# Effects of charge size on explosives thermal initiation critical temperature under constrained conditions

WANG Hong-wei, ZHI Xiao-qi

(*National Defense Key Laboratory of Underground Damage Technology, North University of China, Taiyuan 030051, China*)

**Abstract**: In order to study the relationship between charge size and thermal initiation critical temperature of explosive in defined conditions, cook-off test about JH explosive was carried out at a heating rate of 1 ℃/min using self-designed cook-off experiment setup based on thermostatic control technology. Numerical simulation was conducted to study the effects of different charge sizes on thermal initiation critical temperature of explosives with FLUENT software. Experiment results show that there is a thermal initiation critical temperature in cook-off bomb. Simulation results show that when the ratio of the length to diameter of explosives grains is a fixed value, the thermal initiation critical temperature of explosives decreases with the increase of the diameter of explosives grains. When the grains diameter of explosives increase up to a certain value, the influence of charge size on thermal initiation critical temperature tends to be weakened. Charge size has no influence on the ignition point of explosives. The ignition point is always in the center of the grain.

**Key words**: heating rate; thermal initiation thermostatic critical temperature; slow cook-off

**CLD number**: TJ55 **Document code**: A

**Article ID**: 1674-8042(2015)03-0234-06 **doi**: 10.3969/j.issn.1674-8042.2015.03.006

## 0 Introduction

In the process of manufacturing, transportation and storage and in battlefield environment, the energetic materials are susceptible to ignition or explosion, which causes unacceptable disaster when ammunition is exposed to accidental thermal stimulation. Therefore, the study on ammunition thermal vulnerability has attracted the world's attention. Cook-off test is one of the most important methods to evaluate the thermal vulnerability of ammunition[1]. Researchers at home and abroad have done a lot of researches on the ammunition response characteristics of cook-off tests. Many valuable conclusions have been obtained. A cook-off test about HMX based high energy explosives of LX-04 was carried out by Garcia F, et al[2] to study the effects of different constraints on the response characteristics of cook-off test. Experiment results show that the response intense of cook-off test weakens with the reducing of constraints. FENG Xiao-jun, et al[3] studied the effects of charge size of explosives (JB-B, TNT and R852 explosives) on the response characteristics of slow cook-off tests. Experiments results show that the ambient temperature of cook-off reaction will increase when the charge size increases. Furthermore, the response intense of cook-off will increase when charge size increases to a certain value, while the effects on the ambient temperature of cook-off test will be weakened. Through the cook-off test of passivation RDX, ZHI Xiao-qi, et al[4] investigated the effects of explosive charge density on slow cook-off response characteristics. Experiment results show that charge density has a significant influence on the response intense of cook-off. In addition, there are also some papers about the effects of heating rate, physical interface and free-space on the response characteristics of cook-off[5-7]. However, there are

**Received date**: 2015-06-18

**Corresponding author**: WANG Hong-wei (1290303565@qq.com)

few researches about the effects of charge size on explosives thermal initiation critical temperature in defined conditions.

The explosive used in the experiment is RDX based JH explosive. Cook-off bomb was heated to different preset temperatures at the heating rate of 1 ℃/min and kept it at the preset temperature for a period of time. Then the thermal initiation critical temperature of explosives was obtained by using FLUENT software and the response characteristics at different ambient temperatures were observed. This will be of significance to the design and safe use of insensitive munitions.

In this paper, thermal initiation critical temperature in defined conditions is the smallest temperature that makes cook-off bomb ignite when cook-off bomb is heated to a thermostatic temperature and this temperature is kept for a long time.

# 1 Experiments

## 1.1 Experiment devices

The cook-off experiment set up is composed of computer, cook-off burner, MR13 temperature controller and thermocouple. Cook-off burner is the thermal source of the whole system. Temperature controller is used to ensure that the temperature will increase at the preset heating rate. The case temperature of cook-off bomb is measured by the thermocouple whose measure accuracy is one level. The temperature-time curves during cook-off process can be acquired by self-designed SFO software. Heating rate should be calibrated before experiment to ensure that heating rate of cook-off is 1 ℃/min during heating period. When case temperature was heated to 160, 170, 180, 185, 195 ℃ and kept for 50 min, respectively, and their response characteristics can be got. What should be noted is that two groups of cook-off tests were conducted at every thermostatic temperature to ensure the reliability of test results.

