DEVELOPMENT OF A 10 NEWTON HYDROGEN PEROXIDE MONOPROPELLANT ROCKET THRUSTER

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A project report submitted in fulfillment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

FEBRUARY 2013

Specially dedicated to

My beloved parents

My supervisor

My supportive friends…..

ACKNOWLEDGEMENTS

In the course of preparing this report, I came into contact with several knowledgeable people who contributed significantly towards my understanding and thoughts in this field. First of all, I wish to express my sincere appreciation to my former supervisor, Prof. Dr. Subramaniam Krishnan for his encouragement, guidance, comments and advices during the duration of my research. The knowledge that he shared is especially valuable to us who are still taking our "baby steps" in this rocket science field. Secondly, I would like to thank my current supervisor, Prof Ir. Dr. Wan Khairuddin Wan Ali, for the advice, comment, guidance and the vital role he played in shaping up my research report. Without his support and interest, I wouldn't have been motivated to make this report the best it could be.

I would like to take this opportunity to acknowledge the Ministry of Science, Technology and Innovation (MOSTI) for the trust and funds (vote no. 04-01-06-SF0638) provided by them which really encouraged us to start off this research. However it was later taken over by Universiti Teknologi Malaysia and is currently funded by them.

Furthermore, I would like to thank Mr. Akmal (research officer) and Mr Fayaddh (assistant research officer) for their help, guidance, comments and advices during the duration of research. Thanks to the laboratory technicians too for their help and advices during my research.

My fellow postgraduate students, Norazila Othman and Khafri Izuan should be recognized for their support. My sincere appreciation also extends to all my friends and others who have provided assistance on various occasions. Their views and tips were very useful indeed. Unfortunately, it is not possible to list all of them in this limited space. Finally, I am very grateful to my family members for their constant support and understanding.

ABSTRACT

Propellant is one of the important parts in rocket development. There are many types of propellant such as nitrogen tetroxide and hydrazine but most of them are toxic in nature and can harm our health and environment. This has increased the renewed interest on hydrogen peroxide, also known as “green” propellant that can act as monopropellant or oxidizer which is ideal for spacecraft programs. This research is mainly about developing a rocket thruster by using hydrogen peroxide as monopropellant. Therefore, a 10 Newton rocket thruster has been designed and fabricated. However, in order to test the performance of rocket thruster, there are several preparations that have been done. Firstly, was the preparation of rocket grade hydrogen peroxide (concentration > 85%) from lower concentration of hydrogen peroxide. Next, was development of rocket test facility which consists of two integral parts; (1) static test rig and (2) data acquisition system. Measuring discharge coefficient of the thruster injector was also part of the preparations to ensure the mass flow rate of propellant. Finally, the catalyst pack was prepared where silver screens were used as catalyzer. The hydrogen peroxide would react with the catalyst pack and decompose into water and oxygen. In order to identify the optimum configuration of producing 10 N thrust, several parameters were taken into consideration and they are injector orifice diameter, nozzle throat diameter, type of hydrogen peroxide used, catalyst pack length, compaction pressure of catalyst pack, engine heating temperature and propellant injection pressure. With a total of 5 series of successful hot tests, the optimum configuration of producing 10 N thrust using hydrogen peroxide monopropellant rocket thruster had been achieved. The configuration is: D_i = 0.601 mm, D_t = 2.236 mm, P_{cp} = 9.29 MPa (50 kg by strain gauge) and P_2 = 37 bar.

