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PARAMETERS AFFECTING THE EROSIVE BURNING OF SOLID ROCKET MOTOR

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ABSTRACT

Increasing of velocity of gases inside solid rocket motors with low port-to-throat area ratios, leading to increased occurrence and severity of burning rate augmentation due to flow of propellant products across burning propellant surfaces (erosive burring), erosive burning of high energy composite propellant was investigated to supply rocket motor design criteria and to supplement knowledge of combustion phenomena, pressure, burning rate and high velocity of gases all of these are parameters affect on erosive burning, the used motor in the tests is 2 inch motor, and a modified one with different grain dimensions, the tests show the pressure time curve and the erosive burning phenomena.

KEY WORDS

Erosive burning, solid propellant.

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INTRODUCTION

The erosive burning refers to the increase in the propellant burning rate caused by high velocity flow of combustion gases over the burning propellant surface. It can seriously affect the performance of solid propellant motors. It occurs primarily in the port passages or perforations of the grain as the combustion gases flow toward the nozzle. It is more likely to occur when the port passage cross-section area is small relative to the throat area with a port-to-throat area.

Erosive burning increases the gas mass flow and thus also the chamber pressure and thrust during the early portion of the burning, for a particular motor, as soon as the burning enlarges the flow passage (without a major increase in burning area), the port area flow velocity is reduced and erosive burning diminishes until normal burning will again occur. Erosive burning causes also early burn out of the web usually at the nozzle end, and exposes the insulation and casing to hot combustion gas for a large period of time. This usually necessitates more insulation layer thickness (and more inert mass) to prevent local thermal failure.

A relatively simple model for erosive burning based on heat transfer was first developed in 1956 by Lenoir-Robillard [1] and has since been improved and used in motor performance calculations. The model has the simplified form:

$$r_t = r_o + r_e \qquad (1)$$

where r_t is the total burning rate, r_o is the base burning rate and r_e is the burning due to erosive burning rate.

$$r_t = ap^n + \alpha G^{.0.8} L^{-0.2} e^{(\frac{-\beta * r_t * \rho * p}{G})} \qquad (2)$$

where

$$G = \frac{m^{\cdot}}{A_p}$$

α is the erosive burning coefficient, *G* is the mass flux*,* *L* is the initial grain length, β is the erosive burning pressure coefficient, and ρ_p is the propellant density, A_p is the port area and, d is the inner diameter of the grain.

From Ref. [2], the burning rate equation is represented by:

$$r_t = ap^n + \alpha G^{.0.8} d^{-0.2} e^{(\frac{-\beta * r_t * \rho * p}{G})} \qquad (3)$$

where equation (2) used when depending on the length of the propellant and equation (3) when use the inner diameter of the propellant.

Figure 1 shows the effect of erosive burning, whereas Fig. 2 shows the deviation of the course of pressure variation with time due to erosive burning.

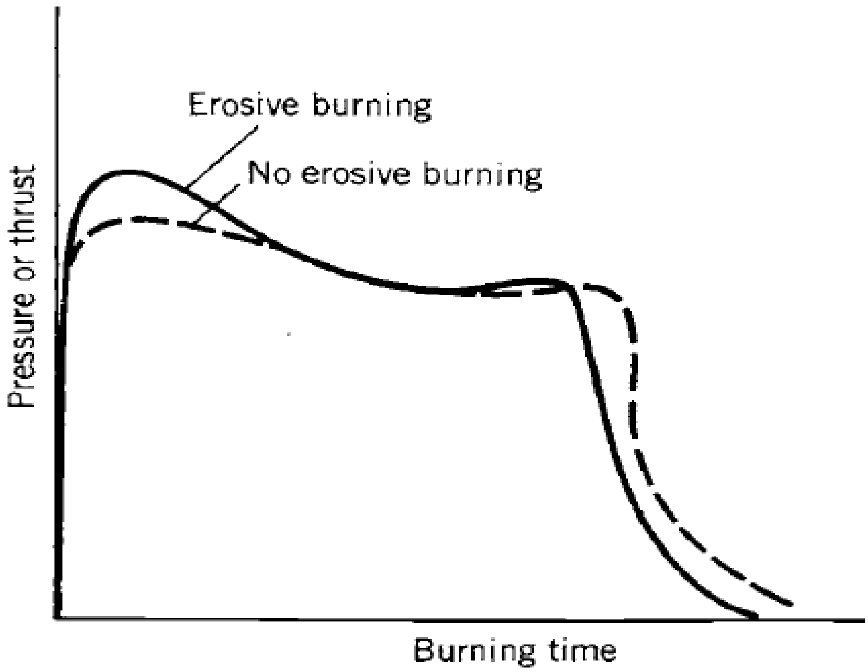

Fig. 1. Erosive burning.

