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On the Characterization of Propulsive Powders: Optimization of the Operating Pressure According to the Combustion Surface. Case of Congolese Propellants

Ponga-Abwe-P.G.A

Researcher in Engineering Science and Space Engineering, Department of Chemistry and Applied Metallurgy
Higher Institute of Applied Techniques of Lubumbashi, Democratic Republic of Congo

Abstract: ***Starting from the Chinese propellants - our reference - of composition well known and different from that of the Congolese propellants, we have in the course of this study, demonstrated by means of gas flow equations and conditions of isentropic expansion that it was possible to provide Congolese propellants with performances similar to those of the Chinese propellant, despite their lower energy characteristics compared to those of the Chinese propellant, by playing on a single physical parameter independent of the composition of the propellant; the combustion surface. This in order to consider a possible substitution of the Chinese propellant by the Congolese propellant for the same rocket engine.***

Keywords: Area, Combustion, isentropic, Performance, Propellant

1. Introduction

In the development of propellant powders for self-propelled engines, several parameters are taken into account for obtaining the most optimal performance characteristics. Some of these characteristics are dependent on the chemical and physical properties of the constituents, while others are independent of the physical properties of the propellant; we investigated the operating pressure in a Chinese-made rocket engine loaded with Congolese-made propellant; which can be significantly influenced by the combustion surface.

The interest of this study is to be able to justify the analogous behavior of a rocket engine designed for a type of propellant and which will have to be used for another type of propellant with weak energetic characteristics by playing on the only physical parameter: "the combustion surface ".

Starting from the theory of the flow of compressible gases and the system of partial differential equations governing the flows of fluids and Knowing that all these theories derive from the application of the general principles of physics which are:

The conservation of the mass.
Conservation of the momentum.

Energy conservation
Based on the simplified equations of Navier-Stockes and the tests carried out on the combustion of several Congolese solid propellants, we have circumscribed for calculation, the characteristics of one of the Congolese compositions to study the variation of the operating pressure. Function of the variation of the combustion surface. Thus we varied the combustion surface of the individual blocks from 626,9952cm^{2}to 900,2223 cm^{2}and determined the variation of the pressure. Parameter used to compensate for low energy performance characteristics of Congolese propellant.

2. Theory and Methodology of Research

2.1 Equations describing the flow of gases

All the calculations and hypotheses used in our study are based on the simplified equations of Navier-Stockes corroborated by the experimental data of several researchers. Where We Consider a Supersonic Flow of a Perfect, Isentropic, Completely Established, Two-Dimensional Fluid and Subject to Negligible External Forces.

Assuming that the flow of gases in a burning powder channel is described by the following simplified equations [1][2][3][4][5][6][7]:

1) The state equation of flue gases:

$$p = \frac{R}{m̡}\rho T \tag{1}$$

2) Assuming that the ejection gases respect the law of perfect gases.
   Where: p, R, T, ρ and m̡ respectively represent the pressure, the perfect gas constant, the temperature, the specific gravity and the average molecular mass of the combustion gases.L ’équationd’ énergie :

$$p = d\frac{u^2}{2} + dH = 0 \tag{2}$$

3) In which knowing that all the combustion gases (crossing the x-axis x and the lateral surface of the block) come from the same isentropic stopping state, one has $u = 0\ and\ T = T_0$and that the temperature T_0varies little along the canal, that is, $dH = C_p dT$ (H is the enthalpy of the mass unit of gases). The energy equation becomes:

$$udu + C_p dT = 0 \text{ Ou en intégrant } \frac{u^2}{2} = C_p(T_0 - T) u \text{ est la vitesse des gaz.}$$

4) The continuity equation:

$$d(\rho u S) = P.\delta.v(p,u).dx \tag{3}$$

With δ the density of the powder, v the linear velocity of combustion under the pressure p of the powder swept by a gaseous stream of velocity u in the slice dx of the lateral surface.

5) The equation of momentum:

$$d(\rho u^2 S) = -Sdp \qquad (4)$$

That takes into account the contribution of material in each section.

Equations (1), (2), (3) and (4) form a system of equations which makes it possible to determine the characteristic functions P, ρ, T *and* u defining the flow of gases.

Les équations (1), (2), (3) et (4) forment un système d'équations qui permet de déterminer les fonctions caractéristiques P, ρ, T *et* u définissant l'écoulement des gaz.

Using the local Mach number (M) which is the ratio of velocity u to local velocity of sound (a).

$$.a = \sqrt{\gamma \frac{R}{m} T} M = \frac{u}{\sqrt{\gamma \frac{R}{m} T}} \qquad (5)$$

And placing ourselves at the limited conditions, which are:

The velocity of the gases in the section$x = 0$ is zero. That is$u\,(0) = 0\,; M(0) = 0\,$;;

1) The isentropic stopping temperature of the gases is constant and equal to the combustion temperature of the powder consideredT0. That is to say:

$$udu + C_p dT = 0 \text{ Ou en intégrant } \frac{u^2}{2} = C_p(T_0 - T)$$

2) The gaseous flow from the section$x = l$ is isentropic and indirectly dependent on the neck area of the nozzle S_c so that M_1 the local Mach number in this section is set only by the ratio of the section S_1 of the channel at this point to section S_c of the collar. That is to say:

$$\frac{S_1}{S_c} = \frac{1}{M_1}\left[\frac{1+\frac{\gamma-1}{2}M_1^2}{\frac{\gamma+1}{2}}\right]^{\frac{\gamma+1}{2(\gamma-1)}} \; if \; \frac{S_1}{S_c} > 1 \text{ Et } M_1 = 1 \; si \; \frac{S_1}{S_c} \leq 1 \; so \; M(l) = M_1$$

All these equations and boundary conditions are established to show how fast the gas velocities can reach sufficiently significant and even very high values at certain points in the chamber.

