PROPELLANT DEVELOPMENT FOR SMALL ROCKETS

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Abstract

The solid propellant rocket is the basis for most recent rocket inventions where it is utilized mostly in military rockets. Solid propellants are the simplest of all rocket propulsion systems and have a variety of materials and methods for development. The purpose of this research is to develop solid propellant based on potassium nitrate, carbon, and sulphur mixture. To obtain an optimum propellant composition and performance, a number of propellant burning-rate tests have been conducted. Seven sets of propellants with different compositions have been produced using the compression method. The results obtained from the burning-rate tests show that propellants at stoichiometric composition gave the highest burning-rate of 0.2734 cm/s.

Keywords: Rockets, solid propellants, potassium nitrate, burning-rate, stoichiometry

1. Introduction

The earliest rockets were developed by the Chinese hundreds of years ago and were used as weapons for the military. In the beginning, solid fuels were used as the propellant for rocket engines. In 1880 Konstantin Tsiolkovsky from Soviet Union presented a theory of using liquid propellant rockets in various phases for space flight. This theory however, was not realised until 1926 when Robert Goddard designed the first practical liquid fuel rocket [1].

Full-blown rocket-related research is practically non-existent in Malaysia. There are some industries supporting space-related activities but rocket-related technology is still in the infant stage [2]. Currently, industries supporting space-related activities are those involved in satellite component manufacturing and testing, electromechanical technology, and telecommunication and information technology.

The agencies or companies involved in this technology are Binariang Sdn. Bhd., Telekom Malaysia Berhad, National Space Agency (Angkasa), Malaysia Institute of Microelectronics (MIMOS), Universiti Teknologi Malaysia, Universiti Sains Malaysia, Universiti Malaya, Universiti Kebangsaan Malaysia, and Universiti Putra Malaysia. However, to advance our capability in space-related technology fully, we need to acquire the capability to develop our own satellite launcher to send our satellite to space.

Currently, Malaysian satellites were launched using foreign-owned satellite launchers from overseas sites such Baikonor in Kazakhstan. These have been very costly and also inconvenient since the launching schedules are beyond our control. For example, there have been times when launching has been postponed to accommodate preparation delays by other users.

Also, most advanced nations which dominate the rocket technologies kept their research under wraps. For example, SEPR 505 rockets use a propellant known as SDI. JATO 16-NS-1000-M15 rockets use composite propellants and 2”25 rockets use JPN Balilistite (double base) propellants, all of which are restricted materials [3]. Thus, we need to conduct researches to develop our own database and produce our own propellant materials.

Hence, by developing our own rocket technology, the nation will benefit from the capability to launch our own satellites such as weather, astronomical, and communication satellites. Also from the military point of view, this could lead to the development of conventional rocket missiles and even more sophisticated modern ballistic missiles [4].

2. Methodology

Theoretical analyses have been conducted on the potassium nitrate-carbon-sulphur mixture to obtain the chemical formula, characteristic formula, molecular weight, stoichiometric ratio, specific heat gas ratio, reaction equation, characteristic velocity, effective exhaust velocity, and thrust force coefficient. Analyses were done using theoretical calculations and the computer program CHEM.

Propellants were prepared using the compression method, which was found to be the most suitable method to obtain a more compact propellant. This method enables the removal of almost all of the trapped air inside the propellant grains, leaving only less than five percent behind. The absence of air bubbles would produce a low burning-rate and high mass propellant as desired [5].

An in-house designed and constructed propellant test rig was used for burning-rate tests at atmospheric pressure. The test rig consists of propellant stand, igniter, and automatic timer. From the burning-rate tests at atmospheric pressure, burning-rate data were obtained. In general, propellant performance can be approximated from burning-rate data at different pressures.

3. Characteristic Analysis and Propellant Burning

To obtain the values for characteristic parameters, the computer program CHEM, from CP Technologies, was used. The input data were 66.45 g of potassium nitrate, 17.76 g of carbon, and 15.79 g of sulphur. A sample of the CHEM input screen is shown in Figure 1. However the CHEM input screen which is shown below is only an example without including the binder composition. The input data were:

Room temperature	= 298 K
Chamber pressure	= 500 psia
Exhaust pressure	= 14.7 psia

The results from CHEM are given in Table 1.

Table 1 Results from CHEM

Parameter	Value
Molecular weight, M	70.08 g/mol
Chamber specific heat, K_c	1.1228
Exhaust specific heat, K_e	1.1228
Specific impulse, I_{sp}	88.6 s
Characteristic velocity, C^*	1844.2 ft/s (562.11 m/s)
Throat temperature, T^*	956 K
Throat pressure, P^*	19.93 atm
Throat area to mass flow-rate ratio, $A/\dot{m}$	0.11466 in^{2}s/lb

From these output data, the characteristic parameters were calculated, as shown in Table 2.