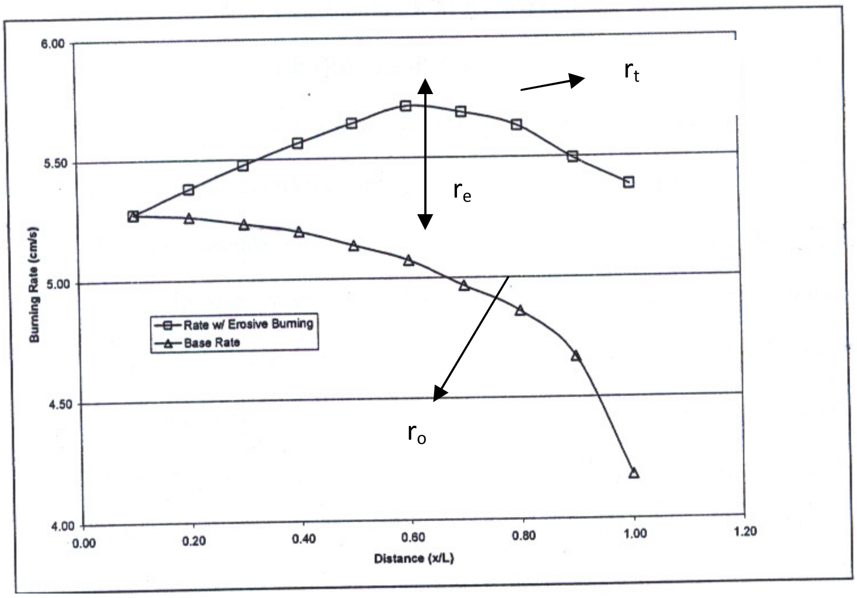

Fig. 2. Erosive burning rate compared to base rate [3].

FACTORS AFFECTING EROSIVE BURNING

Cross flow velocity and pressure, propellant initial temperature, free stream gas temperature, normal burning rate, metal addition, compressibility, oxidizer particle size, rocket motor size, propellant characteristic, mass flux, Reynolds number

USED MOTOR IN EXPERIMENTAL WORK

The two-inch motor used for performing these tests is illustrated in Fig. 3. The main task of the test motor is to determine the burning rate of the propellant, combustion index and burning rate coefficient calculated by fitting curve to determine the burning law. A tubular grain from composite propellant is cast inside a special casing so that the burning is allowed only from inside and from the two ends. The main output of the test is the pressure time-curve.

Fig. 3. Two-inch motor.

RESULTS AND DISCUSSIONS

Group 1 Test Results

The decrease in the port diameter of the grain is one of the main parameters that affect the erosive burning. In the present work, modified grains with different port diameters of 34, 15, 12.5 and 10 mm and same length of 108 mm, respectively are prepared. It is found that, the decrease in diameter increases the velocity of gases parallel to the burning surface which causes erosive burning in the used propellant consisting of ammonium Perchlorate (68-70 %) aluminum powder (16-18 %) and binder (13-15 %). He same results are obtained for the composite propellant [4, 5].

The measured results for the different ports of the propellant grains are listed in Table 1. Figure 4 plots the time history of pressure due to burning a grain of propellant having a diameter of 34 mm whereas; fig. 5 plots the same history for a grain having 10 mm in diameter.

Table 1. Output data of group 1 of tests with different port diameters.

