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### Burning Rate Prediction of Binary Mixture of Magnesium and Sodium Nitrate

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**ABSTRACT:** In this paper, a new version of an existing burning model of binary mixture of magnesium and sodium nitrate particles has been developed. Modifying some parts of the model such as particle burning time, thermo physical properties of combustion products, and the mixture density, the burning rate has been predicted. Then, the effect of composition, magnesium particles size, initial temperature of the mixture, and pressure on burning rate has been discussed. Finally, using the results of the model, the burning rate ballistic parameters such as coefficient, exponent, and temperature sensitivity have been derived and compared to the existing experimental values. The comparison shows good agreement between the predicted and experimental data in composition and pressure dependencies of the burning rate.

**Keywords:** Binary mixture, Burning model, Burning rate, Magnesium particles, Sodium nitrate

### INTRODUCTION

Combustion of magnesium (Mg) and its mixtures has different industrial applications, such as using in pyrotechnic devices and as a fuel in solid propellants [1, 2]. Because of these extensive applications, there have been a lot of studies about the combustion modeling of magnesium and magnesium mixtures. These studies have been started since 1960 and consisted of experimental and theoretical considerations [3]. Most experimental studies are about the combustion of Mg particles with different gaseous [3-7] and solid oxidizers [8-11]. There are also some studies about burning time and burning rate of magnesium particles and their dependency to particle size, oxidizer specifications, initial temperature, and pressure [3]. The burning rate of binary mixtures of magnesium and sodium nitrate has been studied experimentally along with considering different values of mixture ratio in [8]. These results have been compared to the predicted values of an analytical model in [11]. This model predicts the burning rate of a binary mixture of magnesium and sodium nitrate as a function of composition and particle sizes of ingredients with consideration of metal agglomeration during combustion. The burning rate of non-agglomerated part of the propellant can be computed using the mass continuity equation and determined as fractionally weighted sum of non-agglomerated and agglomerated parts of the mixture. This model has been used to compute the burning rate as a function of mixture ratio, pressure, and particle size. There is also a mathematical model for predicting the burning rate of a magnesium and



sodium nitrate mixture in [12]. This model is based on heat flux conservation equation on the burning surface. In contrast with the model of [11], it uses a physical interpretation of phenomena leading to the combustion, such as heat of phase change, particle life time and trajectory. The summary of the two burning models investigated here, has been shown in Table 1 for comparison.

Because of ambiguities of model of reference [12], some modifications have been done in order to more clarification. The calculated method of the burning time of a moving magnesium particle in a gaseous oxidizer was not obvious. So, the burning time was obtained using a metal droplets combustion model in [13]. Also, the thermo physical properties of combustion products were considered constant. By using the chemical equilibrium calculations [17], thermo physical properties have been derived and their dependency to the mixture ratio, initial temperature and pressure has been discussed. The density of the mixture has been stated as a function of the mixture ratio. With these modifications the burning rate will be closer to the existed experimental values. According to this model the burning rate dependence to mixture ratio, magnesium particle size, initial temperature of the mixture and pressure can be easily specified.

Table 1: Comparison of two Burning Rate Model for Binary Mixture of Magnesium and Sodium Nitrate

	Burning model in [11]	Burning model in [12]
Basic equation	Mass continuity	Heat flux conservation
Dependency	1. Composition 2. Magnesium and sodium nitrate particle size 3. Pressure 4. Agglomeration of magnesium particles 5. Ignition delay time of magnesium and sodium nitrate particles	1. Composition 2. Magnesium particle size 3. Initial temperature of the mixture 4. Pressure 5. Conduction and radiation heat flux 6. Combustion of trapped magnesium particles on the burning surface of the mixture 7. Burning time of magnesium particles

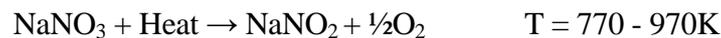
Using the modified model, an extensive study on the burning rate of the binary mixtures of magnesium and sodium nitrate has been conducted. Such mixtures form pyrotechnic compound. The burning rate of such compounds is, generally, a function of the mixture composition, the combustion pressure, the size of metal and oxidizer particles, and the initial temperature. The obtained results give the dependencies and the comparison with the experimental data confirms they are valid.



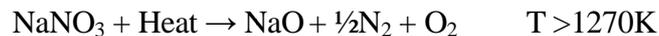
## COMBUSTION MODEL FEATURES

The system under consideration is a dense mechanical binary mixture of finely dispersed magnesium and sodium nitrate particles. A combustion model of this binary mixture has been shown in figure 1. According to this figure, three combustion zones exist.

In zone I, after melting of sodium nitrate at 581 K, the dissociation of sodium nitrate take place in two possible ways. The first is the endothermic dissociation of sodium nitrate to sodium nitrite and oxygen at 770K-970K according to this reaction:

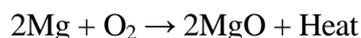


At such low surface temperature the magnesium particles are in condensed phase. An alternative endothermic process is the complete chemical dissociation of sodium nitrate to sodium oxide, nitrogen and oxygen according to



This event is probable when the surface temperature reaches to 1270 K [12]. It is believed that the distance of flame zone determines which process will take place. For high pressure combustion, the flame zone is closer to the burning surface and the second process is more probable. It is assumed that the chemical dissociation of sodium nitrate happens based on the first proposed scheme.

The magnesium particles are carried by the flow of produced gas ( $\text{O}_2$  or  $\text{O}_2$  and  $\text{N}_2$ ) outward of the surface. These moving particles start to burn with available oxygen in zone II. The reaction of magnesium and gaseous oxygen take place in a violent exothermic process and forming  $\text{MgO}$  according to



The heat released from this reaction produces more decomposition of sodium nitrate particles which leads to the increase of oxygen concentration close to the surface. According to available oxygen, some magnesium may remain in this zone after the reaction. These remained particles have been shown in figure 1. After this reactive zone, the final products exist in the highest temperature in zone III.

It is assumed some particles burn on the burning surface using the liberated oxygen. These particles are, somehow, not able to leave the burning surface and are trapped on it. It will increase locally surface temperature and shall affect the burning rate.

1. In description of combustion model all of the magnesium particles are considered spherical with the same size.
2. The weights of magnesium particles and the size of oxidizer particles are neglected.
3. Flow field variations near the surface are effective on burning rate and the effects far from the surface are neglected.
4. The flow is considered single phase and one-dimensional.
5. It is considered a heat release on the surface of the mixture due to the burning of magnesium particles trapped on it.



