SNS COLLEGE OF TECHNOLOGY
(An Autonomous Institution**)**
COIMBATORE–35

DEPARTMENT OF AEROSPACE ENGINEERING

SPACE PROPULSION – Unit III
CRYOGENIC ENGINEERING

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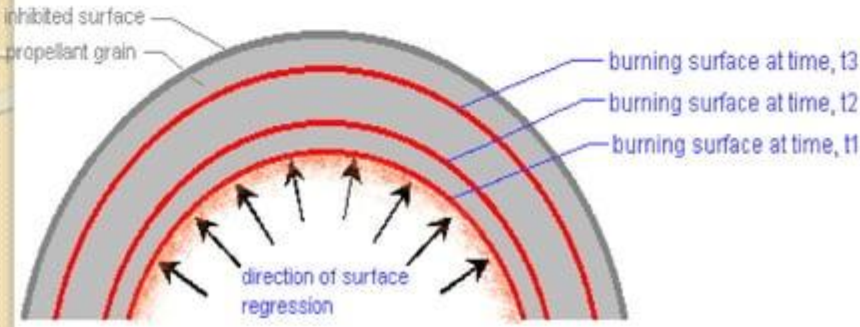
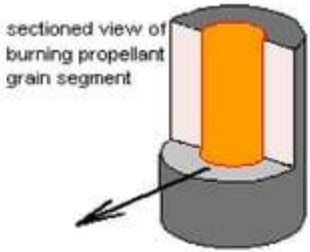
Burning Rate

- The rate of regression is called "burning rate"
- The tendency and rate of materials to burn at given temperature is called burn rate
- This rate will differ with the differing propellants , depending on the various operating conditions as well as the formulation
- Burning rate is a function of propellant composition
- The below figure shows that the burning surface changes with time.

gure 1 -- Burning surface regressio





Factors effecting the burning rate:

- Combustion chamber pressure
- Initial temperature
- Velocity of combusted gases
- Motor acceleration and spin

Relations with burning rate:

To know the effect of the above we need to know the relation between them so we will see below the relation of all the four with the burning rate

Combustion chamber pressure:

- The burning rate normally affected by the chamber pressure because of the burning of grain in the combustion chamber
- The relation between the chamber pressure and the burning rate is given by the saint robert's law…
- This states that the chamber pressure is directly proportional to the burning rate

