CATALYST PACK FOR HYDROGEN PEROXIDE MONOPROPELLANT THRUSTER

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To my beloved mother and father

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ABSTRACT

Silver is one of the common materials used to decompose hydrogen peroxide but it is heavy and does not last very long while manganese catalyst seems to be lighter and lasts longer, giving it the potential to replace silver. Unfortunately, this is yet to be tested. The configuration to produce 100 N thrust by using silver catalyst needs to be determined, and the feasibility of using manganese calcinated on alumina needs to be verified. With theoretical calculation and several trial and error experiments by varying the catalyst pack compaction pressure, injector and nozzle diameters, catalyst pack heating temperature and propellant tank feeding pressure for silver catalyst, the configuration to produce 100 N thrust has been obtained. For manganese catalyst, assorted combinations of alumina sizes and types were tested to be the catalyst carrier. The method of calcination was also developed in order to get the highest amount of manganese deposited and it was found that Sasol γ-alumina spheres with a diameter of 2.4 mm produce the highest amount of manganese deposition with an average of 42% after three calcinations using potassium permanganate as the precursor solution. This was followed by experimental work which found that the usage of manganese calcinated on the alumina cannot cope with high pressure in the thruster and tends to break into small pieces and wash out of the thruster. Silver configuration for producing 100 N thrust has been obtained in this research. Also, it was found that it is not feasible to use manganese with the method described in this work.

ABSTRAK

Perak adalah salah satu bahan yang biasa digunakan untuk menguraikan hidrogen peroksida akan tetapi ianya berat dan tidak kekal lama manakala pemangkin mangan pula adalah lebih ringan dan tahan lebih lama, memberikan ia potensi untuk menggantikan perak. Walau bagaimanapun, ini masih belum diuji. Konfigurasi untuk menghasilkan daya tujah 100 N dengan menggunakan pemangkin perak perlu ditentukan, dan kesesuaian menggunakan mangan yang dikalsinkan pada alumina sebagai pengganti perak perlu disahkan. Melalui pengiraan secara teori dan beberapa ujikaji menggunakan kaedah cuba jaya dengan mengubah tekanan pemadatan pek pemangkin, diameter lubang penyuntik dan nozel, suhu pemanasan pek pemangkin dan tekanan suapan tangki bahan pendorong pemangkin perak, konfigurasi untuk menghasilkan daya tujah 100 N telah diperolehi. Untuk pemankin mangan pula, pelbagai kombinasi saiz dan jenis alumina diuji untuk menjadi pengangkut pemangkin. Kaedah pengkalsinan juga telah dibangunkan untuk mendapatkan jumlah tertinggi mangan yang berjaya dimendapkan dan didapati bahawa sfera γ-alumina Sasol dengan garis pusat 2.4 mm menghasilkan jumlah tertinggi mendapan mangan dengan purata sebanyak 42% selepas tiga kali pengkalsinan menggunakan kalium permanganat sebagai larutan pendahulu. Ini diikuti dengan uji kaji yang mendapati bahawa penggunaan mangan yang dikalsinkan pada alumina ini tidak dapat menampung tekanan tinggi di dalam pendorong dan cenderung untuk pecah menjadi kepingan kecil dan terkeluar daripada pendorong itu. Konfigurasi perak untuk menghasilkan daya tujah 100 N telah berjaya diperolehi dalam kajian ini. Juga, didapati bahawa adalah tidak sesuai mangan digunakan dengan kaedah yang diperihalkan dalam kajian ini.