6. The heat released from combustion of magnesium particles in condensed phase is neglected.

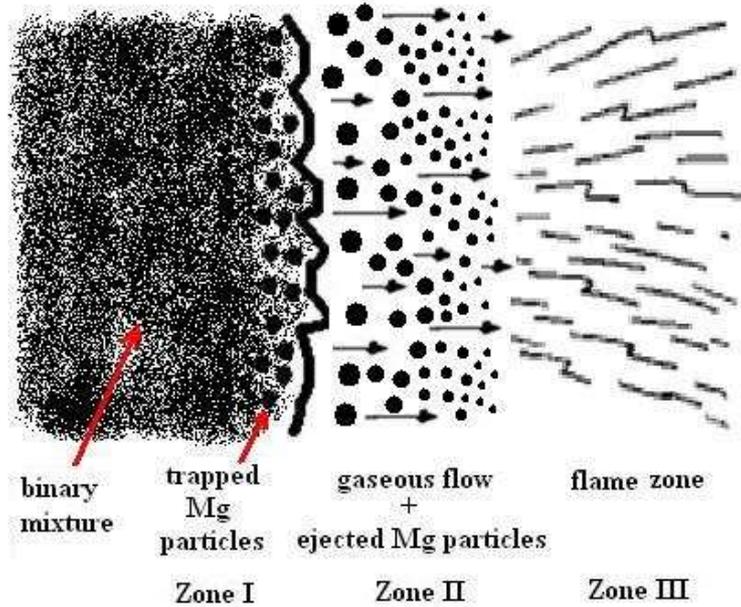


Figure 1. Combustion zones of binary mixture of magnesium and sodium nitrate

### GO VERNING EQUATIONS

The model presented in [12], is repeated here but some variations are exerted to improve it. This model is based on using the energy balance on burning zone, near the burning surface. Using the model physical features and assumptions, the heat flux conservation equation is

$$\dot{m}_{ox}l_{ox} + \dot{m}_{Mg}l_m^{melt} + \dot{m}_s C_{ps}(T_s - T_0) = Q_c + Q_R + Q_{ph} \quad (1)$$

where,  $\dot{m}_{ox}$ ,  $\dot{m}_{Mg}$  and  $\dot{m}_s$  are oxidizer, magnesium and the mixture mass flow rate respectively.  $l_{ox}$  is the heat of melting of sodium nitrate and its decomposition to the nitrite;  $l_m^{melt}$  is the heat of melting for magnesium;  $C_{ps}$  is the heat capacity for the mixture;  $T_s$  is the mixture surface temperature;  $T_0$  is the initial temperature of the mixture;  $Q_c$ ,  $Q_R$  are the conducted and radiated heat fluxes and  $Q_{ph}$  is the heat evolution on the phase transition surface. For determining the composition, the mass fraction of sodium nitrate in the mixture is defined as following

$$\eta = \frac{m_{ox}}{m_{ox} + m_{Mg}} \quad (2)$$

where,  $m_{ox}$  and  $m_{Mg}$  are the mass of sodium nitrate and magnesium in the mixture. Using  $\eta$ , we can write

$$\dot{m}_{ox} = \eta \rho_s \dot{r}, \dot{m}_{Mg} = (1 - \eta) \rho_s \dot{r}, \dot{m}_s = \rho_s \dot{r} \quad (3)$$



where,  $\rho_s$  is the density of the mixture, and  $\dot{r}$  is the burning rate of the mixture. After substituting equation (3), equation (1) becomes

$$\dot{r}\rho_s[\eta l_{ox} + (1 - \eta)l_m^{melt} + C_{ps}(T_s - T_0)] = Q_c + Q_R + Q_{ph} \quad (4)$$

In this equation  $\dot{r}$ ,  $Q_c$ ,  $Q_R$  and  $Q_{ph}$  are unknowns. So, it needs three more equations to obtain the solution. These three equations are heat fluxes equations.

### A. Conduction Heat Flux

Using Fourier law, the conductive heat flux can be written as

$$Q_c = k_g \left. \frac{dT}{dx} \right|_{x=0} \quad (5)$$

where,  $k_g$  is the thermal conductivity of the gaseous flow and  $dT/dx$  is the temperature gradient. The real value of the temperature gradient is substituted by its mean value. So, equation (5) will be

$$Q_c = k_g \frac{\Delta T}{\Delta x} ; \Delta T = T_b - T_s \quad (6)$$

where  $\Delta x$  is the distance from burning surface which the products temperature reaches to  $T_b$ . It is the temperature of combustion final products and is depend on composition, initial temperature and combustion pressure. This temperature has been derived using chemical equilibrium calculations in final products of combustion [17]. Variation of  $T_b$  versus  $\eta$  has been shown in figure 2.  $T_s$  is the burning surface temperature and considered equal to 1000K [12].