D [mm]	Temp [ºC]	Throat [mm]	Wt [Kg]	T_D [ms]	T_B [ms]	T50% [sec]	Pmax [Bar]	IPT [Bar]	Pav [Bar]	P50% [Bar]	R50% [mm/s]	C* [m/s]
34	21	7	.375	20	2.24	2.13	71	151	67	71	6.1	1553
34	21	7	.360	20	2.23	2.09	69	145	65	69	6	1556
15	21	7	.512	12	4.06	3.9	86	199	48	50	5.7	1498
15	21	7	.512	573	4.05	3.9	61	198	49	50	5.7	1491
12.5	21	7	.503	10	4.31	4.1	55	183	42	43	5.6	1401
12.5	21	7	.514	12	4.2	4	115	193	45	47	5.8	1444
10	21	7	.520	209	4.46	4.34	90	194	43	44	5.7	1442
10	21	7	.514	387	4.43	4.32	74	197	43	45	5.7	1475

P

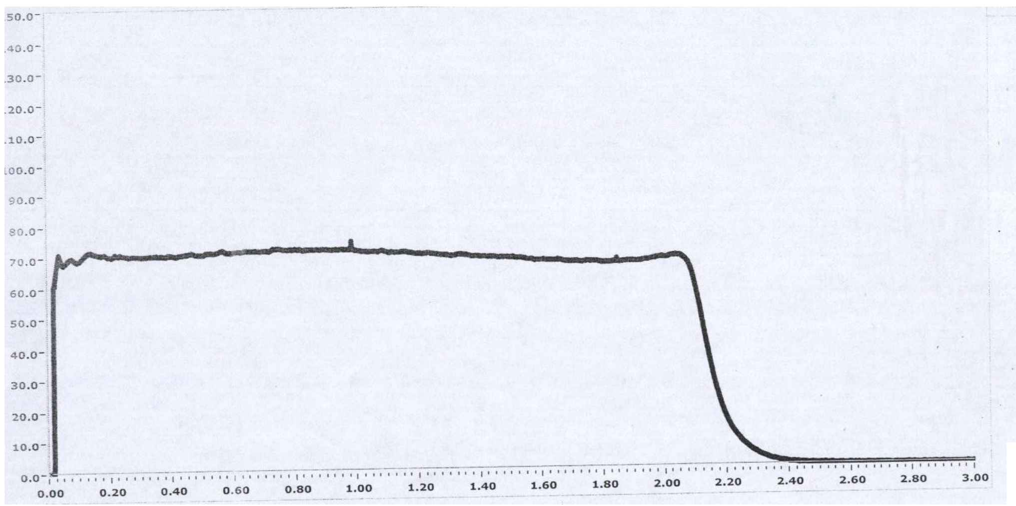

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Fig. 4. Pressure time curve at port diameter 34 mm.

P

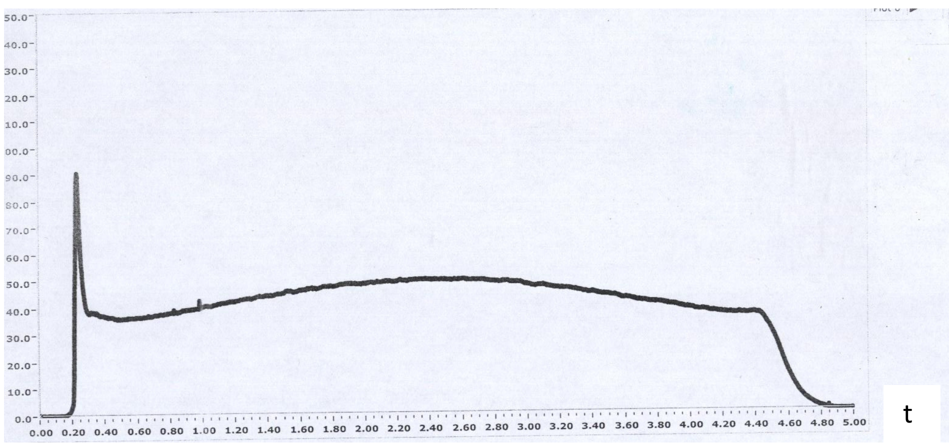

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Fig. 5. Pressure time curve at port diameter 10 mm.
(The curves 4 and 5 are from the experiment sheet)

This increase in the beginning of the propellant burning is due to using greater mass of the black powder.

From the calculation of the parameters of the test and Thermochemical calculation when decrease the port diameter and make the critical diameter constant the velocity of gases increase from 37 to 300 m/s, and the erosive ratio from 1 to 1.36.

