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Effect of Obstacle on Deflagration to Detonation Transition (DDT) in Closed Pipe or Channel–An Overview

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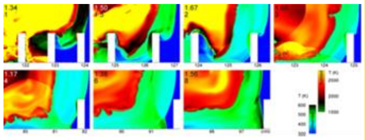
Graphical abstract



Abstract

Due to complicated and rapid process, deflagration-to-detonation transition (DDT) becomes one of the major challenges in combustion theory where the exact mechanism is still poorly understood. Theoretically, the presence of obstacle may disturb flame propagation and hence make the DDT predictions more complex. Thus a comprehensive study is required to acknowledge DDT performance precisely. Lacking of information in literature causes the prediction of the transition period is still uncertain. In contrast, appropriate estimation of the DDT event is crucial for explosion safety. Thus, this present paper discusses the effect of obstacle on prediction transition deflagration to detonation event in pipeline system in order to apply an effective protection and safety systems to prevent and mitigate the gas explosion in industries. In addition the effect of bending on flame acceleration and explosion development would also be explored.

Keywords: Closed pipe/channel/tube; obstacle; flame acceleration; deflagration to detonation

Abstrak

Disebabkan proses pantas dan rumit, peralihan fasa dari deflagrasi ke peledakan (DDT) menjadi satu daripada cabaran utama dalam teori pembakaran, di mana mekanisme yang tepat masih tidak difahami. Dari segi teori, kewujudan penghalang boleh menyebabkan halaju nyalaan api oleh yang demikian jangkaan DDT menjadi rumit. Kekurangan maklumat mengenai faktor yang menyumbang kepada DDT menyebabkan ramalan tempoh peralihan masih tidak menentu. Sebaliknya, jangkaan masa serta tempat dimana peralihan dari deflagrasi ke peledakan (DDT) berlaku penting bagi tujuana keselamatan. Oleh yang demikian, kertas kajian ini bertujuan membincangkan kesan halangan terhadap kejadian peralihan deflagrasi ke peledakan yang berlaku di dalam saluran perpaipan supaya kaedah sistem keselamtan dapat dicadangkan di tempat yang sesuai bagi mengurangkan letupan yang berlaku. Sebagai tambahan, kesan pembengkokan terhadap pecutan api dan pembangunan letupan juga akan dibincangkan.

Kata kunci: Paip/tiub/saluran tertutup; penghalang; deflagrasi kepada peledakan; kelajuan nyala; kegeloraan; gelombang kejutan

1.0 INTRODUCTION

A large number of gas explosions in pipeline system have happened frequently and caused serious damage. The used of pipeline to convey the reactive material from one vessel to another could possibly lead to the development of an explosion and potentially damaging overpressure. In addition, the presence of obstacle such bending, elbow and other fittings in pipeline are also contributes to the potential hazards by promoting flame acceleration and detonation. In most engineering applications, combustion occurs via deflagration mode classified as subsonic combustion and the chemical reactions occur at roughly constant pressure and laminar burning velocity around 1 m/s. However, in detonative mode, supersonic front propagation velocities on the order of a couple of thousand meters per second will be observed and the pressure ratio across the detonation wave is in the range of 15-20 (for stoichiometric fuel air mixtures). This is roughly twice the maximum possible pressure produced by a deflagration in the same mixture under adiabatic, constant volume conditions. Due to complicated and rapid process, deflagration-to-detonation transition (DDT) becomes one of the major challenges in combustion theory where the exact mechanism is still poorly understood and the prediction of the locations/points of DDT occurrence still questionable.

Recently, many experimental and theoretically studies have been undertaken to acknowledge the DDT phenomenology and also factor that governs the DDT performance. Thanks to the extensive and comprehensive study in DDT [1-6] includes investigations of transition to detonation in obstructed tubes with several fuel-air mixtures. Most of them agreed that the presence of obstruction in pipes or channel change the flame velocity, induce the turbulence intensity subsequently support the transition performance. The detail explanation on the mechanism is discussed in section 2 and 3 respectively. It is noted that the presence of obstacle in tube or channel play a major role in flame flow disturbance and yet enhance the DDT performance, thus this paper highlights the summary results from several papers which investigate the effect of obstacle on flame acceleration and potential transition to detonation in a pipeline system.