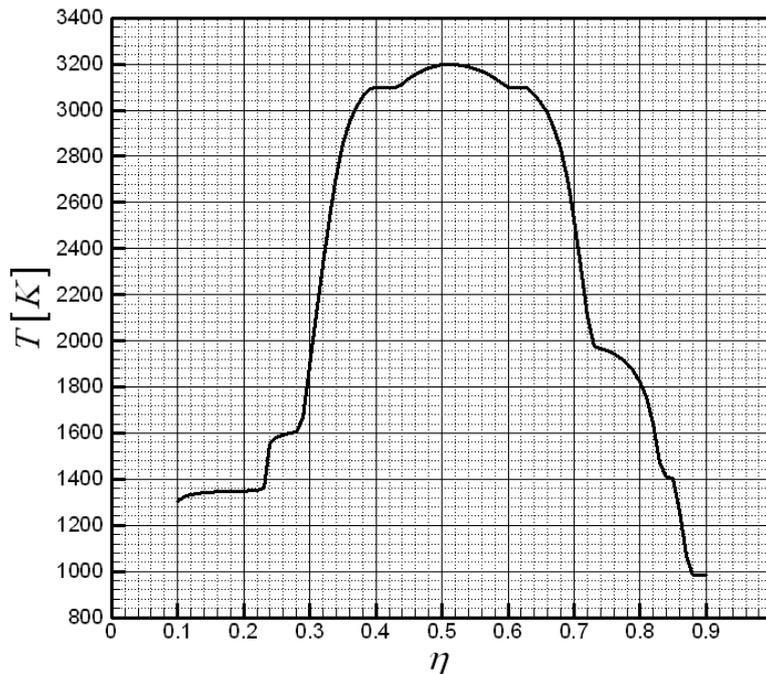


Figure 2.  $T_b$  vs.  $\eta$  for  $P=1$  bar and  $T_0=300$  K

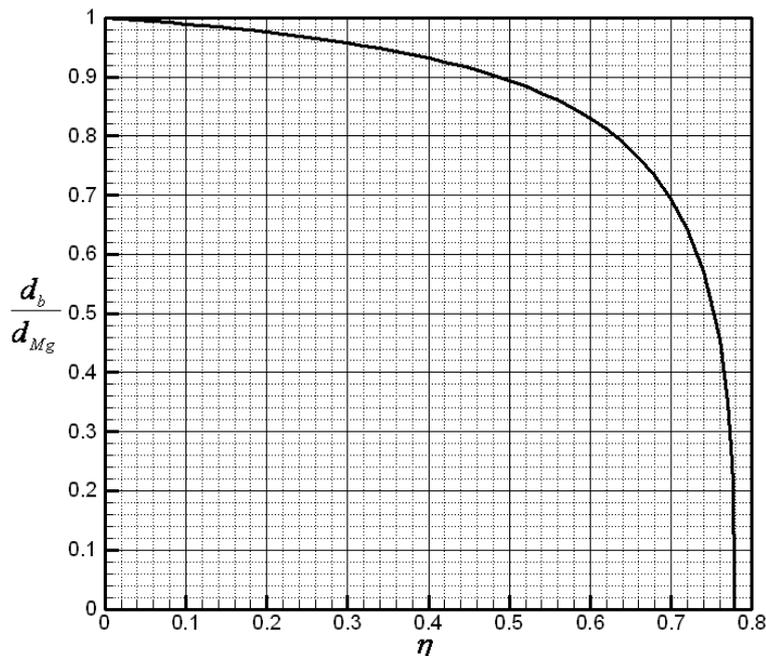
For calculating  $\Delta x$  in (6), we use integrating the equation of moving magnesium particle in the gaseous flow. It results in [12]

$$\Delta x = \dot{r} t_b + \frac{10.5 \mu^{0.8} \rho^{0.2} v^{1.2}}{\rho_{Mg} d_{Mg}^{1.8}} t_b^2 \quad (7)$$

where,  $\mu$ ,  $\rho$  and  $v$  are the dynamic viscosity, density and velocity of the gaseous flow.  $\rho_{Mg}$  and  $d_{Mg}$  are the density and magnesium particle diameter respectively.  $t_b$  is the burning time of magnesium particle which is taken from burning model for combusting metal droplets in a gaseous media [13]. According to this model, the burning time of magnesium particle in a gaseous flow is calculated as

$$t_b = \frac{d_{Mg}^2 - d_b^2}{\frac{4k_g}{\rho_{Mg} C_{pg}} Nu \ln(B+1)} \quad (8)$$

where  $d_b$  is the final diameter of magnesium particle,  $Nu$  is the Nusselt number and  $C_{pg}$  is the heat capacity of the gaseous flow. The final diameter of magnesium particle is depended on the available oxygen. The available oxygen also depends on the sodium nitrate content in the mixture. Therefore,  $d_b$  is a function of  $\eta$ . For determining this relationship, it is supposed that the available oxygen consumes some magnesium. By supposing the spherical particles and using the remained mass, the final diameter can be calculated. This variation has been shown in figure 3.

Figure 3.  $d_b/d_{Mg}$  vs.  $\eta$



According to the particle diameter and the gas flow velocity, the Reynolds number is low. For this flow regime, the Nusselt number is [13]:

$$Nu = 2.15 Re^{0.2} \quad 0 < Re \leq 30 \quad (9)$$

The value of  $B$  in equation (8) is defined as [13]

$$B = \frac{\Delta h_c}{v h_{fg}} \quad (10)$$

where,  $\Delta h_c$  is the stoichiometric heat of reaction of magnesium and oxygen,  $v$  is stoichiometric ratio of this reaction and is equal to 0.658.  $h_{fg}$  is the enthalpy of vaporization of magnesium particle. It is supposed that the oxygen gas surrounds the ejected magnesium particles and the exothermic reaction occurs stoichiometric.



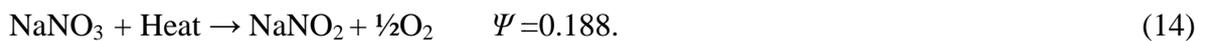
Finally, by defining the gaseous flow Reynolds number as  $\rho v d_{Mg}/\mu$  and using equation (8), the burning time is expressed as

$$t_b = \frac{\rho_{Mg} c_{pg} \mu^{0.2} d_{Mg}^{1.8}}{8.6 k_g \rho^{0.2} v^{0.2} \ln(B_{o,g} + 1)} \left(1 - (d_b/d_{Mg})^{1.8}\right) \quad (12)$$

This equation can be defined based on the burning rate. Using the mass conservation equation for oxygen, it is found that the oxygen leaving the burning surface is equal to the liberated oxygen from sodium nitrate decomposition. Therefore, the velocity of the gaseous flow can be written as

$$v = \frac{\rho_s \Psi \eta \dot{r}}{\rho} \quad (13)$$

where,  $\Psi$  is the ratio of liberated oxygen mass to sodium nitrate mass and is 0.188 according to the reaction of sodium nitrate decomposition



$\rho_s$  is the mixture density that depends on mixture composition and its densification. Using a perfect densification, the mixture density is expressed in terms of  $\eta$  as

$$\frac{1}{\rho_s} = \frac{\eta}{\rho_{NaNO_3}} + \frac{1-\eta}{\rho_{Mg}} \quad (15)$$



Substituting equation (13) into (12) the burning time is

$$t_b = \frac{\rho_{Mg} c_{pg} \mu^{0.2} d_{Mg}^{1.8}}{8.6k_g (\rho_s \psi \eta)^{0.2} \ln(B_{o,q} + 1) \dot{r}^{0.2}} \left(1 - (d_b/d_{Mg})^{1.8}\right) \quad (16)$$

According to equation (16) the burning time is proportional to  $d_{Mg}^{1.8}$  and increases with the increase of magnesium diameter. Figure 4 shows this relation. This complicated behavior comes from the nonlinear dependencies of  $d_b$ ,  $\dot{r}$ , and thermo physical properties of products to the  $\eta$ . The variation of burning time of particles versus its diameter is depicted in figure 5 for several mixture compositions.