ABSTRAK

Propelan adalah salah satu bahagian penting dalam pembangunan roket. Terdapat banyak jenis propelan seperti nitrogen tetroksida dan hidrazin tetapi kebanyakannya adalah toksik dan boleh memudaratkan kesihatan dan alam sekitar. Ini telah meningkatkan semula minat terhadap hidrogen peroksida yang juga dikenali sebagai propelan "mesra alam" yang boleh bertindak sebagai propelan tunggal yang ideal ataupun pengoksida untuk kapal angkasa. Maka, kajian ini adalah tentang pembangunan pendorong roket dengan menggunakan hidrogen peroksida sebagai propelan tunggal. Oleh itu, roket pendorong 10 Newton telah direka dan difabrikasi. Walau bagaimanapun, bagi menguji prestasi pendorong roket, terdapat beberapa persediaan yang telah dijalankan. Pertama sekali adalah penyediaan hidrogen peroksida gred roket (kepekatan> 85%) daripada hydrogen peroksida berpekatan rendah. Seterusnya adalah pembangunan kemudahan ujian roket yang terdiri daripada dua bahagian penting iaitu; (1) rig ujian statik dan (2) sistem perolehan data. Mengukur pekali kadar alir penyuntik juga merupakan sebahagian daripada persiapan untuk memastikan perolehan kadar aliran jisim bahan dorong yang betul. Akhir sekali adalah penyediaan pek pemangkin di mana jaring perak digunakan sebagai bahan pemangkin. Hidrogen peroksida akan bertindak balas dengan pek pemangkin dan terhurai kepada air dan oksigen. Dalam usaha untuk mengenal pasti konfigurasi optimum untuk menghasilkan tujahan 10 N, beberapa pemboleh ubah telah diambil kira iaitu diameter penyuntik, diameter kerongkongan nozel, jenis hidrogen peroksida yang digunakan, panjang pek pemangkin, tekanan pemadatan pek pemangkin, suhu pemanasan pendorong roket dan tekanan suntikan propelan. Setelah 5 siri ujian pembakaran yang berjaya dijalankan, konfigurasi optimum menghasilkan tujahan 10 N menggunakan pendorong roket propelan tunggal hidrogen peroksida telah dicapai. Konfigurasinya adalah: D_i = 0.601 mm, D_t = 2.236 mm, P_{cp} = 9.29 MPa (50 kg oleh tolok terikan) dan P_2 = 37 bar.

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LIST OF SYMBOLS

A_{CP}	-	Area of catalyst pack
A_e/A_t	-	Throat area ratio
A_i	-	Area of injector
A_t	-	Throat area (m^2)
a	-	Acceleration (m/s^2)
C_F	-	Exhaust velocity (m/s)
C_F^0	-	Thrust coefficient
C_m	-	Mass concentration
c_d	-	Discharge coefficient
$\bar{c}_d$	-	Average value of discharge coefficient
c^*_{expt}	-	Experimental characteristic velocity (m/s)
c^*_{theo}	-	Theoretical characteristic velocity (m/s)
D_{CP}	-	Diameter catalyst pack (mm)
D_i	-	Diameter injector (mm)
D_t	-	Nozzle throat diameter (mm)
dp_2 / dt	-	Derivative of injection pressure
dp_4 / dt	-	Derivative of nozzle entry pressure
F	-	Force (N)
F_1	-	Thrust based on mass flow rate through injector.
F_2	-	Thrust based on choked mass flow rate through nozzle.
F_{vac}	-	Thrust in vacuum condition
H2O2	-	Hydrogen peroxide

I_{sp}	-	Specific impulse
K	-	Kelvin
L_{CP}	-	Length of catalyst pack
m	-	Mass
$\overline{m}$	-	Molar mass
$\dot{m}_p$	-	Propellant mass flow rate
$\dot{m}_1$	-	Propellant mass flow rate through injector orifice
$\dot{m}_2$	-	Propellant mass flow rate through choked nozzle
P_{atm}	-	Atmospheric pressure
P	-	Static pressure
P_{cp}	-	Catalyst pack compaction pressure
p_{0n}	-	Nozzle entry stagnation pressure
p_{0n}/p_e	-	Ratio of chamber and exit pressure
P_{0hpi}	-	High pressure tank initial pressure
P_{ocp}	-	Catalyst pack entry pressure
P_0	-	Nitrogen pressurization tank
P_1	-	Propellant tank pressure
P_2	-	Injection pressure
P_3	-	Pressure before catalyst pack
P_4	-	Nozzle entry pressure
$P_2 - P_3$	-	Injector pressure drop
$P_3 - P_4$	-	Catalyst pack pressure drop
Re	-	Reynolds number
R_u	-	Universal gas constant
T	-	Temperature
T_{atm}	-	Atmospheric temperature
T_{cp}	-	Catalyst pack temperature