■2.0 PHENOMENOLOGY OF DDT

DDT is a complicated and rapid process in which becomes a major challenge in combustion theory. The acceleration of the flame from laminar to the magnitude of sonic velocity of 1200 m/s, leading to turbulence generation due to reflected shock collide with the flame before DDT appear. It indicates that various effects had been determined in contributing on the DDT phenomenon. Several studies shown that the presence of obstacle (baffle/bend/elbow) in piping system would affect the flame stability, subsequently enhance the DDT [7-12]. For instance, as shown in Figure 1, flame start accelerates right after the obstacle. Generally, the presences of obstacle may initiate the turbulence leading to increase the burning rate as well as initiate the DDT performance [5]. In simulation observation, Gamezo et al.,[2] found that DDT is appearing when the reflected shock from the bottom wall collides with the obstacle, further creating turbulent flame to induce DDT phenomenon as illustrated in Figure 2. They also reported that the presence of the bend in the duct also enhances the formation of hot spot, another possible causes leading to DDT at two different locations. Wang et al.,[13] and Han et al.,[1] supported the previous finding by explaining that detonation is triggered when the two hot spots collides each other as shown in Figure 3.

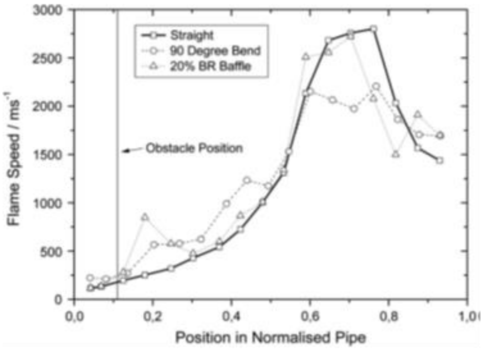


Figure 1 Flame speed profile in pipe containing baffles and bends [5]

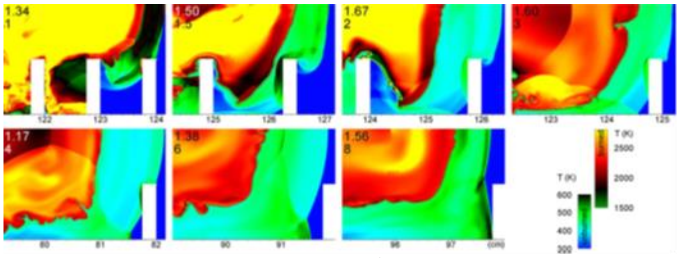


Figure 2 Flame-shock configuration [3]

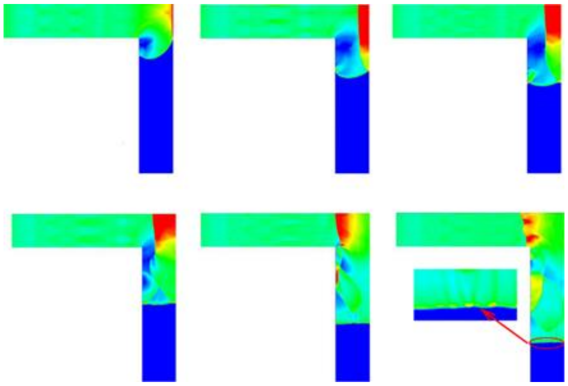
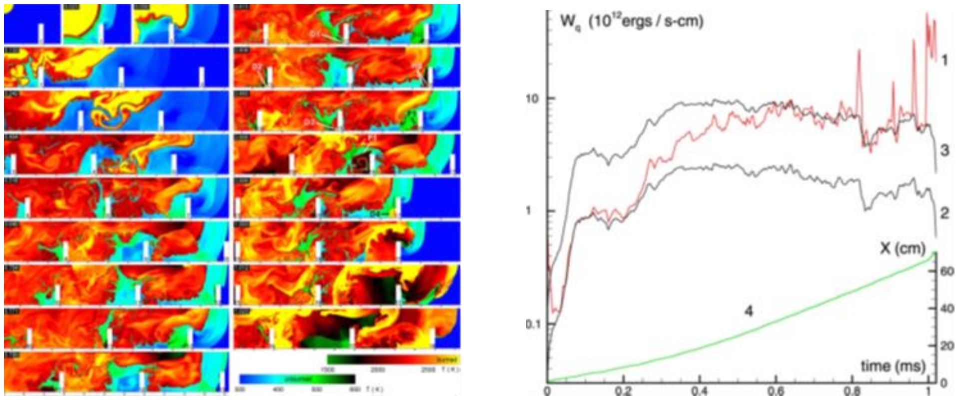