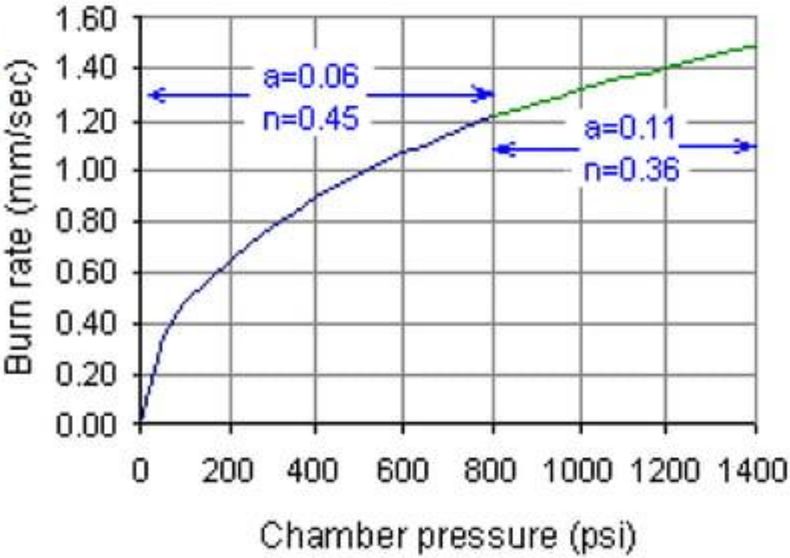
$$r = a\,Pc^{\,n}$$

Where a – burn rate constant

r – burn rate

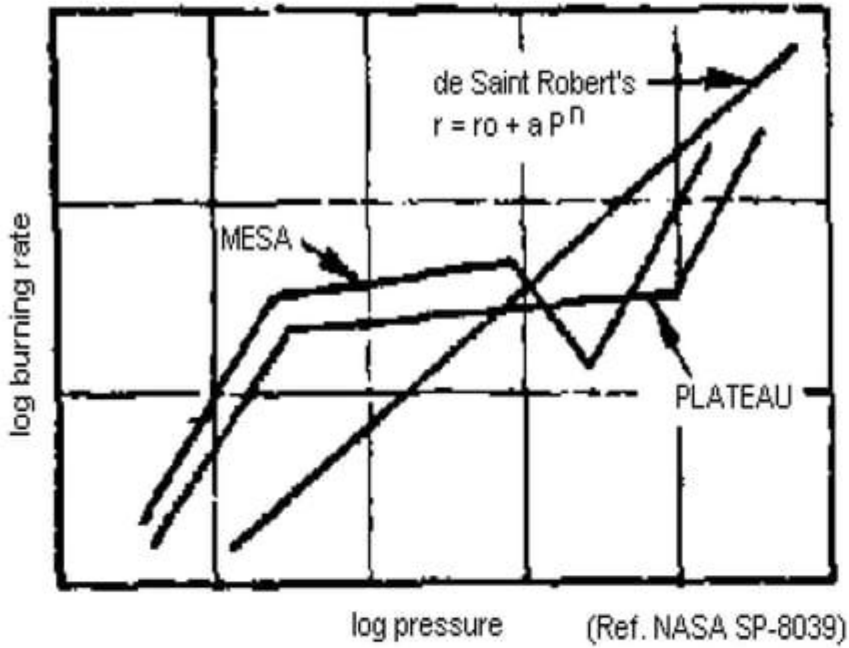
n – pressure exponent

The values of a and n are determined empirically for a particular propellant formulation



saint robert's graph burn rate vs pressure

- This graph mainly depends on the propellant used
- If this graph is plotted log –log then the function will be a straight line.
- Certain propellants deviate from this behavior and exhibit the sharp change in the burn rate behavior.
- The different behavior of the propellants is two types: 1.mesa,2.plateau
- These behaviors are shown in the below graph.
- Burning rate can be sensitive to the pressure exponent ‘ n’.


de Saint Robert's
r = ro + a P n
MESA
PLATEAU
log burning rate
log pressure
(Ref. NASA SP-8039)

- High pressure exponents are undesirable due to the low sensitivity of burn rate due to pressure at the low end of the pressure regime
- Due to these reasons , there may be difficulty in the engine starting.
- This implies that the burning is being directly or linearly proportional to the chamber pressure.

Temperature:

- Temperature affects the rate of chemical reactions and thus the initial temperature of the propellant grain influences burning rate.
- The sensitivity of the burning rate to propellant temperature can be expressed as the form of temperature coefficients , the two most common being

$$\sigma_p = \left(\frac{\delta \ln r}{\delta T}\right)_p = \frac{1}{r}\left(\frac{\delta r}{\delta T}\right)_p$$

$$\pi_K = \left(\frac{\delta \ln p}{\delta T}\right)_K = \frac{1}{p_1}\left(\frac{\delta p}{\delta T}\right)_K$$

σ_p, known as the *temperature sensitivity of burning rate*,

π_K as the *temperature sensitivity of pressure*

K is a geometric function,

The burning rate changes with the temperature as shown below

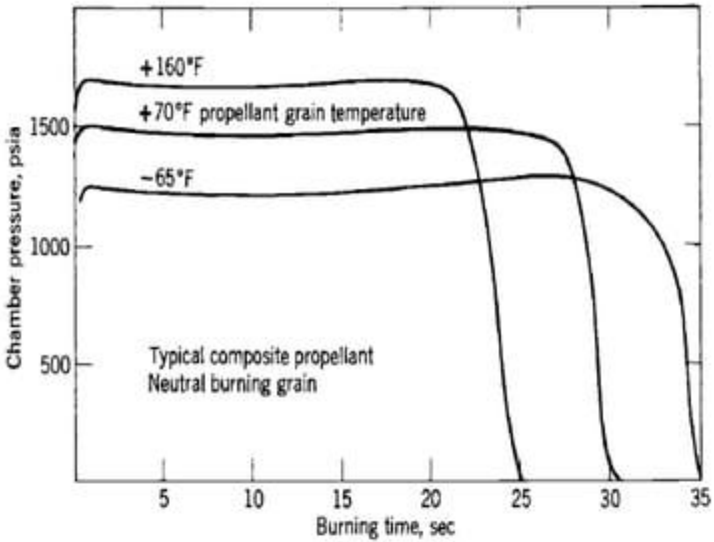


FIGURE 11–8. Effect of propellant temperature on burning time and chamber pressure for a particular motor. The integrated areas under the curves are proportional to the total impulse, which is the same for the three curves.