This data is not enough to investigate the phenomena of erosive burning. In group 3 of tests the length of the rocket motor will be increased to investigate the phenomena of erosive burning.

Calculation of Burning Law Parameters

By taking the value of P 50% and r 50% from the experiment and put them in excel sheet and by using the curve fitting and draw the liner equation of these values we determine the burning law, we convert the values of P50% and r50% to Log values then calculate the burning law.

Computer Program

The computer program is capable of calculating performance of tabular grain and draw pressure time curve, the program computes in SI units which are used to calculate the main parameters and performance of solid propellant rocket motor, the program may be used for rocket of all size, the main task of the program is to draw the P-T curve and to calculate and see the phenomena of the erosive burning.

We will divide the web thickness into equal segment for easy calculation and to determine the output with minimum error.

MODIFIED TWO-INCH MOTOR

Modified two-inch motor consists of 3 segmented grains each one 108 mm (Fig. 10) by separating them using a small ring similar to the outer case each ring of width 10 mm and assembled together [6]. The results will be show later.

The only change of the modified 2 inch motor is to change the length of the motor case; all the other dimensions are the same as the standard 2 inch motor.

Also, by changing the critical section of the nozzle we can get different pressure and different erosive ratio.

Results of Modified Two-Inch Motor of SP Type 3 (D_{cr} = 9 Mm).

Experimental results

The length of grain = 324 mm divided into 3 equal parts of solid propellant each one 108 mm separated by 2 steel rings each one of width 10 mm, the outer diameter = 60 mm and the inner diameter = 10 mm, nozzle critical section = 9 mm.

In group 2 of tests the composition of propellant changed so the burning law of the propellant changes also.


Fig. 6. Propellant inner diameter 10 mm and ring of width 10 mm.

Fig. 7. Combustion chamber of modified two-inch motor.

Fig. 8. Parts of modified two-inch motor.

Fig. 9. modified two-inch motor.

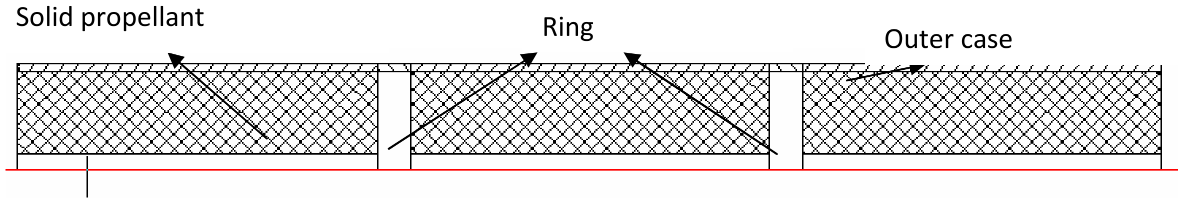

Fig. 10. Segmented propellants in rocket motor**.**

The pressure at the head end of the grain is measured experimentally while pressure at nozzle end of the grain is predicted from the theoretical model.

Table 2. Results of modified two-inch motor.

Gr. No.	Temp [ºC]	Throat [mm]	Wt [Kg]	T_D [ms]	T_B [ms]	T50% [sec]	Pmax [Bar]	IPT [Bar]	Pav [Bar]	P50% [Bar]	R50% [mm/s]	C* [m/s]
1	20	9	1.573	28	2.992	2,557	187	334	111	130	9.7	1352