Figure 3 Detonation wave propagation in 90° bend [1]

■3.0 INFLUENCE OF OBSTACLE ON FLAME AND DDT DEVELOPMENT

3.1 Case 1

In order to identify the DDT performance precisely, the mechanism need to be well described. The effect of obstacle in channel filled with hydrogen-air mixture was studied by Gamezo *et al.* [2] and the influence of obstacle spacing by Gamezo *et al.* [3]. In the simulation works done by Gamezo *et al.* [2] the presence of obstacle in channel shows strong effect on flame acceleration. They speculated that the growth of flame surface area as the main mechanism responsible for the increased of burning rate yet triggering DDT in the obstructed channel. It shown that the hot flame expand along the channel, and distorted when interact with the obstacle subsequently turn into turbulent due to Rayleigh –Taylor (RT) instability. They also found that the turbulent flow generates compression waves and when coupling with the flame front, shock is formed. In particular, the shock reflects after collide with the obstacle and side wall subsequent create hot spot or center ignition which can be spontaneous wave. All of this evolution makes the flame surface area, the energy-release rate and the shock strength increase (Figure 4) follow by DDT occurrence. Moreover, Gamezo *et al.* [3] showed that the obstacle spacing also affected DDT. Indeed, the flame acceleration increases linearly with obstacle spacing. By increased the obstacle space, more flow perturbation (turbulence) created and hence flame surface area increase quickly and easily to form shock or so called leading shock (Mach stem). They also observed that DDT is formed behind leading shock right after reflected shock collided with an obstacle. The transition can easily perform providing the space between obstacles is sufficiently enough for Mach stem creation. Kessler *et al.* [12] support the above hypotheses by reproduce the DDT performance in large obstructed channel filled with stochiometric methane-air mixture. It was shown that the increase of geometrical size promote the formation of Mach stems and more non-uniform flow would be in favor created favorable to DDT event. This postulates that, the hypotheses reported by Gamezo *et al.* [2] is also significant for the large scale obstructed channel.



(a) (b)

Figure 4 Flame acceleration and DDT in channel with obstacle (a) and the energy-release rate profile(1,2,3) in different obstacle spacing (b) [3]

3.2 Case 2

Another mechanism found by Bychkov et al [6] and support by Valiev *et al.* [4] suggest that the physical mechanism of flame acceleration as the main mechanism triggering DDT in channels with obstacle. In the simulation work by Bychkov et al [6], turbulence playing only supplementary role in flame propagation thus the proposed mechanism is independent of the Reynold number. They found that, the flame accelerates fast throughout the unobstructed part of the channel and pushed the unburnt gas downward in between of the obstacle. This make the unburnt gas trapped and delay the burning rate. In particular, Valiev *et al.* [4] observed that, the trapped unburnt gas in between obstacle was at rest initially, concurrently flame propagates extremely fast along the un-obstruction part as shown in Figure 5. When the trapped unburnt gas burning, it creates a powerful jet-flow, driving the acceleration in which favorable transition to detonation occurred. Also noted that the new mechanism which proposed by Bychkov et al [6] and Valiev *et al.* [4] highlighting the influence of trapped unbrunt gas in between obstacle support the flame acceleration as well as DDT performance. They also found that the concept is more significant if the obstacle depth is small and the width is large in which can increase the amount of trapped unburnt gas and also increase the intensity of jet-flow. Somehow, the new mechanism contradicted with the classical Urtiew and Oppenheim [14] mechanism who disclosed that the presence of obstacle in the channel induces the turbulence to support DDT. The unused of element flame dynamic in the model to scale the acceleration rate could be the reason on the variation findings.