With increasing the pressure according to the model in [13], the flame zone around the particle will be closer to the particle surface and the rate of heat transfer to the particle surface will increase. Therefore, the particles will burn faster. The effect of combustion pressure on the burning time of particle is shown in figure 6. It is not possible to determine the burning time explicitly, at this stage. The final results for burning rate and a complete set of input data are used to obtain these figures.

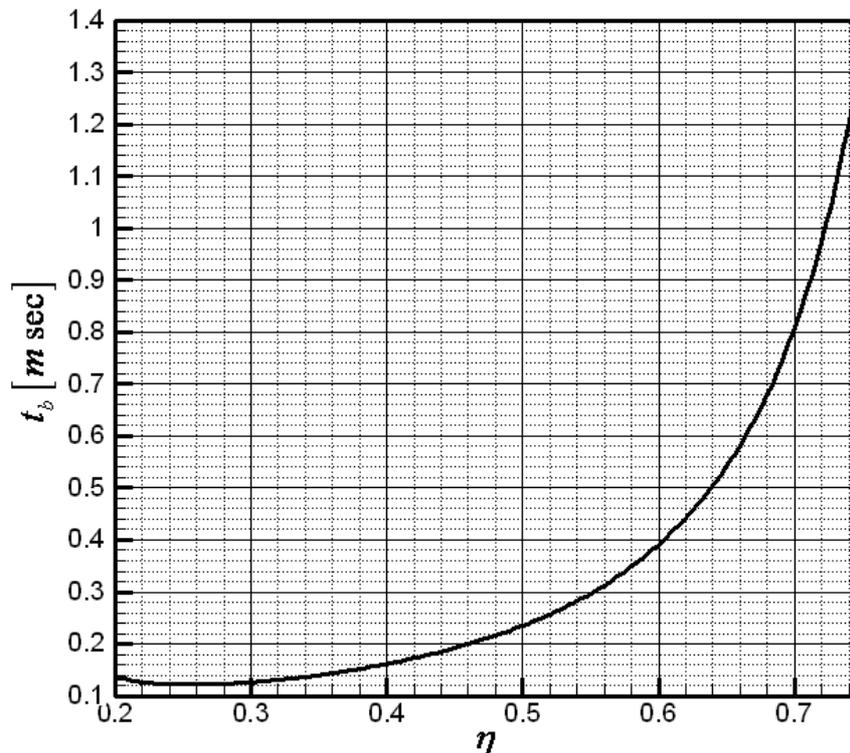


Figure 4. Dependency of burning time to composition of mixture for a  $90 \mu m$  magnesium particle at  $P=1 \text{ atm}$ ,  $T_0=300 \text{ K}$

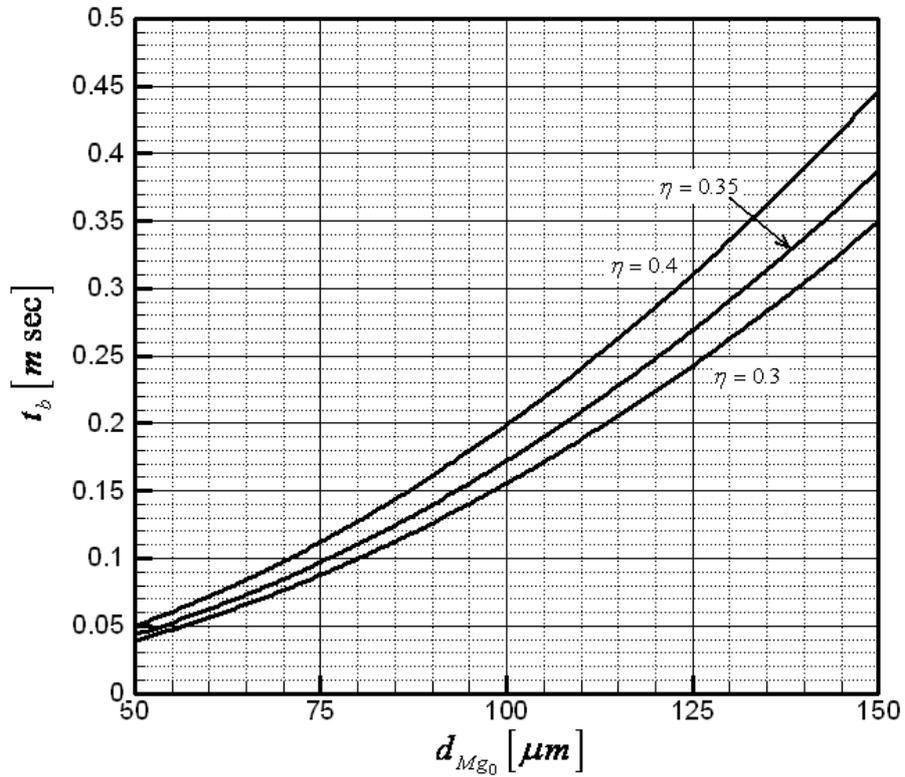


Figure 5. Variations of burning time in terms of magnesium particle diameter,  $P = 1$  atm,  $T_0 = 300$  K