3. Result Analyses

Influence of the increase of the combustion surface on the operating pressure of the rocket engine.

Dimensional characteristics of the propellant blocks used
Chinese Propellant

- Weight: 500,72g
  Length: 40cm
  Outsidediameter: 4cm
  Insidediameter: 8mm
  Combustion surface: $626{,}9952 cm^2$
- Number of blocs : 7
- Total combustion Surface : $7\ x\ 626{,}9952 cm^2 = 4388{,}9664\ cm^2$

Congolese Properllant
Weight: 700 g
Length: 40 cm
Outside diameter: 5 cm
Inside diameter: 19 mm
Burning surface: $900{,}2223\ cm^2$
Number of blocs: 5
Total combustion surface: $5\ x\ 900{,}2223\ cm^2 = 4501{,}1115 cm^2$

It has been shown that all these equations and conditions describing the flow phenomenon could be expressed only in terms of M ($Mach\ number$) in a single equation of form [1]:

$$\frac{\gamma P_0}{a_0 \beta P_0^{\alpha}} \int_0^{M_1} \frac{f(M)}{1+E(M)} dM = \delta \frac{P_0 l}{S_0} \qquad (6)$$

We can see that in the second member of this equality $P_0 l l$ represents the total surface S in combustion of the block. Knowing that we usually define by:

- The ratio $\frac{S_t}{S_c} = K$engine operating throttling;
- The ratio $\frac{S_t}{S_1} = K_p$the block's own throttling;
- The factor $E(\frac{M_1}{n})$the relative increase in the rate of burning of the powder due to erosion.
- To estimate the operating pressure of our engine (using the ratio $\frac{P_0}{P_0^0}$) we have made the following assumptions:
- All dimensional parameters of the motor and the nozzle do not vary, The Mach number is the variable parameter on which the variation of the surface influences the boundary conditions and varies between 0 and 1 ($0 \leq M \leq 1$);
- The ratio $\frac{K_p}{K} = \frac{1}{M_1}\left[\frac{1+\frac{\gamma-1}{2}M_1^2}{\frac{\gamma+1}{2}}\right]^{\frac{\gamma+1}{2(\gamma-1)}}$ which is the inverse of the surface ratio, accounts for the superposition of erosion effects and the throttling of the propellant block with consequent incidence on the operating pressure.
- The surface of the neck remaining invariable, only the total combustion area of the block can affect the speed of the combustion gases.
- At ordinary temperature we will take for the usual pressure range (20 à 300 Kg/cm^2) [1],

$$\alpha = 0{,}654;\ \beta = 0{,}411; \gamma = 1{,}20\ etn = 2$$

In relation (5) we find that M is as high as if the numerator is large or if the denominator is small. For the first condition, the speed is likely to be modified in practice to vary M by increasing the volume of the combustion gases, and therefore by increasing the combustion area of the propellant.

This is also easily perceptible in equation (6) by the term $\frac{P_0 l}{S_0}$ witch represents this ratio of surfaces. So for fixed values of M, we calculated the values of the ratio$\frac{K_p}{K} = \frac{1}{M_1}\left[\frac{1+\frac{\gamma-1}{2}M_1^2}{\frac{\gamma+1}{2}}\right]^{\frac{\gamma+1}{2(\gamma-1)}}$ As shown in Table 1 below:

Table 1: *Variation of the ratio* $\frac{K_p}{K}$, $\frac{S_t}{S_c}$ *and* $\frac{P_0}{P_0^0}$ *according the Mach number*

Value of M	The ratio $\frac{K_p}{K}$	The ratio $\frac{S_t}{S_c}$	The ratio $\frac{P_0}{P_0^0}$ *
a	3,258	0,306	1,562
0,4	1,615	0,619	2,530
0,6	1,198	0,834	3,604
0,8	1,040	0,960	4,977
1	1	1	6,205

*Values of the pressure ratio (with throttling effect and without throttling effect) calculated on the basis of the values obtained by Paul TAVERNIER and Jean BOISSON [1].

The values of $\frac{S_t}{S_c}$ and $\frac{P_0}{P_0^0}$,indicate that these ratios increase with the increase of the values of M following the increase of the combustion surface which increases the operating pressure which reaches values up to one and a half times the initial values.

All things remaining equal (influence of the block's own strangulation, the influence of the erosion of the powder), we proceeded to the firing tests which gave us corroborating and confirming results.

In fact, the combustion surface of a Chinese propellant block is $626{,}9952cm^2$ while that of the Congolese propellant block is $900{,}2223\ cm^2$. For a machine with a chamber of burning 4000 mm in height, 105 mm in internal diameter and 18 kg in weight, we used 7 blocks of Chinese propellant and 5 blocks of Congolese propellant reaching a maximum range respectively of 15 Km and 12 Km.

4. Conclusion

Knowing the low-energy characteristics of the Congolese propellant vis-à-vis the Chinese propellant, it is obvious that only the importance of the large combustion surface of the Congolese rocket block allowed us to reach the performance values close to those of the Chinese propellant.

Knowing that the function of the nozzles is to convert the thermal energy from the combustion chamber into kinetic energy, they can thus convert the gases of low speed, pressure and high temperature gas very high speed but low pressure and temperature.

We therefore believe that since it is difficult at this stage to significantly increase the performance of our propellants by modifying their compositions, we can give them a gain in compensatory energy just by giving them an appropriate shape and adapted to a well-defined rocket engine that can give them a combustion surface to burn the amount of propellant per unit of time necessary for propulsion.

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