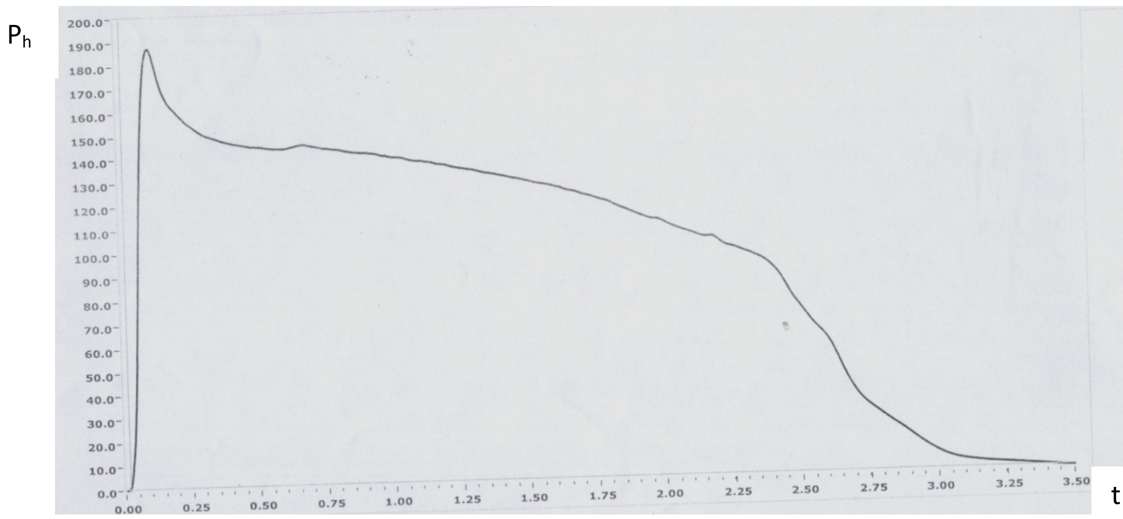

Fig. 11. Pressure time curve of type 3 of propellant.

(This curve is from the experiment sheet)

In the beginning of the ignition the pressure increases in small port area and the velocity of gases increased which causes erosive burning.

Very important conclusion could be drawn concerning the effect of very high pressure, very high velocity and the erosive burning. The critical section of the nozzle increases with respect to time, by measuring the critical section of the nozzle before and after burning, the critical section increase from 9 mm to 10.5 mm. it is observed that an increase of the critical area of about 25 %, which result in drop in the pressure at the end of burning.

So there is a factor taken during calculation of the critical area which is the increase in the critical section with respect to time.

Comparison between Experimental and Theoretical Results

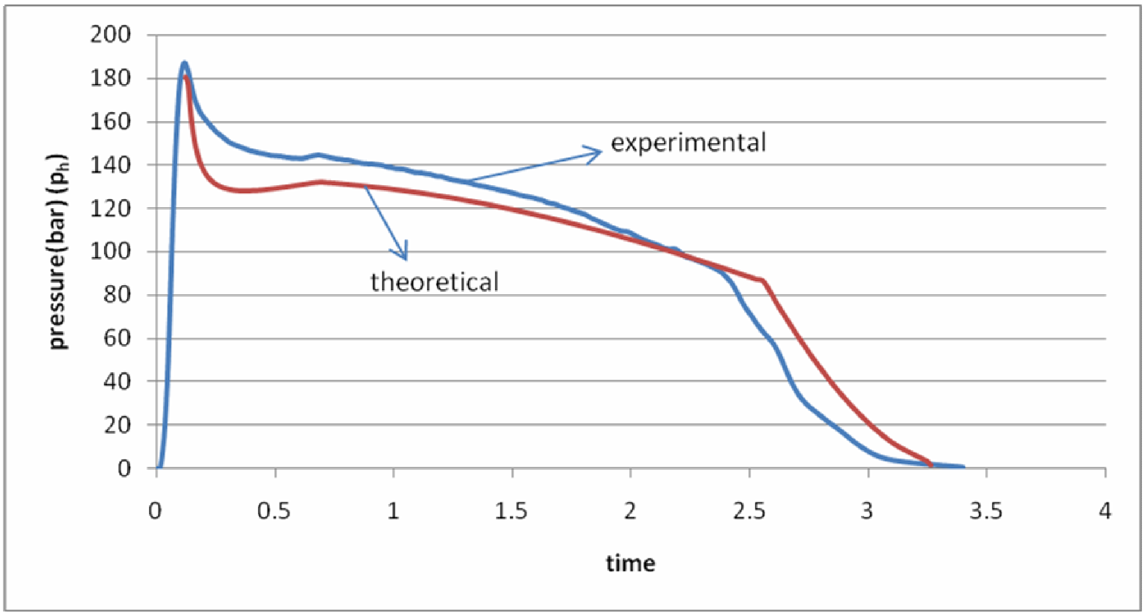

Fig. 12. Experimental and theoretical pressure time curves.