Propellant stoichiometric mixture was determined by balancing the equation of the chemical reactions between potassium nitrate, sulphur and carbon. The following simplifying assumptions about the chemical reactions were made:

1. The chemical reactions involve potassium nitrate, sulphur and carbon only. The surrounding air was not taken into account.
2. The products of the chemical reactions were carbon dioxide (CO_2), nitrogen (N_2), potassium oxide (K_2O), carbon monoxide (CO), carbon sulphate (CSO), carbon sulphide (CS_2), potassium cyanide (KCN), and potassium (K). No other component was produced, to simplify the equation.

Table 2 Characteristic parameters calculated

Parameter	Value
Gas constant, R	118.64 J/Kg-K
Mass flow factor, C_m	1.779 x 10^{-3} s/m
Effective exhaust velocity, C	869.166 m/s
Thrust coefficient, C_f	1.546

With these assumptions, the balanced chemical reaction equation is as shown below:

$$4KNO_3 + 3S + 9C \rightarrow 4CO_2 + 3/2\ N_2 + K_2O + 2CO + CSO + CS_2 + KCN + K \quad \text{…(Eqn. 1)}$$

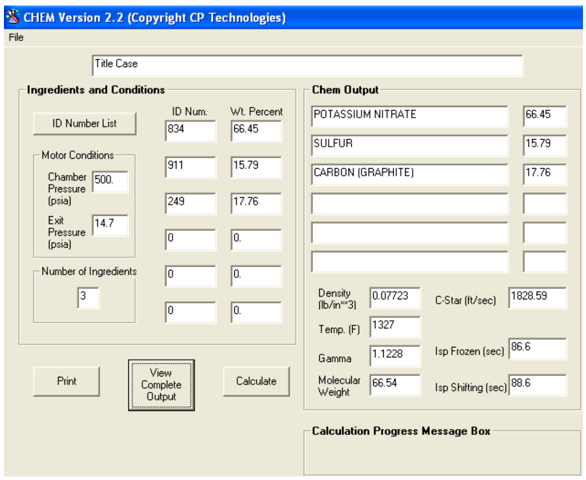

Figure 1 Sample CHEM input screen

In other words, propellant stoichiometric condition happened at the composition of 66.45% potassium nitrate, 15.79% sulphur and 17.76% carbon.

Table 3 Burning-tests results from different compositions of potassium nitrate, sulphur and carbon mixtures

Set	Composition (%)			Time (s)				r
	KNO_3	S	C	t_1	t_2	t_3	t_p (ave)	(cm/s)
3	64.45	15.79	19.76	40.880	48.822	46.464	45.389	0.2203
4	66.45	15.79	17.76	30.962	37.957	40.799	36.573	0.2734
5	68.45	15.79	15.76	55.480	54.487	40.519	50.162	0.1994
6	70.45	15.79	13.76	70.147	80.608	62.373	71.043	0.1408
7	72.45	15.79	11.76	79.117	79.244	81.400	79.920	0.1252

4. Propellant Preparation

The first step in propellant preparation was to grind and mix both potassium nitrate and sulphur together to obtain a homogeneous mixture with the desired weight and particle size. An in-house propellant mixer was designed and constructed for this purpose as shown in Figure 2. This propellant mixer consists of an electrical motor rotating an aluminum container for the propellant mixture. Inside the container, there is a cylindrical roller to grind the mixture to the desired fineness with uniformity. The speed of rotation maybe varied using a switch controlling the motor. Also this mixer is controlled by a timer.

Figure 2 Propellant mixer

Potassium nitrate and sulphur were weighed and mixed according to the specified composition ratios in the aluminum container. The mixing process was done for about 30 minutes to ensure that fine grains were obtained. A fine texture of the materials would produce a better propellant burning-rate. To ensure grain size uniformity a sieve was used, with mesh size of ±0.5 mm.

This mixture was then mixed with carbon according to the specified weight ratio, followed by 22% of binder. This whole process was done at room temperature.

Once the mixture was even, it was poured into the propellant casing. The propellant mixture was then compressed inside the casing using a cylindrical rod under a predetermined compression pressure applied by a hydraulic compressor. Pressure, which was gauged using a load cell, was applied for approximately five minutes to ensure trapped air inside the mixture was released. The propellant compression rig set-up is as shown in Figure 3.

The propellant was then cured inside an oven at a temperature of 64˚C for three days to ensure that the binder was fully dried and became integrated into the propellant structure. After this the propellant became ready for testing.

