

GAS EXLOSION CHARACTERISTICS IN CONFINED STRAIGHT AND 90
DEGREE BEND PIPES

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LIST OF ABBREVIATIONS

ADC	-	Analogue/digital conversion
<i>a</i>	-	Constant
BR	-	Blockage ratio
CFD	-	Computational Fluid Dynamics
CO	-	Carbon monoxide
CO ₂	-	Carbon dioxide
C ₂ H ₂	-	Acetylene
C ₂ H ₄	-	Ethylene
C ₃ H ₈	-	Propane
CH ₄	-	Methane
CH ₂ O	-	Formaldehyde
CH ₂ CO	-	Ketene
CO	-	Carbon monoxide
<i>c_p</i>	-	Specific heat
<i>c_μ</i>	-	constant in k-ε equation (<i>c_μ</i> =0.09)
<i>μ_{eff}</i>	-	effective viscosity
DNS	-	Direct numerical simulation
<i>Da</i>	-	Damköhler number
dP/dt	-	Rate of pressure rise
dt	-	time step
E	-	Expansion ratio
E _a	-	Activation energy
FS	-	Full scale
FLACs	-	Flame Acceleration Computational simulator
G	-	Generation rate of turbulence
H	-	Hydrogen
H ₂ O	-	Water
K	-	Thermal conductivity

K	-	kinetic energy of turbulence
K-H	-	Kelvin – Helmholtz
Ka	-	Karlovitz number
L	-	Length
Le	-	Lewis number (dimensionless)
L-D	-	Landau – Darrieus
LPG	-	Liquefied petroleum gas
LFL	-	Lower flammability limit
L/D	-	Ratio of pipe length to diameter of pipe
LES	-	Large eddy simulation
l_T	-	Turbulent length scale
MISC	-	Malaysian International Shipping Company
Mach	-	Object speed divided by speed of sound, (dimensionless)
Ma	-	Markstein length
NG	-	Natural gas
O	-	Oxygen
OH	-	Hydroxide
P	-	Pressure
P_{max}	-	Maximum pressure
PG:	-	Pressure gauge
P_1 - P_6	-	Pressure transducer at position 1-6
R	-	Gas constant
R	-	Flame radius
R-T	-	Rayleigh – Taylor
R-M	-	Richtmyer – Meshkov
Re_T	-	Turbulent Reynolds number
SGS	-	Sub grid-scale
S_f	-	Flame speed
S_g	-	Unburned gas velocity
S_L	-	Laminar flame
S_T	-	Turbulent flame
T_b	-	Maximum flame temperature
T_u	-	Unburned gas temperature
T_1 - T_7	-	Thermocouple at position 1-7
t_f	-	The time after the distinct change of output signal

t_i	-	The time before the distinct change of output (flame arrival time)
UFL	-	Upper flammability limit
V1 & V2	-	Valve 1 and valve 2
V	-	Voltage
W	-	Width
WHRU	-	Waste heat recovery
X_f	-	Distance of the next thermocouple from the ignition point
X_i	-	Distance of the previous thermocouple from the ignition point
Y	-	Reactant concentration
ρ_u	-	Density of unburned gas
ρ_b	-	Density of burned gas
τ_r	-	Reaction time,
β	-	Zeldovich number (dimensionless)
γP	-	Fuel dependent parameter
ε	-	rate of dissipation
1D	-	1 diameter
2D	-	2 dimension
Φ , ER	-	Equivalence ratio,
δ	-	laminar flame thickness

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ABSTRACT

Gas explosion inside a pipe is a complex phenomenon. Extensive studies have been carried out to investigate factors governing to the explosion development i.e. the flame speed and the maximum pressure. However, most of the works are limited to open straight pipes. Worst, the effect of the obstructions on the explosion severity is still unclear. Most of the gases used in the industrial piping are highly combustible and has a potential to initiate detonation hazard. In this work, gas explosions inside closed pipes are considered. Experimental and Computational Fluid Dynamic (CFD) analyses using FLACs are adopted to investigate the physical and dynamic behaviour on gas explosion development in pipes. Hydrogen, acetylene, ethylene, propane and methane were used as fuels. The effect of pipe configuration (straight and 90 bend pipe) with different length to diameter ratio (L/D) was investigated. From the results, it was observed that the presence of 90 degree bend enhances the explosion severity by a factor of 1.03-3.58 as compared to that of the straight pipe. Based on the simulation analysis, the compression effect at the bending region and at the end of the pipe plays an important role to attenuate the burning rate, which resulting to a higher flame speeds and hence, increases the overpressure. Interestingly, a maximum overpressure of 14 barg with flame speed of 700 m/s was observed in the smaller pipe of $L/D=40$ with acetylene fuel which indicated that the detonation-like event take place. The ability of the flame to quench becomes insignificant in a smaller pipe, promoting a strong interaction of the fast flame and turbulence, particularly at the bending. This phenomenon amplifies the mass burning rate, increases the flame speeds and leading to a higher pressure rise. From the results, it shows that fuel reactivity and pipe size and configuration gives a significant effect to the overall overpressure and flame acceleration development which can lead to a catastrophic explosion.

ABSTRAK

Letupan gas di dalam paip adalah satu fenomena yang kompleks. Kajian menyeluruh telah dijalankan bagi mengkaji faktor-faktor yang mengawal kejadian letupan seperti kelajuan api dan tekanan maksimum. Walau bagaimanapun, sebahagian besar daripada kajian-kajian yang telah dijalankan terhad kepada paip lurus terbuka. Malangnya, kesan halangan terhadap tahap letupan masih tidak jelas. Kebanyakan gas yang digunakan di dalam paip perindustrian adalah sangat mudah terbakar dan berpotensi untuk mengundang bahaya letupan. Dalam kajian ini, letupan gas di dalam paip tertutup dipertimbangkan. Ujikaji dan Pengkomputeran Dinamik Bendalir (CFD) digunakan untuk mengkaji tingkah laku fizikal dan dinamik kepada kejadian letupan gas di dalam paip. Hidrogen, asetilena, etilena, propana dan metana telah digunakan sebagai bahan api. Kesan konfigurasi paip (lurus dan 90 darjah lentur) serta perbezaan nisbah panjang kepada diameter (L/D) telah dijalankan. Hasil daripada keputusan, didapati bahawa kehadiran 90 darjah lentur meningkatkan tahap letupan dengan faktor 1.03-3.58 berbanding dengan paip lurus. Berdasarkan analisa simulasi, kesan mampatan di rantau lenturan dan dihujung paip memainkan peranan penting bagi meningkatkan kadar pembakaran, yang membawa kepada perambatan kelajuan api yang lebih tinggi serta meningkatkan tekanan lampau. Menariknya, tekanan lampau maksimum 14 barg dengan kelajuan api 700 m/s diperhatikan dalam paip yang lebih kecil daripada $L/D=40$ pada bahan api asetilena dan ini menunjukkan bahawa fenomena letupan telah berlaku. Keupayaan untuk pemadaman api menjadi tidak penting di dalam paip yang lebih kecil dan ia menggalakkan interaksi yang kuat di antara api dengan pergolakan terutama di bahagian lentur. Fenomena ini menguatkan lagi kadar pembakaran, meningkatkan kelajuan api dan kenaikan tekanan yang lebih tinggi. Daripada keputusan, ia menunjukkan bahawa kereaktifan bahan api serta saiz paip dan konfigurasi memberikan kesan yang besar kepada pembangunan tekanan lampau dan kelajuan api yang boleh membawa kepada bencana letupan.

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