The assumption of the burning rate is taken to be linear along burning, so there is an error between the experimental and theoretical values.

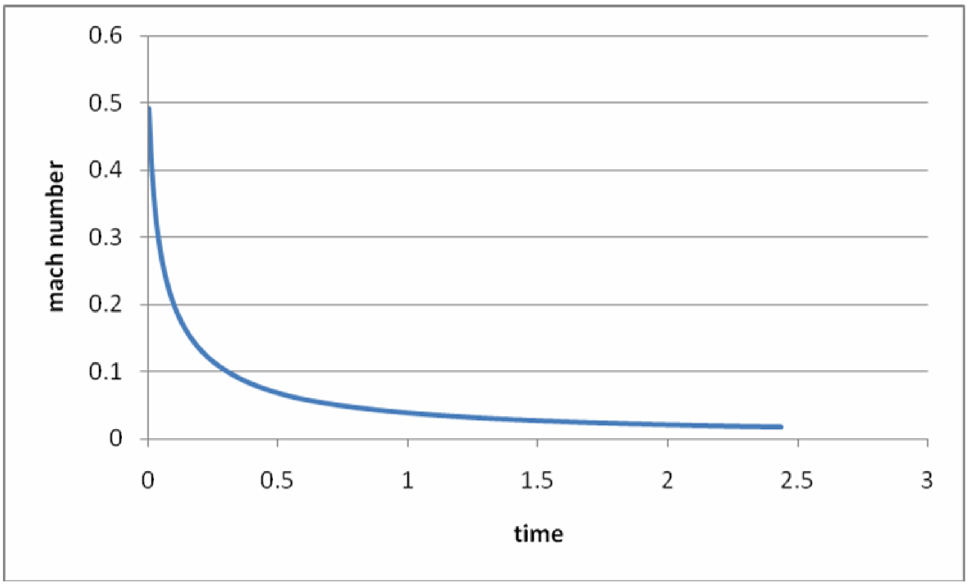

Fig. 13. Mach number versus time.

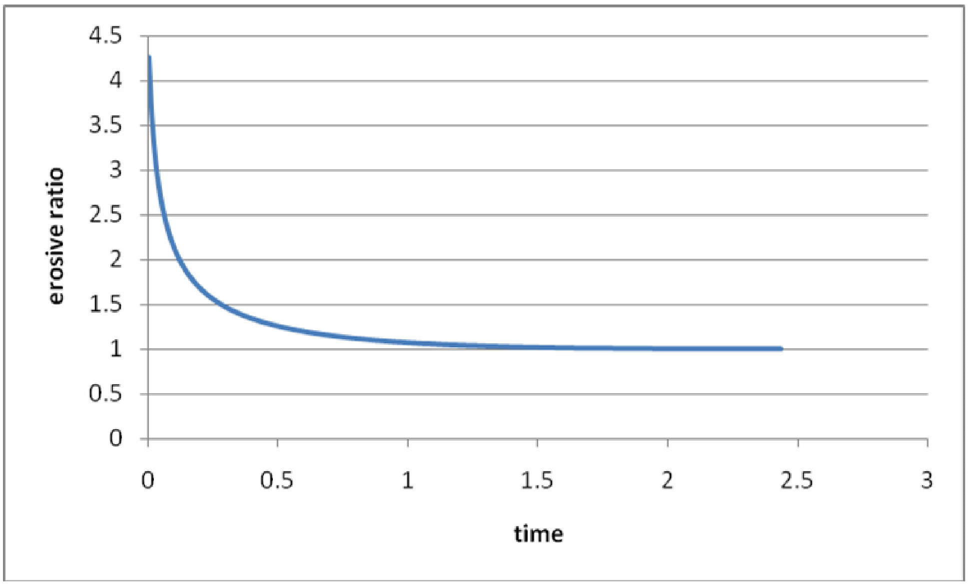

Fig. 14. Erosive ratio versus time.