T_{ad}	-	Adiabatic temperature
T_0	-	Combustion chamber temperature
t_A	-	Countdown zero; this is the time at which propellant injection starts
t_B	-	Time at which injection pressure has reached the maximum
$t_{B'}$	-	Time at which maximum dP_2/dt occurs
t_C	-	Time at which the nozzle entry pressure P_4 has reached maximum
$t_{C'}$	-	Time at which maximum dP_4/dt occurs
t_D	-	Burnout time
V	-	Volume
$\dot{V}$	-	Rate of volume
W	-	Weight
v	-	Velocity
Γ	-	Lambda
γ	-	Gamma
$\Delta H^{\ominus}$	-	Delta heat release
$\Delta G^{\ominus}$	-	Delta Gibbs function
ΔP_{avg}	-	Average pressure
ΔP_{cp}	-	Pressure drop through the catalyst pack
Δp_i	-	Pressure drop at the injector
ΔP_{in}	-	Pressure drop through the injector
Δt_{in}	-	Ignition delay
Δt	-	Residence time
η_{c^*}	-	Efficiency of H2O2 decomposition
η_{C_F}	-	Efficiency of nozzle flow
$\eta_{c^*_{N_2}}$	-	Efficiency for nitrogen flow through injector orifice

μ_{H2O2}	-	Viscosity of hydrogen peroxide
μ_{w}	-	Viscosity of water
ρ	-	Density
ρ_{H2O2}	-	Density of Hydrogen peroxide
ρ_{p}	-	Propellant density
ρ_{w}	-	Density of water
Φ	-	Mass flux
Φ_1	-	Mass flux based on mass flow rate through injector
Φ_2	-	Mass flux based on choked mass flow rate through nozzle

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Monopropellant propulsion systems have become an attractive mechanism for orbit maintenance and attitude control due to their simplicity compared to bipropellant systems [1]. However, these systems mostly use hydrazine or nitrogen tetroxide as monopropellant. These propellants are highly toxic and dangerously unstable substances [2].

Concern on toxic-free propellants is the latest headlines in rocket and propulsion industries. Nowadays, there have been rapid developments in rocket fuel propulsion technology to meet the challenges of reducing the toxicity produced by rocket thruster exhaust. Furthermore, there is also an issue of "green" disposal to be taken into consideration to save our environment. Recently, low toxicity ("green") storable liquid propellants have attracted attention as possible replacements for hydrazine. This is due to the search for propellants with lower production costs as well as easier handling methods. [3].

This pursuit has led to a renewed interest in the use of hydrogen peroxide (H2O2) as a rocket propellant. It is a non-toxic and non-carcinogenic "green" propellant. Hydrogen peroxide also promises significant cost savings due to the drastic simplifications in health and safety protection procedures during its production, storage, and handling .The use of H2O2 offers versatility of operating the rocket engine on dual mode, namely, a bipropellant mode for operating the engine in large thrust requirement (either as bipropellant liquid engine or a hybrid rocket engine) and on a monopropellant mode for small thrust applications. On adoption of a suitable catalyst, H2O2 decomposes into super-heated steam and oxygen at temperatures in excess of 1000 K. This leads to automatic ignition either with a liquid fuel in a bipropellant rocket engine or with a solid fuel in a hybrid rocket engine. This automatic ignition in a rocket propulsion system, without the dependence on an external ignition system, is a great advantage that substantially enhances the system reliability [4-9].

Thus, the versatility of the H2O2 with the additional advantage of auto-ignition makes this “green” propellant an attractive field to enhance the research on. As such, H2O2 was selected as the monopropellant for this research.