Combustion gas velocity:

The propellant burning rate caused by the high velocity flow of the combustion chamber gases over the burning propellant surface is increased .

- The augmentation of burning rate is done by the increase of combustion gas velocity.
- This process of augmentation is called "erosive burning" .
- Erosive burning increases the mass flow and thus also the chamber pressure and thrust during the early portion of the burning .
- Since the propellant is consumed more rapidly during the erosive burning , there will reduction of flow and thrust at the end of the burning .

- The relation between the burning rate and the gas velocity is as shown below

$$r = r_0 + r_e$$
$$= ap^n + \alpha G^{0.8} D^{-0.2} \exp(-\beta r \rho_b / G)$$

where r – burn rate

G – mass flow velocity per unit area

D – 4A/S

A – port area

Other are empirical constants

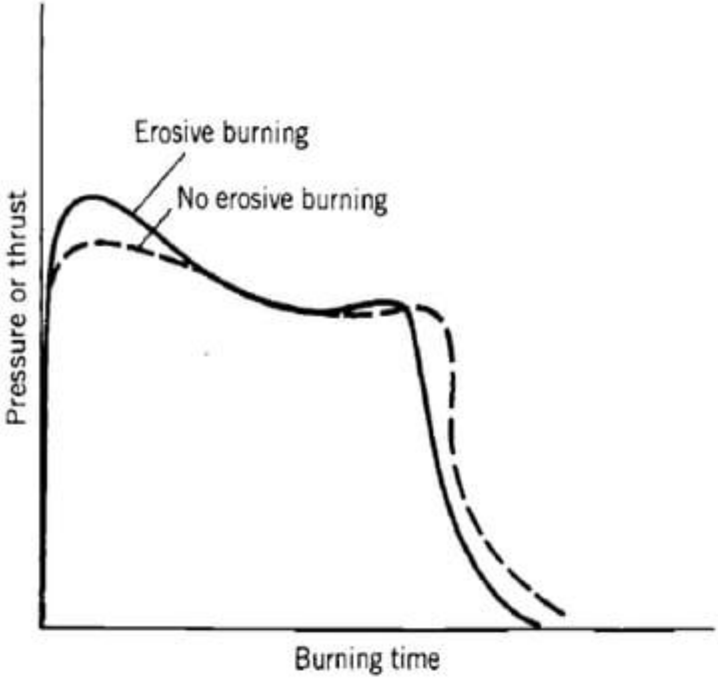


FIGURE 11–9. Typical pressure–time curve with and without erosive burning.

Motor acceleration and spin:

- Enhancement of burning rate can be expected in vehicles that spin the rockets motor about longitudinal axis or have high lateral or longitudinal acceleration as occurs typically in antimissile rockets.
- The accelerated burning behavior of candidate propellants for a new motor design is often determined in small scale motors
- The embedding of wires or other shapes of good metal heat conductors in the propellant grain increases the burning rate.
- The effect of spin on a motor with the composite propellant burning rate is shown in the below graph

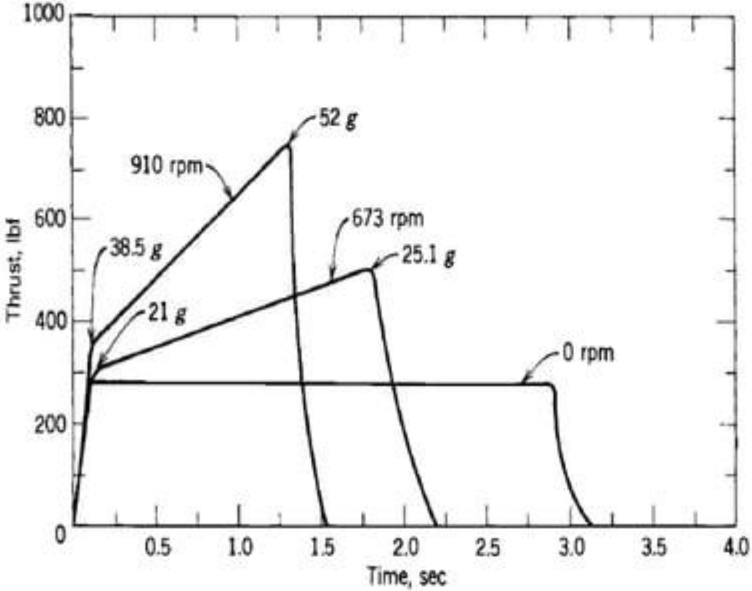


FIGURE 11–12. Effect of axial spin on the thrust–time behavior of a rocket motor with composite propellant using aluminum and PBAN (polybutadiene acrylonitrile) as fuels. (Adapted with permission from Ref. 11–7.)