## 1.2 Structure of cook-off romb

Fig. 1 is the physical model of cook-off bomb, which is composed of the case, the cover and some explosives. The case material is No. 45 steel. The inner wall size of the cook-off bomb is Φ19 mm × 38 mm. The cover wall size is 1±0.03 mm. Whorls are used to connect the case and the covers. Explosive mass ratio is that RDX occupies 95.0% and additive occupies 5.0%. Explosive grain diameter is Φ19 mm. The density of grain is 1.628 g/cm$^3$.

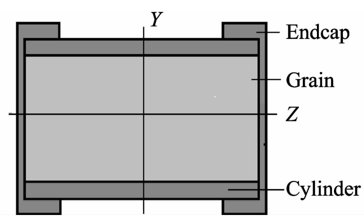


Fig. 1 Physical model of cook-off bomb

## 1.3 Experiment results

Table 1 shows the cook-off experiment results. Fig. 2 is the explosive decomposition rate curve at different thermostatic temperatures.

It can be seen that the explosive decomposition percentage increases with the increase of thermostatic temperature.

**Table 1 Experiment results of cook-off test**

| Explosive name | Thermostatic temperature (℃) | Thermostatic temperature (min) | Loss of explosive (g) | Loss ratio of explosive (%) | Response result |
|---|---|---|---|---|---|
| JH explosive | 160 | 50 | 0.18 | 1.022 | no response |
| | 170 | 50 | 0.23 | 1.261 | no response |
| | 180 | 50 | 0.36 | 1.987 | no response |
| | 185 | 50 | 0.47 | 2.629 | no response |
| | 195 | 48 | — | — | detonation |

It can be seen from Table 1 and Fig. 2 that the decomposition rate of RDX based explosives is very slow when thermostatic temperature is smaller than 185 ℃. And the relationship between thermostatic temperature and explosives decomposition rate is liner. However, when thermostatic temperature is greater than 185 ℃, the decomposition rate of RDX increases absolutely and is strong non-linear relationship. In a word, there is an inflection temperature. When ambient temperature is greater than this inflection temperature, decomposition rate increases sharply and self-heating reaction occurs, which results in ignition.

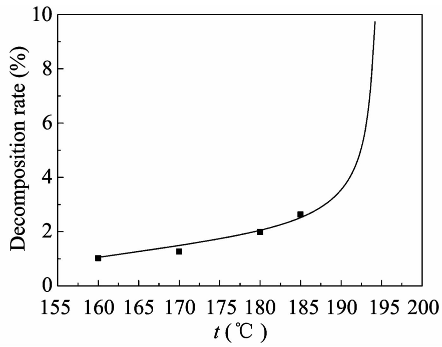


**Fig. 2 Curve of decomposition rate of explosive at different temperatures**

The thermal initiation thermostatic critical temperature of explosive and others in different charge sizes has not been studied due to the limited thermostatic time and economic reasons[8]. Therefore, numerical simulation will be conducted to study grains thermal initiation critical temperature with explosive grain diameter of 19, 30, 40, 50 mm respectively and the ratio of length to diameter of 2 : 1.

# 2 Numerical simulaton

## 2.1 Establishment of physical model

When conducting numerical simulation of cook-off process of RDX based explosives, the following assumptions should be made:

1) There is no gap between the cook-off bomb case and the explosives grains.

2) The material parameters of the case and the inner wall are constant during cook-off process.

3) Thermal reaction and thermal conductivity of explosive grains follow Frank-Kamenetskill equation.

The grain appears cylindrical. In order to decrease the calculation work, calculation model is a 1/2 model. Fig. 3 is the physical model.

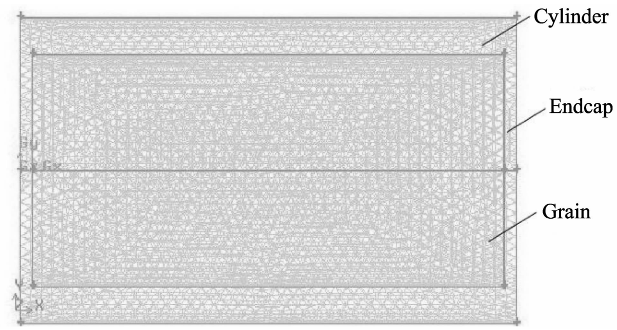


**Fig. 3 Physical model of cook-off system**

## 2.2 Establishment of mathematical model

In cylindrical coordinates, temperature field control equations[9] can be expressed as

$$\rho c_v \frac{\partial T}{\partial t} = \lambda\left(\frac{\partial^2 T}{\partial r^2} + r\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \varphi^2} + \frac{\partial^2 T}{\partial z^2}\right) + QaA\,e^{-\frac{E}{RT}},$$

where $\rho$ is reactant density (kg/m$^3$); $c_v$, specific heat capacity (J/(kg·K)); $\lambda$, thermal conductivity (J/(m·K·s)); $a$, reaction score; $Q$, reaction thermal of reactants (J/kg); $A$, pre-exponential factor (s$^{-1}$); $E$, activation energy (J/mol); R, gas constant (J/(mol·K)).