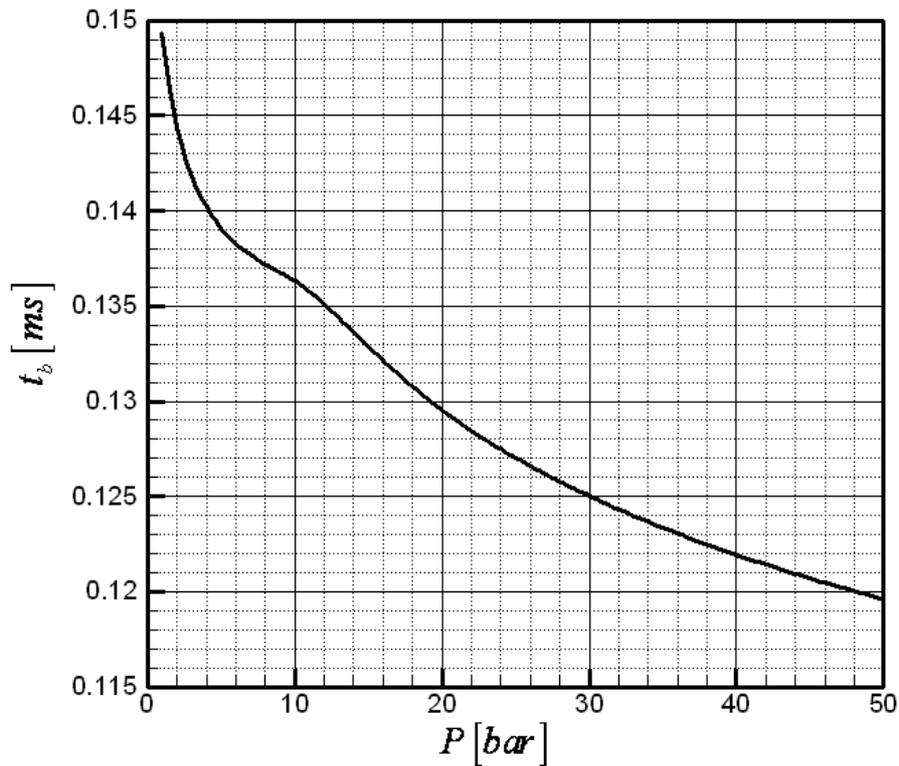


Figure 6. Burning time dependency to pressure for a  $90\mu m$  magnesium particle  $\eta=0.3$ ,  $T_0 = 300$  K



Finally, using equations (6), (7), and (16) the conductive heat flux will be reduced to

$$Q_c = K_c d_{Mg}^{-1.8} \dot{r}^{-0.8} \quad (17)$$

where,  $K_c$  is

$$K_c = \frac{k_g (T_b - T_s)}{\frac{\rho_{Mg} C_{pg}}{8.6 k_g \ln(B+1)} \left( \frac{\mu}{\rho_s \psi \eta} \right)^{0.2} \left[ 1 + \frac{1.221 \rho_s \mu \psi \eta C_{pg}}{\rho k_g \ln(B+1)} \right]} \quad (18)$$

### B. Radiation Heat Flux

There is also a radiated heat flux due to the existence of solid particles in combustion products that can be expressed as

$$Q_R = \varepsilon_f \sigma (T_R^4 - T_s^4) \quad (19)$$

where  $T_R$  and  $\varepsilon_f$  are the magnesium oxide melting temperature and emissivity respectively, and  $\sigma$  is the Stefan-Boltzmann constant.

### C. Heat flux due to the burning of magnesium particles trapped on the surface

For calculating this flux, it is assumed that  $\beta$  percentage of all magnesium particles in the mixture will burn on the surface. Total number of the magnesium particles in the mixture can be calculated by dividing the mass of all particles to the mass of one magnesium particle considering assumption (1) as below:

$$n_{Total} = \frac{6(1-\eta) \rho_s V_s}{\pi \rho_{Mg} d_{Mg_0}^3} \quad (20)$$

Therefore, the number of trapped magnesium particles per unit surface area per unit burning time is

$$n_{trapped} = \frac{6\beta(1-\eta) \rho_s}{\pi \rho_{Mg} d_{Mg_0}^2 t_b} \quad (21)$$

Finally, this heat flux is calculated using the multiplication of the number of trapped magnesium particle by the heating power of a magnesium particle shown by  $H_u$ .

$$Q_{ph} = K_{ph} d_{Mg}^{-0.8} \dot{r}^{0.2} \quad (22)$$

where,  $K_{ph}$  is



$$K_{ph} = \frac{8.6\beta k_g (1-\eta) \rho_s^{1.2} (\psi\eta)^{0.2} \ln(B+1) H_u}{\rho_{Mg} c_{pg} \mu^{0.2}} \quad (23)$$

Variations of non-dimensional three kinds of heat fluxes have been shown in figure 7 for different mixture compositions.

Finally, using equations (17), (19), and (22) the heat flux conservation equation can be written as

$$K_A y^{1.8} - K_{ph} y - Q_R y^{0.8} = K_c \quad (24)$$

where,  $K_A$  is

$$K_A = \rho_s [\eta l_{ox} + (1-\eta) l_m^{melt} + C_{p_s} (T_s - T_0)] \quad (25)$$

and  $y$  is expressed as

$$y = \dot{r} d_{Mg} \quad (26)$$

In equation (24) the only unknown to be calculated is  $y$ . By calculating  $y$  the burning rate of the mixture can be found easily through equation (26).

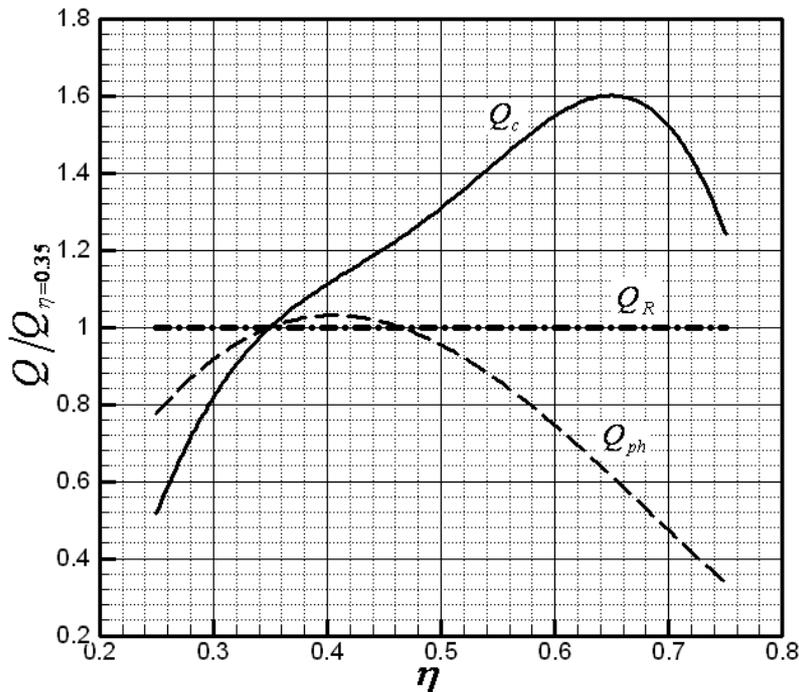


Figure 7. Contribution of various heat fluxes in terms of mixture composition  $\eta$  for  $90 \mu m$  magnesium particles in the mixture and  $P = 1 \text{ atm}$ ,  $T_0 = 300 \text{ K}$

**RESULTS AND DISCUSSION**

Solution of equation (24) can be obtained numerically. According to four factors including composition, size of Mg particles, initial temperature and combustion pressure are investigated on the burning rate and compared with some available experimental data. The model results are found in its closed form. The values used for the physical constants are listed in Table 2. The properties of combustion products in terms of the molar mass are determined using the chemical equilibrium calculation code of [10].