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LIST OF SYMBOLS

A_{CP} = Cross sectional area of catalyst pack

A_e = Nozzle exit area

c_d = Coefficient of discharge for the injector orifice

$c^*{}_{exp}$ = Experimental characteristic velocity

$c^*{}_{theo}$ = Theoretical characteristic velocity

C_F^0 = Characteristic thrust coefficient

$C_{F_{sl-\mathrm{exp}}}$ = Experimental sea level thrust coefficient

$C_{F_{sl-theo}}$ = Theoretical sea level thrust coefficient

d_i = Injector orifice diameter

D_{CP} = Catalyst pack diameter

D_e = Nozzle exit plane diameter

D_t = Nozzle throat diameter

F = Thrust

$I_{sp_{sl-\mathrm{exp}}}$ = Sea level specific impulse

L_{CP} = Catalyst pack length

$\overline{m}$ = Molar mass of decomposed gas

$\dot{m}_p$ = Propellant mass flow rate

p_a = Ambient pressure at sea level

p_e = Nozzle exit plane pressure

p_{0CP} = Catalyst pack entry pressure

p_{0i} = Injection pressure

P_{0n} = Nozzle entry stagnation pressure

p_{0hp_f} = High pressure tank final pressure

p_{0hp_i} = High pressure tank initial pressure

p_{0pt} = Propellant tank pressure

R_u = Universal gas constant, 8314.3 j/kmol-K

T_{0ad} = Adiabatic flame temperature

T_{0n} = Nozzle entry stagnation temperature

V_{hpt} = High pressure tank volume

V_{pt} = Propellant tank volume

γ = Ratio of specific heats for the neutral gas in the high pressure tank

ε = Nozzle area ratio, A_e / A_t

Δp_{CP} = Catalyst pack pressure drop

Δp_i = Injector pressure drop

Δp_{oo} = On/off valve pressure drop

Δp_{PR} = Minimum pressure difference across pressure regulator

Δt_F = Thrusting time

Δt_{rt} = Residence time in catalyst pack

η_{c^*} = c^* efficiency

η_{C_F} = C_F efficiency

ρ_{0n} = Nozzle entry stagnation density

ρ_p = Propellant density

ϕ = Gas mass flux through the catalyst pack

CHAPTER 1

INTRODUCTION

Liquid rocket propellant system commonly divided into two types which are monopropellant and bipropellant [1]. In a monopropellant rocket system, a single liquid system is used as propellant. The most commonly used monopropellant is hydrazine (N_2H_4) which is highly toxic and very unstable unless handled in solution [1]. While in bipropellant rockets, two types of liquid system are used. The liquids are categorized into two which are the fuel and the oxidizer. The most common combination of bipropellant are monomethylhydrazine (MMH) and nitrogentetroxide (N_2O_4) both of which are highly toxic and unstable [1-2]

The above propellant mixtures require particular propellant handling and prelaunch preparation. Because of the requirement, hydrazines and nitrogen tetroxide have become less attractive fluid while hydrogen peroxide (H_2O_2) seems better as potential alternative [3-7]. Wernimont E. J. [8] stated that the non-toxic chemical which is rocket grade H_2O_2 (concentration greater than 85%) has a natural familiarity to human chemistry thus it is the best wide-ranging solution for space, land, air and sea applications. When choosing H_2O_2 as a monopropellant, the other benefits are the significant cost saving and simplification of health and safety precautions needed throughout the fabrication, storage and handling of the propellants [2].

The cost of manufacturing and preparing the thruster does not scale down proportionally with the thruster size due to the advantages. These advantages have special relevance to low or medium thruster. The propulsion mechanism was derived from silver meshes that act as a catalyst for the decomposition of H_2O_2. Since decomposition products are safe, H_2O_2 monopropellant also can be considered as safe. The reaction equation for the decomposition process is as per equation (1.1):

$$2H_2O_2(l) \xrightarrow{Catalyst} 2H_2O(l) + O_2(g) + Heat \qquad 1.1$$

Equation (1.1) shows that superheated steam and oxygen with heat are released from the decomposition process. It means that no other lethal gas is released to the atmosphere. Based on this fact, concentration up to 90% of the H_2O_2 rocket grade was prepared. In order to achieve higher specific impulse which can give more thrust, higher concentrations of H_2O_2 were needed. Unfortunately, silver catalyst cannot withstand the heat generated by the decomposition process while adopting high concentration of H_2O_2. By introducing alumina coated with manganese oxide, experiments were conducted in order to validate this catalyst for satellite propulsion usage. These ceramic based catalysts are expected to be lighter, cheaper, and of longer life.

1.2 Statement of the problem

For the improved application of hydrogen peroxide in rocket propulsion, major research activities are presently moving towards indentifying suitable catalyst system to decompose hydrogen peroxide. Traditionally screen of pure silver or silver coated nickel or stainless steel have been adopted. Silver based catalysts are heavy and of short life. Furthermore, when the concentration of hydrogen peroxide increases (to realize higher specific impulse), the silver based system cannot withstand high temperatures (>1000K) of the decomposed products of hydrogen peroxide. In searching for suitable alternative catalyst, manganese oxide calcinated on the substrates of alumina, titanium oxide, or cordierite has been shortlisted as the candidates for the catalyst system. These ceramic based catalysts are expected to be lighter, cheaper, and of longer life. However, detailed characterization of the system has not been reported.

1.3 Objective

1. To determine the sustainability of the conventional silver catalyst in the development of a H_2O_2 monopropellant rocket engine of 100N thrust.
2. To find out the feasibility of using alumina based catalyst in the development of monopropellant thruster.

1.4 Scope of Project

In order to achieve the objectives of the project, several scopes have been adopted. The scopes include using FORTRAN programming to ease the calculation of the parameters needed for the design, designing and fabricating the thruster using the parameters that have been calculated. It also include preparing silver and ceramic catalyst using methods applied by others and developing own method of preparation for ceramic catalyst.

1.5 Outline of Thesis

This thesis consists of six chapters. In this chapter, introduction, objective, statement of problems, scope of this project and summary of works are reviewed. While in Chapter 2, theory and literature reviews on hydrogen peroxide and its catalyst, thruster, micro thruster and its applications from various resources are summarized.

In Chapter 3, the discussion is on the methods of completing this project using hardware and software implementation together with catalyst preparation and testing procedures. The design process is elaborated in Chapter 4. The entire experimental results and discussion are described in Chapter 5. Lastly, Chapter 6, encompasses conclusion of this project and future work which can be done hence recommended.

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