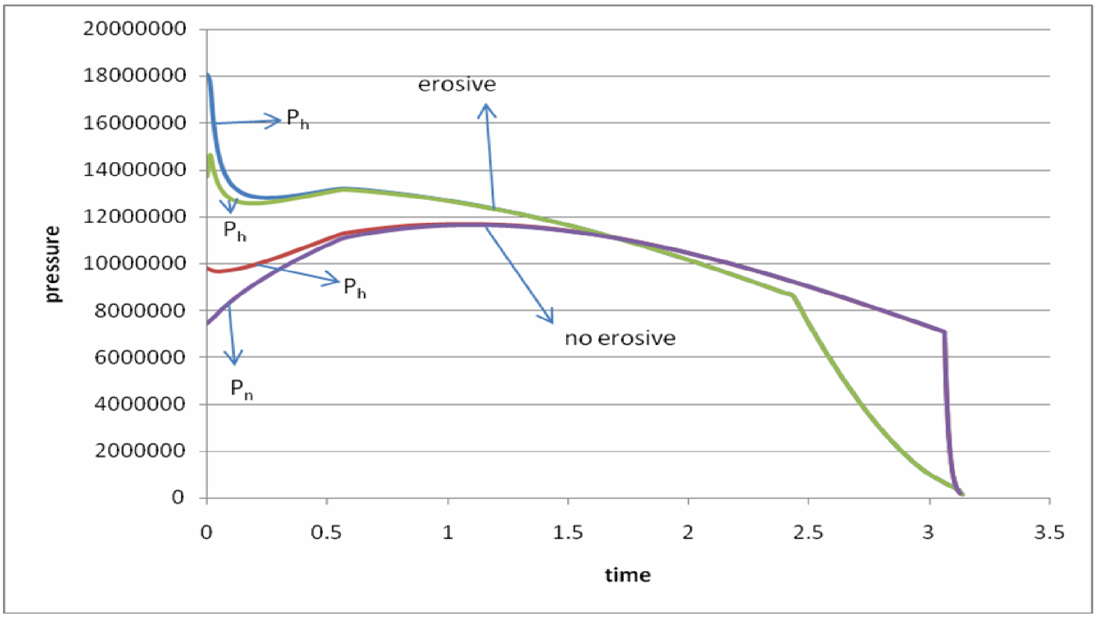

Fig. 15. Pressure time cure with and without erosive burning.
(In case of no erosive α is taken equal to zero. (α = 0))

The difference between the pressures at the head end and nozzle end of the grain is due to erosive burning, where at erosive the mass discharge is increased which causes this difference.

CONCLUSION

The flow of combustion gaseous product at high velocity parallel to the surface of solid propellant is often found to lead to a significant increase in burning rate. This phenomenon is referred to as erosive burning and the increase in burning rate is known as the erosive burning rate. Studying the erosive burning is very important for better understanding of effects on the performance of the rocket motor. Good design of solid propellant rocket motor should account for possible erosive burning in order to thoroughly predict the pressure-time history and act accordingly for safe and best performance.

During the present study test rocket motors of standard and modified configurations were designed, manufactured and tested at different working conditions to investigate effects on the burning rate and their impact on the performance.

In parallel, a theoretical model of the burning rate was developed and the proposed numerical solution was implemented as a computer code capable to predict the behavior of the combustion pressure. In particular the code treats the case of erosive burning.

The comparison between theoretical and experimental results showed fair agreements, which proves the validity of the code.

The following results could be drawn from the present investigations:

1- By varying the grain length-to-diameter ratio or the critical diameter, in order to change the mass flux parallel to the surface, it was possible to generate experimentally and theoretically the condition of erosive burning. It was possible to predict the threshold velocity above which the erosive burning occurs. For a given type of propellant the erosive ratio and threshold velocity are dependent on the combustion pressure. In the present study, it was found that with the higher pressure, lower erosive ratio, lower threshold velocity and higher threshold flux were encountered.

2- With smaller value of (a, n) in the burning law, higher erosive ratios are encountered.

3- Some sort of oscillation occurs in the theoretical model. This may be attributed to the admitted values of the error considered in Mach number, mass balance and burning rate. More runs have been done for smaller values of permitted error between successive iterations and finally smooth curve could be reached. Clever choice of error values should be considered after several trials to get smooth variation of produced curve.

4- The erosion at the nozzle critical section was measured and considered in the theoretical prediction. It has a significant effect on the combustion chamber pressure and consequently on the burning rate.

The code can be trusted for usage in novel designs, and further investigations, saving numerous firing tests which are costly, time consuming and risky.

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