Table 2: Physical Constant Parameters [10]

Parameter	Value	Unit
$\rho_{Mg}$	1740	kg/m <sup>3</sup>
$\rho_{NaNO_3}$	2257	kg/m <sup>3</sup>
$M_{Mg}$	24.3	-
$T_s$	1000	K
$C_{p,NaNO_3}$	1170	J/Kg K
$L_M^{MELT}$	1090	J/Kg K
$I_{NaNO_3}$	194.5	kJ/kg
$H_u$	1535	kJ/kg
$\beta$	0.025	-
$\Delta h_C$	601.4	kJ/mol
$h_{fg}$	5.25	MJ/kg
$T_R$	3070 K	-
$\epsilon_f$	0.5	-
$\sigma$	$5.67 \times 10^{-8}$	W/m <sup>2</sup> K <sup>4</sup>

**A. Composition**

The model has been used to investigate the effects of mixture composition on the burning rate. The variations of burning rate of the mixture for 50  $\mu$ m particle size, 1 bar pressure and 300 K initial temperature are shown in figure 8. In the figure, the burning rate shows a progressive increase with increasing  $\eta$ . A peak occurs around  $\eta=0.3$ . The maximum combustion temperature of mixture and burning time of particles shows a plateau in range of 1000-1100 K. While  $\eta$  increases  $T_b$  remains almost constant and  $t_b$  increases with burning rate.

A comparison between the predicted burning rate and experimental results is shown in figure 8. In [8], the burning rate values for a grain length containing magnesium and sodium nitrate particles for 20% to 60% sodium nitrate content in the mixture are compared. The value of burning rate are in well agreement. It seems that the role of the products play in this issue.

The effects of sodium nitrate content of the mixture and particle size are shown in figure 9. The general trend



sensitive to particle size. However, this figure shows the effect of particle size on the burning rate is highlighted for around the stoichiometric composition.

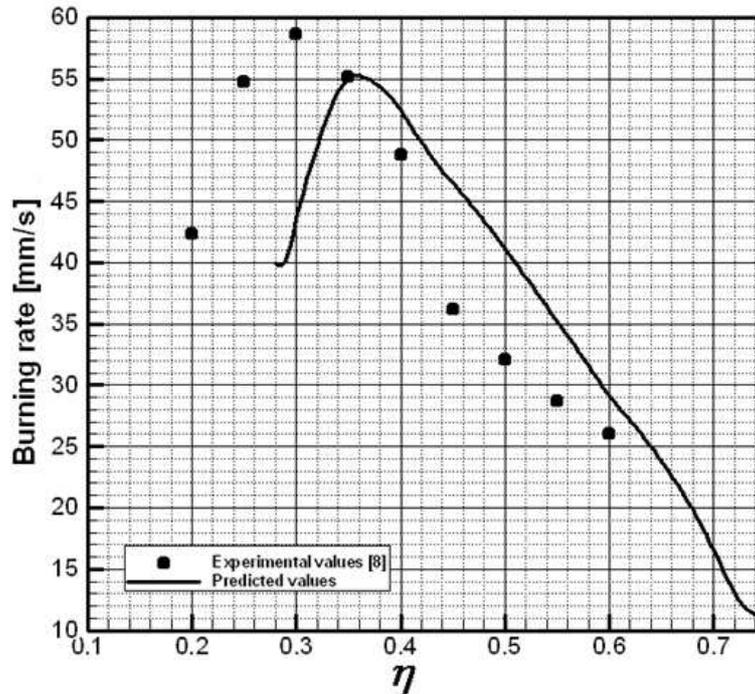


Figure 8. Burning rate vs.  $\eta$  for 50  $\mu\text{m}$  magnesium particles diameter and  $P = 1\text{ bar}$ ,  $T_0 = 300\text{ K}$

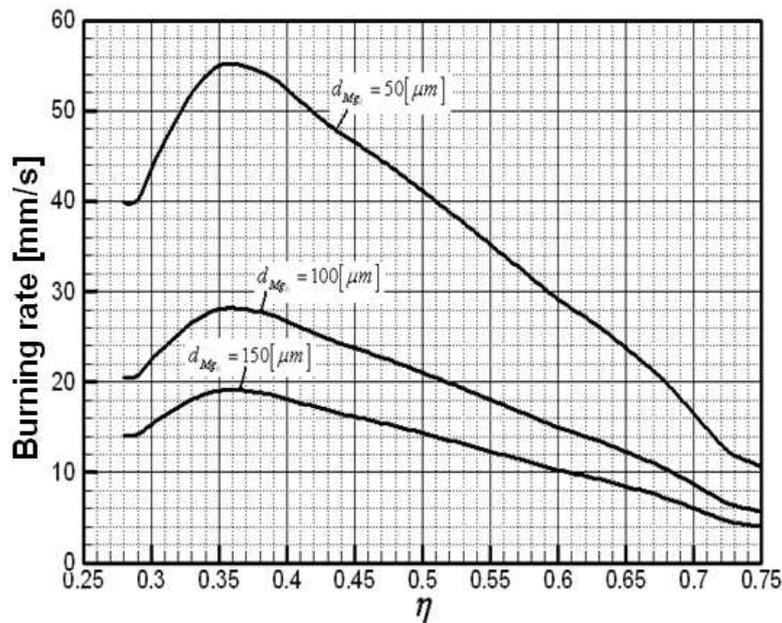


Figure 9. Burning rate vs.  $\eta$  for different values of magnesium particle diameter and  $P = 1\text{ bar}$ ,  $T_0 = 300\text{ K}$



## B. Particle Size

In general, according to Fig. 5, the burning time of magnesium particles increases with the particle size. Therefore, the magnesium particles burn in longer time and travel more distance from the surface. It means the conductive heat flux reduces and the burning rate decreases.