The chemical reaction exothermic section of JH explosive was embedded in FLUENT[10] main program by self-written subroutine. Material parameters[11] used in simulation are listed in Table 2.

**Table 2 Material parameters**

| Material | $\rho$ (kg/m$^3$) | $c_v$ (J/(kg·K)) | $\lambda$ (J/(m·K·s)) | $Q$ (J/kg) | $A$ (s$^{-1}$) | $E$ (J/mol) | $R$ (J/(mol·K)) |
|---|---|---|---|---|---|---|---|
| JH | 1 640 | 1 130 | 0.213 | $2.101\times10^5$ | $2.01\times10^{18}$ | 204 230 | 8.314 |
| Case | 7 850 | 480 | 43 | — | — | — | — |

## 2.3 Numerical simulation of critical temperature of JH explosives

Fig. 4 shows the temperature-time curves of the projectile body outer wall in the heating process at 185 ℃. It can be seen that the temperature-time curves of experiment and simulation results are almost the same, which means that simulation parameter values are suitable.

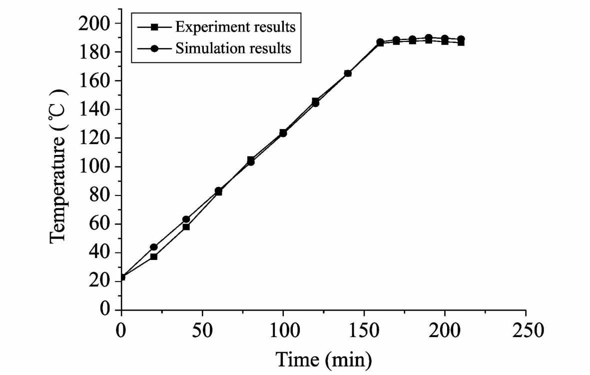


**Fig. 4 Temperature-time curves of simulation and experimental results of projectile body outer wall at 185 ℃**

Fig. 5 presents the critical temperature distribution of cook-off bombs with diameters of 19, 30, 40 and 50 mm and the ratio of length to diameter of 2∶1. From Figs. 5(a) and (b), we can see that no matter the thermostatic time is 180 min or 1 500 min, the highest temperature (center) in grain is 199 ℃ with thermostatic temperature of 191 ℃ and the grain diameter of 19 mm. The thermal decomposition reaction of solid state dynamite advances very slowly under these conditions. Cook-off system is in thermal equilibrium status and self-heating ignition reaction can not occur. However, when the thermostatic temperature is 192 ℃, the highest temperature (center) in grain is 202 ℃ with thermostatic time of 90 min. The highest temperature (center) in grain is 238 ℃ when thermostatic time is 207 min. In these conditions, thermal released by decomposition reaction can not be completely lost to the environment and cause thermal accumulation phenomenon. The thermal equilibrium of cook-off system is imbalance and leads to ignition. All in all, when the diameter of cook-off bomb is 19 mm, its thermal initiation critical temperature is 192 ℃.