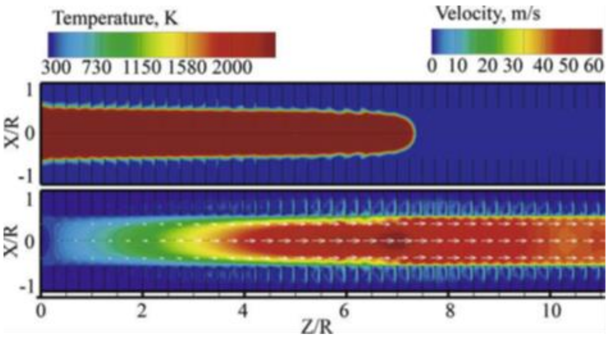


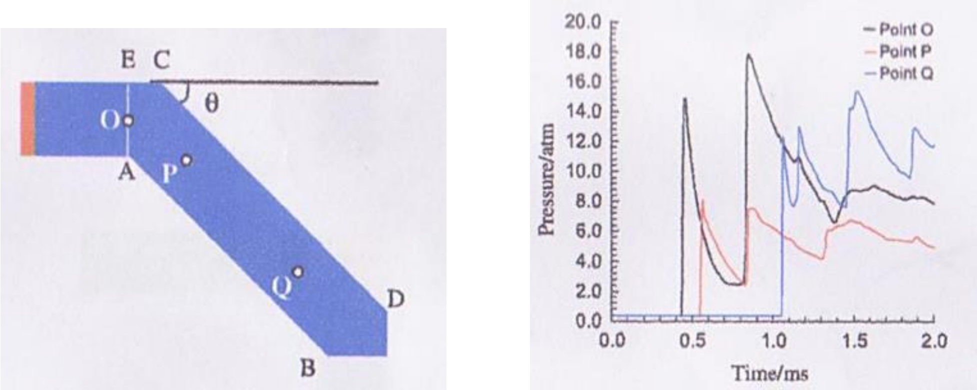
Figure 5 Flame acceleration in obstructed channel, simulated version [4]

■4.0 INFLUENCE OF BENDING ON FLAME ACCELERATION AND EXPLOSION DEVELOPMENT

Bend or elbow in pipeline system is part of obstruction which may increase the flame speed as well as increase the potential of explosion development [1, 5, 8, 13, 15-17]. Most of them confirmed that, the pressure difference at inner and outer part of the bend or elbow caused the flame flow unstable when passes the bend, is the main factor to induce turbulence intensity, thus speed-up the burning velocity before explosion take place (Figure 6). Indeed, the bend angle also affected explosion development, as postulated by Guo *et al.* [13] and Wang *et al.* [1]. From their work they found out that the 90° bend is more significance to enhance the explosion development neither 30°-45° nor 65°-70° bend. They observed that detonation wave diffracted and also reflected when passing through the 90° bend. When these waves interact, hot spot is formed concurrently to support second explosion and trigger detonation as well. However no observation on DDT made by Wang *et al.* [1] causes this model is insignificant for transition observation.

■5.0 CONCLUSION

It is clearly shows that the transition deflagration to detonation is unpredictable. There is no solid reference can answer exactly the "when" and "where" DDT appears in obstructed tube or channel. For instance, in case 1, the appearance of DDT is located behind leading shock right after reflected shock collided with an obstacle It is may be in the flame fold or in the preheat zone in which induce by the shock-wave intensity which is still doubtful. Unlike in case 2, the burning of trapped unburnt gas in between the obstacle creates a powerful jet-flow, driving the acceleration in which favorable transition to detonation occurred. The difference mechanism shows that many aspects is needed to be considered with. However, by considering the fluid dynamic effect and the dynamic of flame propagation, more realistic description can be produced to describe the DDT regime accurately.



(a) (b)

Figure 6 Computational model (a) and pressure profile in 90° bend (b) [1]

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