Modifying the burning rate

- Sometimes it is needed to modify the burning in some cases such that it suits that grain configuration
- For example if we consider a motor having large L/D ratio to generate high thrust , the web would be consequently thin resulting in a sort burn duration . Reducing the burning rate is beneficial.

The ways to modify the burning rate are :

- Decrease the oxidizer particle size
- Increase or reduce the percentage of oxidizer
- adding burning rate catalyst
- operate the motor at lower or higher chamber pressure .

- Decreasing the oxidizer particle size , the burn will increase a lot . By using the fine powdering method , the burn rate will be increased by 16% at ambient pressure .
- The burn rate is strongly affected by the oxidizer to fuel ratio , but normally this is not in use because the performance of the motor as well as mechanical properties of the grain are affected a lot.
- Addition of catalyst is the best and most used method of increasing the burn rate . The catalyst types are: 1) enhancing the fuel decomposition
2)enhancing oxidizer decomposition
3)accelerating vapourised fuel reactions in the combustion zone
4)increasing heat transfer

Some examples of them are:

- Ferric Oxide (Fe_2O_3), copper oxide (CuO), Manganese Dioxide (MnO_2) are commonly used catalysts in AP based composite propellants, as is copper chromate ($Cu_2Cr_2O_5$ or 2CuO Cr_2O_3).
- Potassium dichromate $K_2Cr_2O_7$ or ammonium dichromate $(NH_4)_2Cr_2O_7$ for AN based mixtures.
- Ferric Oxide (Fe_2O_3), Iron sulphate ($FeSO_4$) and potassium dichromate for KN-Sugar propellants
- Lampblack (carbon) may slightly increase the burn rate of most propellants through increased heat transfer from the combustion flame to the propellant surface.

Measuring of burning rate

There are three methods of measuring the burning rate . They are:

- Standard strand burners
- Pressure time trace
- Ballistic evaluation motors

Standard strand burners:

- . The strand is electrically ignited at one end, and the time duration for the strand to burn along its length (cigarette fashion) is measured.
- In this we use lead wires to measure the burning rate using standard strand burners

- The burn rate is obtained by knowing the burning distance as well as the burning time between the lead wires .

Pressure time trace:

- The instantaneous burning rate of a propellant may be estimated from the *pressure-time trace* obtained from a motor firing. This method is based on the knowledge that motor chamber pressure and burn rate are directly related in terms of Kn, c^* and the propellant density. The burn rate coefficient and the pressure exponent may also be estimated

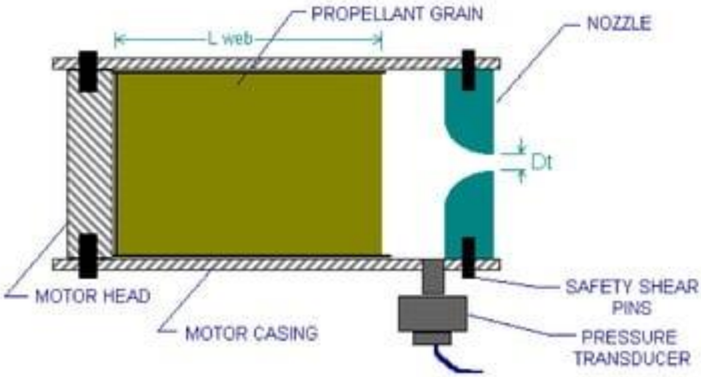
- Steady-state chamber pressure may be expressed in terms of the propellant properties, Kn, and burn rate

$$P_o = K_n \rho_p c^* r$$

where *Kn* is the klemmung, r*p* is the propellant mass density, *c** is the propellant characteristic velocity, and *r* is the burn rate. Steady-state implies that the motor is operating under the condition of choked nozzle flow whereby any chamber pressure variation is due solely to grain geometry, and excludes the "pressure build-up" or "tail-off" phases of operation.

Ballistic evaluation motors;

- The principle used in this motor is at one end the grain ignition will occur and burning will be along the length of the web .
- As the surface area is constant and the steady state operating pressure is also constant and the burning rate is obtained from length of the web divided by the burn time



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Queries?

Thank you…….