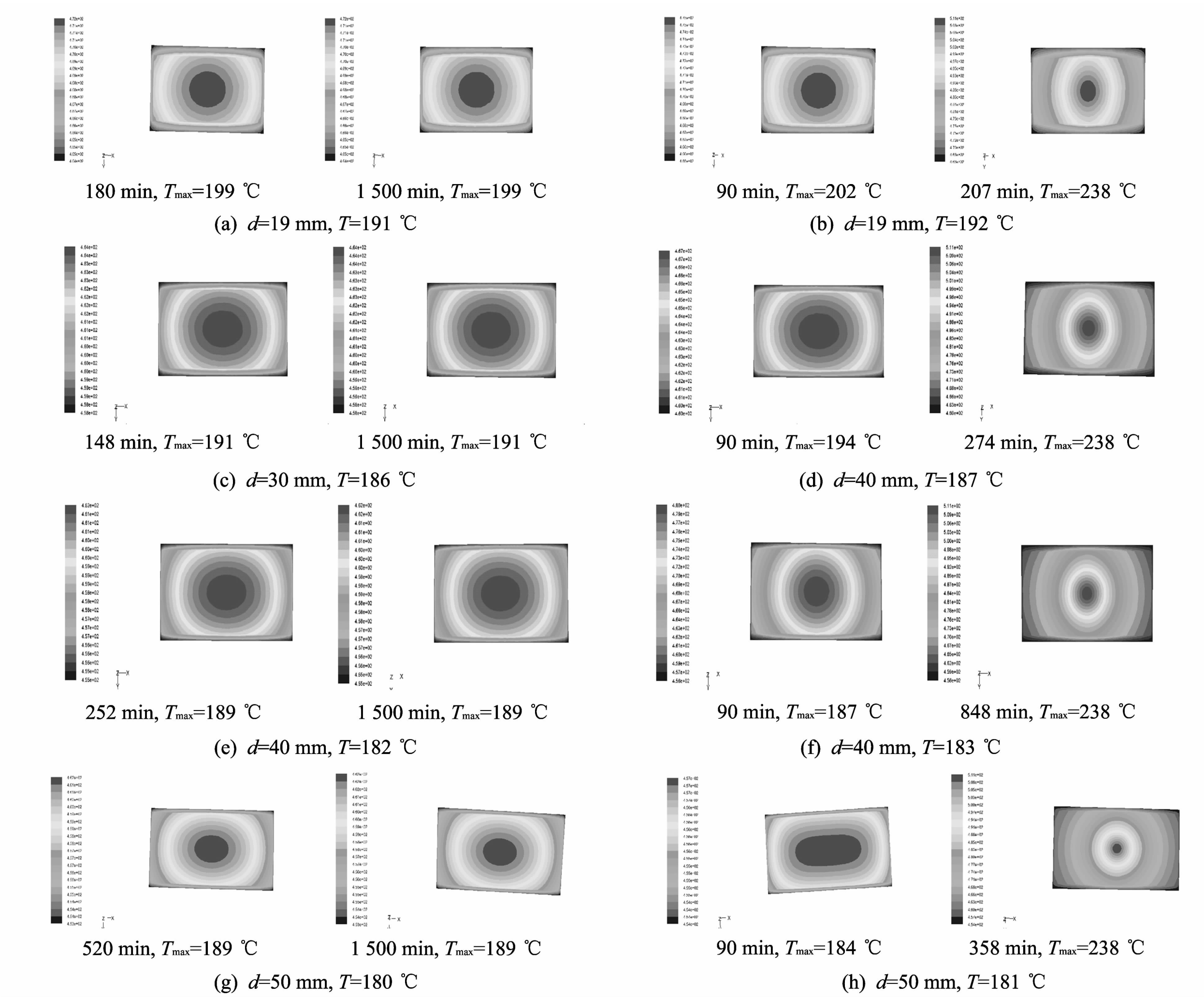


**Fig. 5 Temperature distribution of case at different thermostatic temperatures and different charge sizes**

Using the same analysis method, it can be seen from Figs. 5(c) and (d) that the thermal initiation thermostatic critical temperature is 187 ℃ when the diameter of cook-off bomb is 30 mm. In Figs. 5(e) and (f), the thermal initiation critical temperature is 183 ℃ when the diameter of cook-off bomb is 40 mm. In Figs. 5(g) and (h), the thermal initiation critical temperature is 181 ℃ when the diameter of cook-off bomb is 50 mm.

We can also draw the conclusion that the highest temperature is always in the center of the grain when explosives are ignited, as shown in Fig. 5. Therefore, charge size has no influence on the ignition point, which is always in the center of the grain.

Fig. 6 shows the relationship between the charge size and the thermal initiation critical temperature.

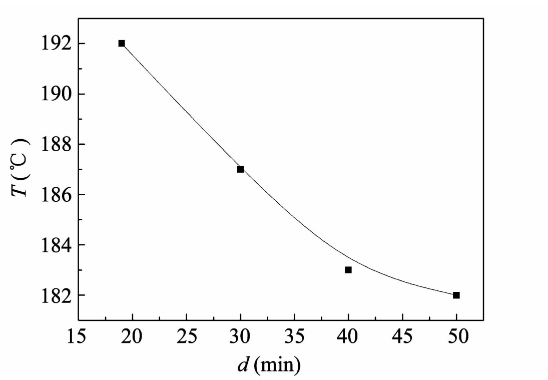


**Fig. 6 Relationship between charge size and thermal initiation thermostatic critical temperature**

It can be seen from Fig. 6 that the thermal initiation critical temperature decreases with the increase of the charge size when the ratio of length to diameter is identical. When the charge size increases to a certain value, the influence it has will decline. When cook-off bomb is heated to a certain thermostatic temperature and kept at the thermostatic temperature for a long time, the cook-off bomb ignites because the heat generation rate is greater than the heat loss rate if the thermostatic temperature is large enough. Then, heat will be accumulated in explosive grains and accelerate the self-heating reaction, which results in ignition. The larger the charge size is, the greater the explosives quantity is. Heat release by explosives decomposition will be larger at the same thermostatic temperature and thermal feedback will be intenser. The thermal initiation critical temperature will be lower. When the explosive amount (charge size) is large enough, this influence will be weakened. These conclusions are similar to HE Guang-bin's research results who studied the thermal initiation critical environment of explosive[8].