1.2 Importance of this research

In recent years, there has been a rapid increase in interest shown on aerospace industry by the Malaysian government. The universities are highly encouraged to venture into aerospace related research with sufficient financial support by government bodies. Their main aim is to have an established space industry in this country as well as South East Asia region [10]. One of the researches is on development of satellite mainly for telecommunication and mapping purposes.

However, one of the main cores in satellite development is attitude control system for maneuvering purpose. This is where the small rocket thrusters are introduced to lift the satellites into the desired orbits. Too much of thrust or thrust at the wrong time can cause a satellite to be placed in the wrong orbit or set the satellite too far out into space to be useful. Too little thrust can cause the satellite to fall back to earth. Due to that, liquid propellant rocket thrusters would be the best selection because of their capability to control the thrust by varying the amount of propellant that enters the combustion chamber. Besides that, liquid rocket thrusters can start or stop the thrust according to necessity unlike solid propellant rockets. A computer in the rocket's guidance system determines the amount of thrust that is needed and controls the propellant flow rate [11].

Considering the space and cost consumed on satellite development, monopropellant thruster is the best choice for attitude control system because of its simplicity. This research would be the pioneer for monopropellant rocket development in this country while taking into consideration the environmental sustainability as well as the economical factor.

1.3 Problem statement

Using pure silver as catalyst pack may increase the development cost of the thrusters since the price of the silver in the market has been increasing for past few years. With other types of catalyst packs such as platinum or manganese base still under research, silver has shown promising results when H2O2 is used as a propellant with concentration of below 92 % [2, 12]. But due to concerns on the cost, consumption of silver needs to be minimized while still maintaining the performance of rocket thrusters.

Besides, development of monopropellant rocket thrusters involves 2 important supplement parts, namely suitable propellant and test facility. But the stumbling block is the availability of rocket grade H2O2, which is of mass concentration above 85 % and free of stabilizers. Development of test facility from zero being the other challenge since it requires high safety measurements.

1.4 Objective of the research:

The main objective of this research is to develop a 10 Newton hydrogen peroxide monopropellant rocket thruster.

1.5 Scope of the research:

In order to achieve the objective of this research, there are several parts that need to be complied. They are:

(1). Preparing and characterizing rocket grade hydrogen peroxide

(2). Design and assemble a suitable test facility for static firing of small rocket thrusters using H2O2 monopropellant.

(3). Design and fabricate the 10 Newton hydrogen peroxide monopropellant rocket thruster.

(4). Conduct the hot test and determine the optimum configuration of producing 10 Newton thrust using 10 Newton hydrogen peroxide monopropellant rocket thruster.

1.6 Outline of thesis

The thesis on this research is divided into 6 chapters. Chapter 1 outlines the background studies for this research, importance of this research, problem statement, objective, scopes and outline of the thesis.

Chapter 2 starts with some explanations on rocket fundamentals as well as liquid rocket systems and goes on to describe monopropellant thrusters. Information on hydrogen peroxide and its history in rocket applications is also provided in this chapter. In addition to that, a list of commercial grade H2O2 available in open market and some important features of H2O2 for rocket applications are provided. There is also a brief explanation on catalysts used in the monopropellant rocket system. Finally latest researches on the H2O2 thruster were briefly explained in this chapter.

Chapter 3 focuses on a brief explanation of the methodology employed in this research. It was further illustrated in a flow chart with short explanations. Hot test procedures were explained in this chapter as well as the design and fabrication of the 10N H2O2 monopropellant rocket thruster. Besides that, Chapter 3 also explains the parts that need to be done before conducting a hot test on the rocket thrusters. They are namely preparing rocket grade H2O2, development of rocket test facility, injector orifice characterization, preparation of catalyst pack and understanding hot test procedures.

Chapter 4 details about the method of performance calculations on hot tests output which is later analysed and discussed in Chapter 5. The conclusion and recommendations are presented in Chapter 6.

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