The predicted values of burning rate for different particle sizes have been shown in Fig. 10 and compared to the available experimental values [11]. The comparison shows the general behaviour of burning rate dependency on particle size is predicted well but the values are not in agreed. The main role of particle in the model is burning time. It directly affects the receiving heat flux of the burning surface. Trajectory of particles leaving the burning surface is not as simple as assumed in the model. Particle collision and other factors may affect the travelling distance.

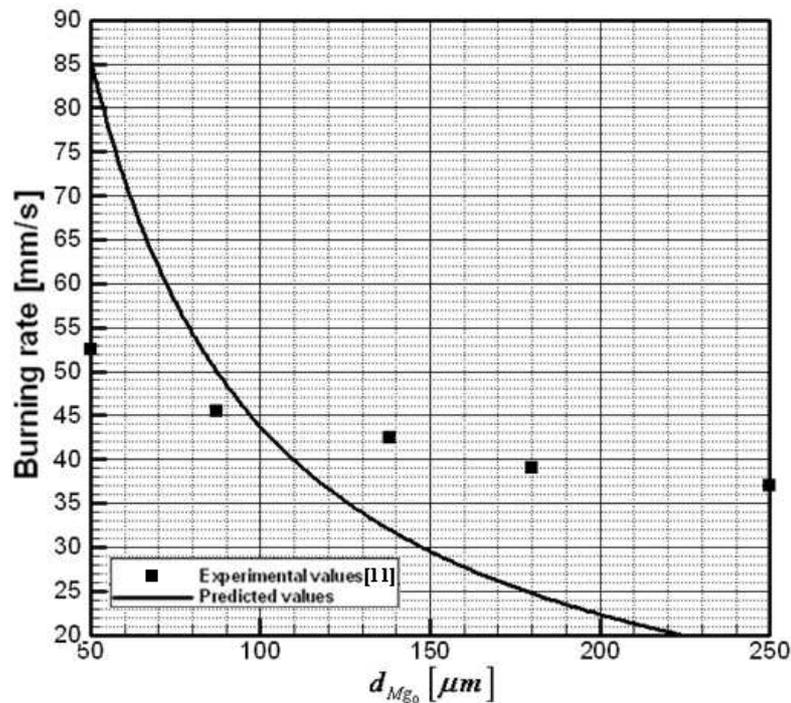


Figure 10. Burning rate vs. magnesium particle diameter for  $P = 1$  bar,  $T_0 = 300$  K

## C. Initial Temperature of the mixture

The effect of initial temperature  $T_0$  is on the required heat to warm up the mixture. Increasing this factor, the reached heat to the surface is consumed for magnesium particle burning in state of surface warm up. Therefore, the burning rate will increase. The effect of this parameter in solid propellants is shown by  $\sigma_p$  and its values are usually between 0.0006-0.0018 [16]. In constant pressure, the thermal dependency of the burning rate is defined as [16]:

$$\sigma_p = \frac{\partial \ln(\dot{r})}{\partial T} \quad (27)$$

The effect of initial temperature on burning rate has been investigated and shown in figure (11) for different values of  $\eta$ . In this figure,  $\Delta T$  is the difference of the initial and the reference



temperature, says  $\Delta T = T_0 - 298$ . The analyses of the results of figure 11 are summarized in table III. The thermal sensitivity of the mixture burning rate is extremely dependent on the composition.

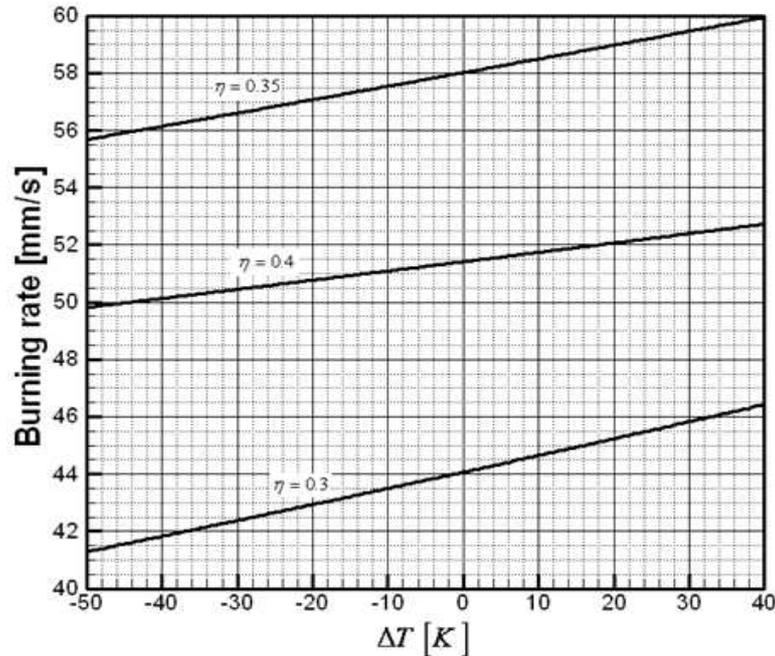


Figure 11. Burning rate vs.  $\Delta T$  for  $50 \mu\text{m}$  of magnesium particle diameter and  $P=1$  bar

Table 3: Temperature sensitivity vs  $\eta$  for  $P = 1\text{bar}$ ,  $d_{Mg_0} = 50\mu\text{m}$

$\eta$	$\sigma_P$
0.3	0.0013
0.35	0.00082
0.4	0.00063

#### D. Pressure

Variations of burning rate in terms of combustion pressure are shown in figure 12. This figure shows the burning rate increases monotonically with pressure. Increasing the pressure causes decreasing in the burning time of the particles (figure 6), traveling distance of the particles (or width of zone II), increasing  $T_b$ , and changing thermo physical properties of the products. All these result to increasing the burning rate with pressure. The modeling results are also compared with available experimental data [11] in figure 12. It shows excellent agreement. For solid propellants, the well known St. Robert burning rate model is expressed as [16]:

$$\dot{r} = aP^n \quad (28)$$

where,  $a$  is the burning rate coefficient and  $n$  is the burning rate exponent.  $a$  can be considered as the burning rate in the standard pressure and depends on burning rate and pressure units.  $n$  is dependent on the composition of the mixture and has the value between 0.2-0.6 [16].