Figure 3 Propellant compression rig set-up

5. Burning-Rate Tests

The propellant burning-rate test is the simplest propellant performance test to be carried out, by using a small propellant rod or strand. The propellants are shaped into rods 10mm in diameter and with a length of 210 mm. However, for the burning-rate test, only 100 mm of the propellant length was considered, as shown in Figure 4.


Figure 4 A 210 mm propellant rod with markers 100 mm apart

Two markers were placed on the propellant at a distance of 100mm apart using adhesive tapes. Gasket pads and fuses were placed at the markers. The gaskets were to protect the fuses from melting prematurely due to the high temperature or sparks from the burning propellant. The test rig is shown in Figure 5.

The idea of this set-up was to measure the time taken for the propellant to burn from the first marker to the second marker.

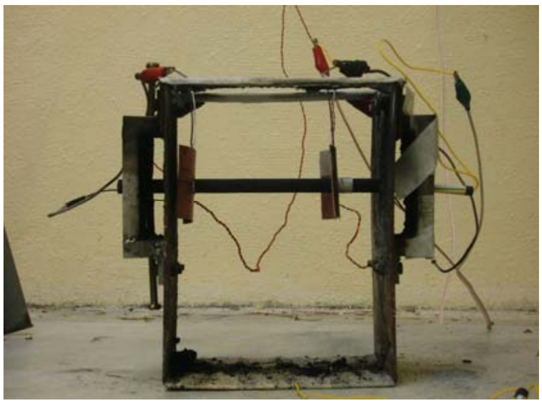
Figure 5 Test rig for propellant burning-rate

6. Results and Discussions

Seven sets of propellants with varying compositions have been produced for the burning-rate tests. Sets 1 and 2, of carbon contents 23.76% and 21.76% respectively, have been rejected after they were found to be fragile and sensitive to handling due to their high carbon contents. The remainder, with carbon contents less than 20%, however, exhibited better structural properties.

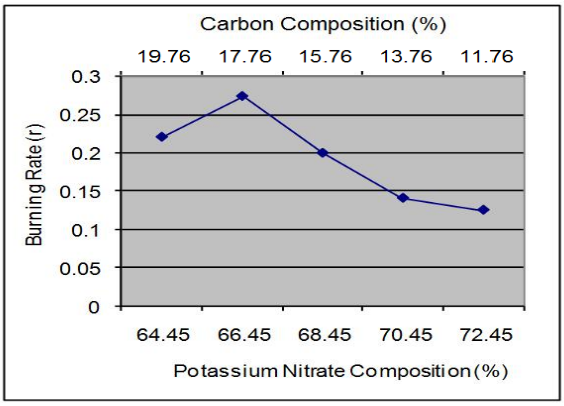

Figure 6 The results of burning-rate test with different chemical compositions

For these tests the sulphur composition was fixed at 15.79% and the binder at 22%, so that only the effects of 15.79% the oxidant (potassium nitrate) and the fuel (carbon) towards burning-rate can be studied.

Figure 6 shows burning-rate versus percentages of carbon and potassium nitrate in the propellant. It can be seen that the peak burning-rate occurred when the composition was 66.45% potassium nitrate and 17.76% carbon. The burning-rate achieved for this was 0.2734 cm/s.

From this study, the propellant characteristic parameters related to the composition giving the peak burning rates were as shown in Table 4.

This clearly showed that the peak burning-rate was achieved at propellant stoichiometric mixture, at the composition of 66.45% potassium nitrate, 15.79% sulphur and 17.76% carbon, which was in line with the theoretical calculations as shown in Eqn. 1 earlier.

The results also indicate that any fuel addition which is above the balanced limits would not be used in the burning process and hence would be wasted.

Table 4: Propellant characteristic parameters for the peak burning rate composition

Parameter	Value
Carbon content	17.76%
Potassium nitrate content	66.45%
Sulphur content	15.79%
Binder content	22.00%
Propellant burning-rate, *r*	0.2734 cm/s
Propellant density, ρ_p	2.1229 g/cm^3
Mass flow rate, $\dot{m}$	0.4558 g/s
Weight flow rate, W_p	0.00447 N/s

7. Conclusions

From the burning-rate tests performed, the peak burning-rate obtained was 0.2734 cm/s in the atmosphere, for propellant with a composition of 66.45% potassium nitrate, 15.79% sulphur, and 17.76% carbon. These proved that propellants at stoichiometric mixture gave a good performance compared to other propellant mixtures.

For the tests done, the basic materials used for producing solid propellants were only the oxidizer and the fuel. For further research, other additives and burning enhancers such as nitrocellulose, hydrazine nitrate and urea can be added to the propellant and studied for their effects on propellant performance characteristics.

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