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A Method for Estimating the Burning Velocity in a Tube by Using Experimental Pressure Records and the 1-D RCMLAB code

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Introduction

Gas explosions in pipes and tunnels represent a significant hazard potential. In Norway, accidents like the H₂-explosion in a 1 km pipeline in Porsgrunn 1997 (Pande and Tonheim, 2000) and the flare explosion on the Sleipner platform last year are examples of such unwanted events. Even though gas explosion in pipes has been studied since 1883 we still do not have a complete understanding of the phenomena and we lack simple and good models for predicting such explosions. Better understanding of the burning velocity is essential for such models. This paper describes a method for determining the quasi one-dimensional burning velocity for a gas explosion experiments in a smooth tube from pressure records using the RCMLAB code

Experimental set-up

The experimental set-up consists of 4 steel tubes with an inner diameter of 22 mm and lengths of 1, 2, and 5 meter. In the experiments the tube was filled with premixed stoichiometric propane-air. The flow was controlled by flow meters. Immediately before ignition the tube inlet of was closed by a ball valve. The outlet was open. A spark at the inlet ignited the gas. Four Kistler 7261 pressure transducers measured the explosion pressures and the results were recorded digitally. The location of the pressure transducer #1, #2 and #3 were respectively 100 mm, 0.38 times the tube length and 0.70 times the tube length from the tube inlet and #4 was 100 mm from the tube outlet.

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The Random Choice Method (RCM)

A 1-D Random Choice Method code has been written in MATLAB (Bjerketvedt and Mjaavatten, 2001). The RCM has a unique capability for predicting complex wave interactions while maintaining the discontinuities of shock waves and contact surfaces. The principle of the RCM is to solve the Riemann problem in the domain between two neighboring grid points, the left domain [i,i+0.5] and right domain [i+0.5,i+1]. In order to find the exact solution of the Riemann problem one has to find the contact surface pressure p^* and velocity u^* . A random number sequence, in this case the Van der Corput pseudo random number, is used to choose sampling points ($i + \zeta$) for each zone. The combustion model in RCMLAB, illustrated in Figure 2, treats the combustion wave as a discontinuity (Bjerketvedt, 2002). We assume that the burning velocity, S, is known and we can then find the weak deflagration solution.

The thermodynamic data used in the RCMLAB simulations were determined by SuperSTATE (reference for SSS). In the present simulations the tubes were modeled as a 1-D planar geometry with 120 grid points per meter. The exterior at the tube exit was modeled as a 1-D spherical geometry of 0.3 meter (40 grid points). For the 5 meter case the simulation took less than 1 hour on a 1.7 GHz PC.



Estimator

The burning velocity, S(t) was estimated by using a proportional controller. The method for calculating the deviation between the measured pressures from the experiments and the model prediction is illustrated in Figure 3. At time t, the flame is located at x_F and x_{TD} is the pressure transducer position ahead of the flame. A perturbation caused by a change of burning velocity S(t)

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will not reach x_{TD} until the time t_{TD} . The right running characteristic Γ_+ illustrates this. The pressure, $p_{TD}(x_{TD}, t_{TD})$, should therefore be used for estimating S(t). To work out the equivalent pressure, $p_{RCM}(x_{TD}, t_{TD})$, for from the numerical code, we calculated the position of x_B from the right and left running characteristics Γ_+ and Γ_- . Then we solved the Riemann problem with the right state given by state at (x_F , t) and the left state given by the state at (x_B , t), to obtain $p_{RCM}^*(x_{TD}, t_{TD})$. This was done in a single time step (i.e. Δt) with the standard RCMLAB Riemann solver. The estimation of S(t) was based on the pressure record closest to the flame in the unburned gas. For the five-meter tube, pressure record #1 was active up to 20 ms, followed by # 2 up to 110 ms, #3 up to 180 ms and thereafter #4 was active. The equation for determining S(t) is shown below. This can be regarded as a proportional controller with Δp as the disturbance and K as the gain.

$$S(t) = S(t-dt) + K(p_{TD}(x_{TD}, t_{TD}) - p*_{RCM}(x_{TD}, t_{TD})) = S(t-dt) + K\Delta p(x_{TD}, t_{TD})$$



Figure 3: Location of Δp (x_{TD}, t_{TD})

Results and Discussion

Figure 4 shows the measured pressure records (dotted) the pressures from RCMLAB calculations (black), and the flame position (dashed) for the 5 m tube experiments. For transducer #1, #2 and #3 the agreement is quite good, especially in the first 50 ms. We find that our results qualitatively agree with the observations made by Clanet and Searby (1996) using high speed film in a similar experimental set-up. The estimated pressure for pressure transducer 4 (i.e. 100 mm from tube exit) was quite noisy. The model for the expansion at the tube exit is currently not optimal and needs improvements. In the region when the rarefaction wave from the exit is interfering with the flame

front the burning velocity goes to zero during some intervals. The numerical noise caused by the exit may explain these low burning velocities. The burning velocities in the initial state (t < 13 ms) are quite similar for all three experiments with a maximum of 5 m/s. It appears from the 1 m tube case that when the rarefaction wave reach the flame the burning velocity stabilizes at around 5 m/s for an extended time period.



Figure 4 : Pressure records and flame location



Figure 5 : Estimated burning velocity

Conclusions

We have developed a model for determining the burning velocity for a gas explosion in a smooth tube by using experimental pressure records and the RCMLAB code. The model seems to work quite well. We believe this method can give us new insight to flame acceleration mechanisms in pipe.

References

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