In figure (13), the burning rate laws for different compositions are shown. They show similar trend while having different coefficients and exponents. For several different cases, the burning rate coefficient and exponent are calculated and summarized in tables (4) to (6). It is



indicated in these tables, that the burning rate exponent is a function of mixture composition. It is show no dependency on either particle size or initial temperature.

Table 4: Burning rate coefficient and exponent vs.  $\eta$  for  $T_0 = 300$  K,  $d_{Mg_0} = 50 \mu m$

$\eta$	$a$	$n$
0.3	25.6	0.185
0.35	35.9	0.203
0.4	31.6	0.218

Table 5: Burning rate coefficient and exponent vs. Initial diameter of magnesium particle

for  $\eta=0.3$ ,  $T_0 = 300$  K ,  $d_{Mg_0} = 50 \mu m$

$d_{Mg_0}$	$a$	$n$
50	48.35	0.168
100	24.55	0.166
150	16.62	0.164

Table 6: Burning rate coefficient and exponent vs. change of initial temperature of the mixture

for  $\eta=0.3$ ,  $d_{Mg_0} = 50 \mu m$

$\Delta T$	$a$	$n$
-50	46.62	0.169
0	48.35	0.168
+40	49.42	0.167

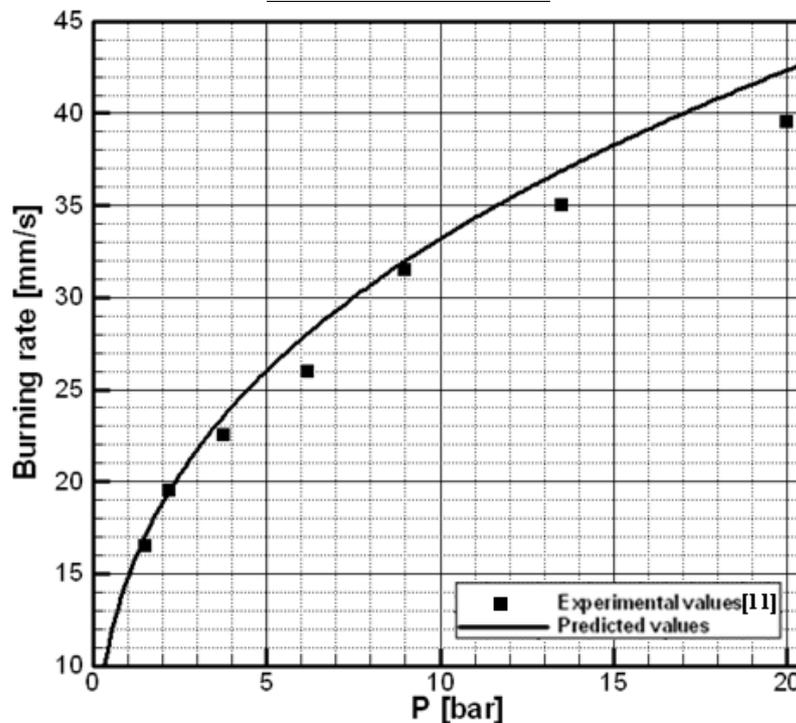


Figure 12. Burning rate vs. pressure for  $50 \mu m$  of magnesium particle diameter and  $\eta=0.6$ ,  $T_0 = 300$  K

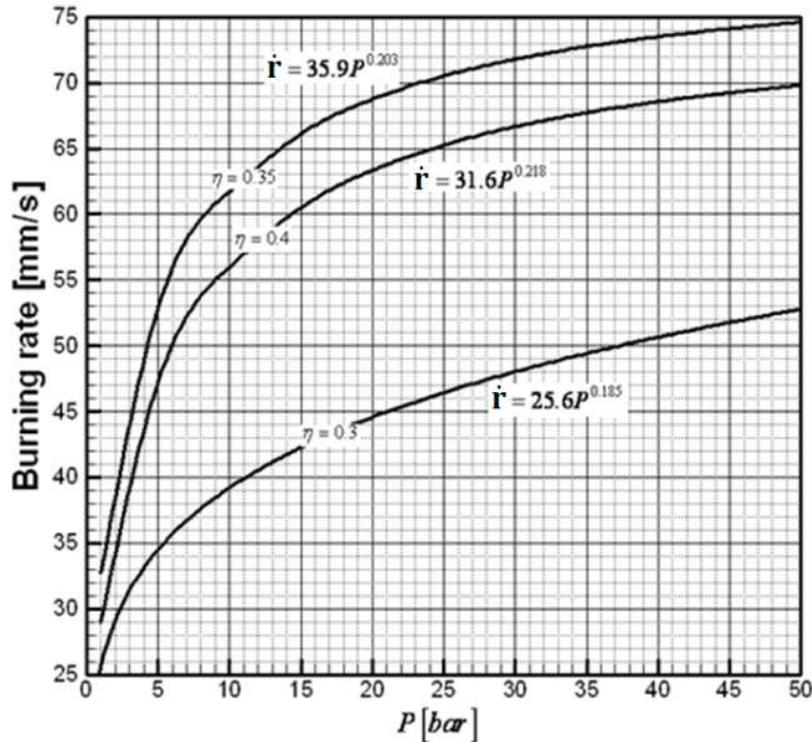


Figure 13. Burning rate vs. pressure for different values of  $\eta$ ,  $90\mu\text{m}$  of magnesium particle diameter and  $T_0 = 300\text{ K}$

### CONCLUSIONS

Modification of an existing combustion model of binary mixture of magnesium and sodium nitrate is provided a powerful tool to study the burning rate. The model is able to describe of one dimensional particle motion, carrier gaseous flow, the distance of flame zone from the mixture surface, burning time of particles, and finally the details burning rate law of the mixture. The temperature sensitivity of the burning rate, the burning rate coefficient, and the burning rate exponent are the burning rate ballistic parameters to be calculated. The temperature sensitivity is a function of composition. It is not sensitive to the particle size and pressure but it decreases with increasing  $\eta$ . The burning rate coefficient is also a function of mixture composition. It increases with initial temperature and decreases with the particle size. The burning rate exponent is a function of mixture composition and increases with  $\eta$ , but it is not a function of particle size and initial temperature. These predicted burning rate ballistic parameters can be used to simulate the behaviour of a combustion chamber.

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