



Fig. 4 Photo of  $\text{Al}_2\text{O}_3$  pellets (a), and KI-impregnated pellets (b)

## VIII. THE THRUSTER TEST FACILITY

The experimental testing of the 5N thruster prototype is done using  $\text{H}_2\text{O}_2$  test facility. It consists of the thruster, a feeding system, a custom-made test bench, and data measuring system designed for delivering  $\text{H}_2\text{O}_2$  to the thruster at the desired mass flow rate and pressure as shown in Fig. 5.

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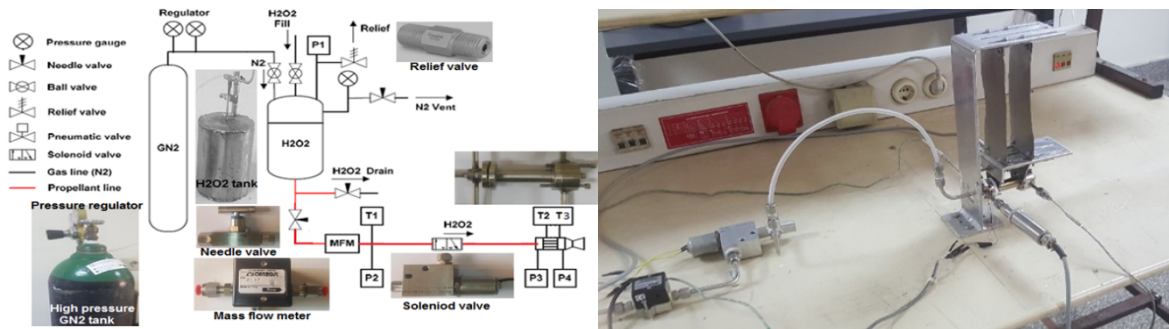


Fig. 5 The thruster Test Bench

## IX. FIRING TEST

Initial testing began with leak tightness of the system without the thruster connected. Afterwards the cracking pressure of the relief valve was tested and adjusted to protect the feeding system from sudden pressure increase. The third test was done with water to check the functionality of the feeding system elements and to adjust the liquid volume flow rate using the flowmeter and the needle valve and to make sure the mass flow rate of the water as the required value. The firing tests can be done using two different types of heating which are the electrical heating using heating coil or short HTP pulses to pre-heat the catalytic bed. pulsed pre-heating has no temperature limit because the fresh cool HTP flow maintained the injector assembly below 120°C. Not all testing experiments are investigating as some were for devices and measurement check and verification and some were several repeats to confirm reliability and fix some problems. Thruster firing is shown in Fig. 6.

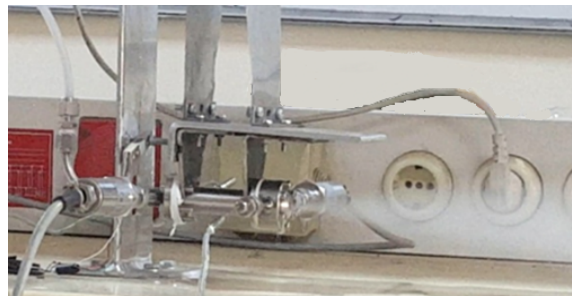


Fig. 6 Thruster hot firing

## X. RESULTS AND DISCUSSION

10 runs are conducted with heating including propellant pulsing to pre-heat the KI before firing. The thruster initial input temperature is about 50°C and the output initial temperature is  $\approx 80^\circ\text{C}$  after heating. It is shown in Fig. 7 that the chamber input pressure rises to 11 bar and the input temperature is 50°C after firing, the output pressure and temperature are around 10.6 bar and 360°C, the difference in pressure is 0.6 bar which represents the pressure drop due to the catalyst. The thrust reaches the value of 4.3 N and the average mass flowrate is about 4.19 g/s so the experimental  $I_{sp}$  is  $\approx 101\text{s}$ . the decomposition efficiency reached 90%. It was also noticed that the pressure and thrust increases due to the increase in the initial temperature at the same mass flow rate which agrees with [13], [12]. It was possible to increase the decomposition temperature if we apply insulation material on the thruster body to decrease the heat losses.



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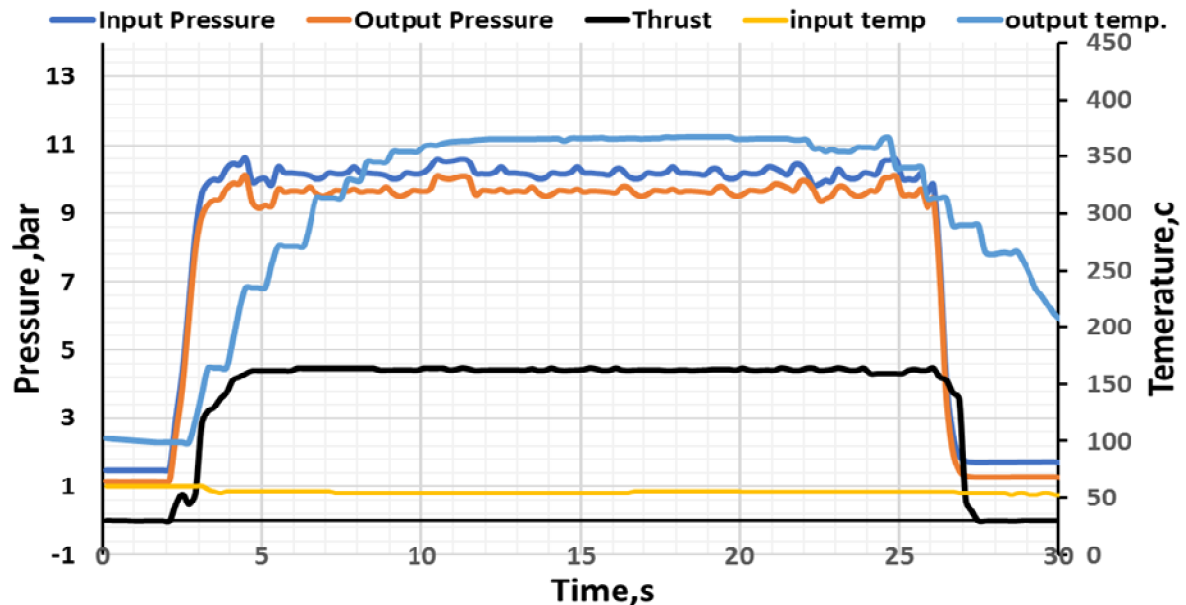


Fig. 7 Thruster performance with KI

## XL CONCLUSION

A5 newton  $H_2O_2$  monopropellant thruster which can be utilized in remote sensing satellites for attitude control and orbit maneuver was designed and manufactured successfully. The test results show the inhouse manufactured Potassium iodide (KI) loaded on  $Al_2O_3$  high surface catalyst support pellets  $160 \text{ m}^2/\text{gram}$  decomposed hydrogen peroxide efficiently. However, the actual measured thrust reaches the value of  $\approx 4.3 \text{ N}$ , the average mass flow rate is  $\approx 4.19 \text{ g/s}$  and the thruster experimental  $I_{sp}$  is  $\approx 101 \text{ s}$ , which is an accepted performance due to then insufficient quality of the  $H_2O_2$  the surface area catalyst support which leads to higher loading factor of catalyst which improves the decomposition process, and heat losses through the thruster walls.

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