## 3 Conclusions

1) The charge size of explosives grain has influence on explosive thermal initiation critical temperature in defined conditions. The thermal initiation critical temperature decreases with the increase of the charge size. When the charge size increases to a certain value, the influence it has on thermal initiation critical temperature will be weakened.

2) Charge size has no influence on the ignition point of explosives in defined conditions. The ignition point is always in the center of the grain.

## References

[1] MIL-STD-2105C. Military standard-hazard assessment tests for non-nuclear munitions. 2003.

[2] Garcia F, Vandersall K S, Forbes J W, et al. Thermal cook-off experiments of the HMX based high explosive LX-04 to characterize violence with varying confinement. In: Proceedings of the 14th APS Topical Conference on Shock Compression of Condensed Matter, Baltimore, 2006: 1061-1064.

[3] FENG Xiao-jun, WANG Xiao-feng, HAN Zhu-long. The study of charge size influence on the response of explosires in slow cook-off test. Explosion and Shock Waves, 2005, 25(3): 285-288.

[4] ZHI Xiao-qi, HU shuang-qi. Influence of charge densities on responses of explosives to slow cook off. Explosive and Shock Waves, 2013, 33(2): 221-224.

[5] NIU Yu-lei, NAN Hai, FENG Xiao-jun. The cook-off experiment and numerical simulation of RDX based PBX explosive. Chinese Journal of Explosives & Propellants, 2011, 34(1): 436-441.

[6] GAO Feng, ZHI Xiao-qi. Effect of physical interface on slow cook-off characteristics of explosives. Chinese Journal of Explosives & Propellants, 2014, 37(6): 53-57.

[7] YU Yong-li, ZHI Xiao-qi. The research of free-space influence on response of characteristic of explosive on slow cook-off condition. Science Technology and Engineering, 2015, 33(2): 221-224.

[8] FENG Chang-gen. Thermal explosion theory. Beijing: Sci-

ence Press, 1988.
[9] DONG Hai-shan, ZHOU Fen-fen. High energy explosives and related properties. Beijing: Science Press, 1989.
[10] ZHU Hong-jun, LIN Yuan-hua, XIE Long-han. Fluent12 fluid analysis and engineering simulation. Beijing: Tsinghua University Press, 2011.
[11] HE Guang-bin, FENG Chang-gen. A study on the critical ambient temperature for the thermal explosion of explosive cylinders. Journal of Beijing Institute of Technology, 1995, 15(3): 251-256.

# 装药尺寸对限定条件下炸药热起爆临界温度的影响

王洪伟，智小琦

（中北大学 地下目标毁伤技术国防重点实验室，山西 太原 030051）

**摘　要：** 为研究装药尺寸与限定条件下炸药热起爆临界温度之间的关系，利用自行设计的烤燃试验装置，以 RDX 为主的 JH 炸药为试验材料，在 1 ℃/min 的升温速率下，采用恒温控制技术进行了不同温度下的烤燃试验。利用 FLUENT 软件对不同装药尺寸下炸药的热起爆恒温临界温度进行了数值计算，研究了装药尺寸对炸药热起爆恒温临界温度的影响。试验结果表明，烤燃弹存在一个热起起爆恒温临界温度。仿真结果表明:当药柱的长径比相同时，随着药柱尺寸的增加，炸药的热起爆恒温临界温度逐步降低。当药柱尺寸增大到一定值时，装药尺寸对烤燃弹的热起爆恒温临界温度的影响将减弱。装药尺寸对点火点的位置无影响，均为中心点火。

**关键词：** 升温速率；热起爆恒温临界温度；慢速烤燃

**引用格式：** WANG Hong-wei, ZHI Xiao-qi. Effects of charge size on explosives thermal initiation critical temperature under constrained conditions. Journal of Measurement Science and Instrumentation, 2015, 6(3): 234-239. [doi: 10.3969/j.issn.1674-8042.2015.03.006]