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# Blast wave from bursting enclosure with internal hydrogen-air deflagration

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# Presentation outline

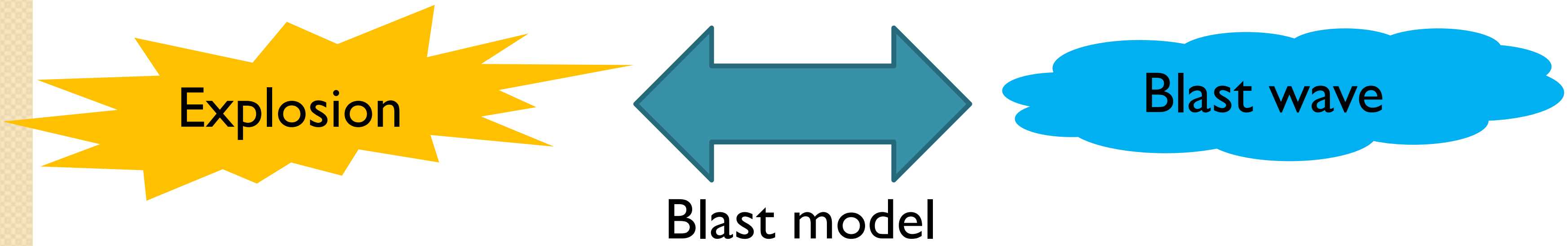
- Introduction
- Experimental
- Results and Discussion
  - Peak overpressure
  - Impulse
- Concluding remarks

# Background (1/3)

Blast wave damages wide area and is one of the significant elements which make the damages of gas explosions larger.

To take the safety measure to decrease damages, it is necessary to know the relation between gas explosion and blast wave.

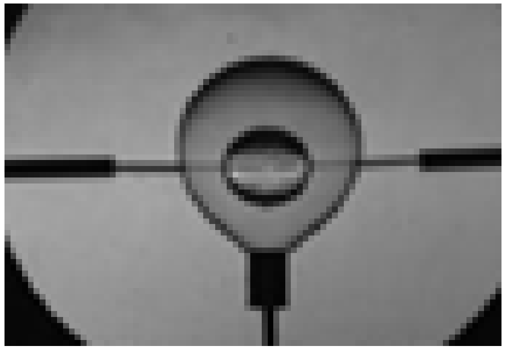
Gas explosion accident at the hot spring facility
(2007, Japan)
http://www.bousaihaku.com



# Background (2/3)

Many researches have been studying blast waves from gas explosions experimentally and theoretically.


Plastic tent
(K.Wakabayashi et al,2007)



Soap bubble
(W.K.Kim et al,2013)

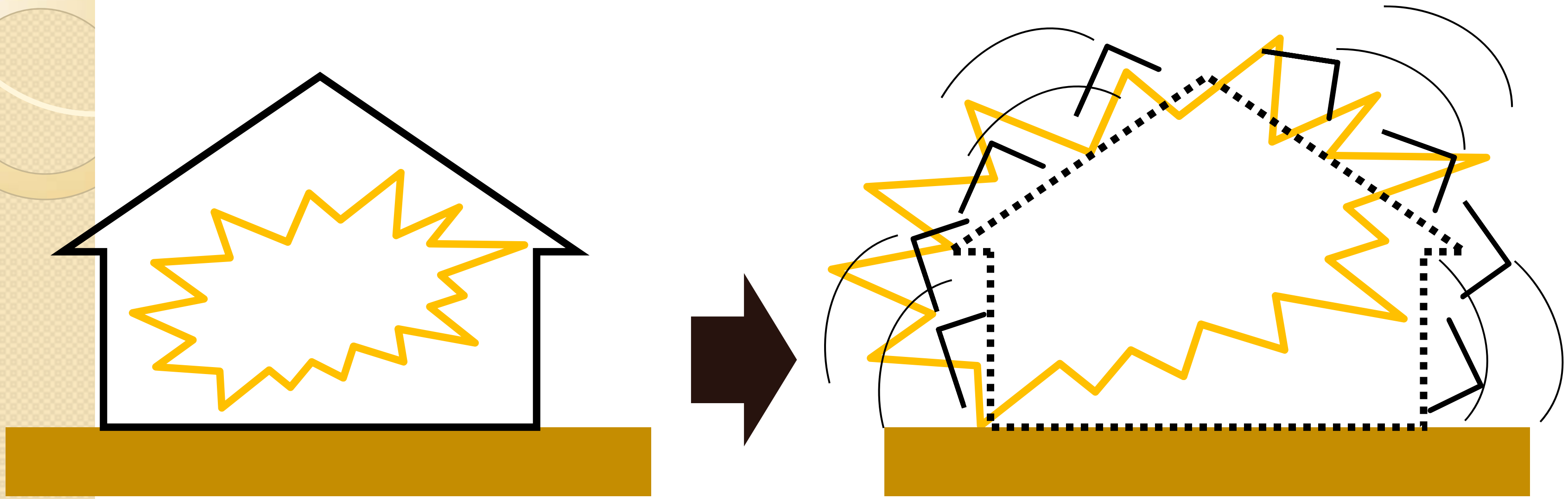
Pressure of blast wave
from spherical gas deflagration
(W.K.Kim et al,2013)

$$p = \frac{\rho}{d}(\varepsilon - 1)\left\{2\varepsilon^2 S^2 t + r^2 \frac{dS}{dt}\right\}$$

$\rho$: Density $\varepsilon$: Volumetric expansion ratio $d$: Distance
$S$: Burning velocity $t$: Time $r$: Flame radius

It is known that the pressure of blast wave depends on flame propagation speed.

# Background (3/3)



① Leaked flammable gas is mixed and ignited in confined space, such as vessels or buildings.

②Pressure in the confined space increased. Then vessel is broken and blast wave is generated.

Is the blast wave from this explosion same as that from open space gas explosion？

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# Baker model

Baker studied the blast waves from bursting sphere vessels in which pressures were larger than ambient pressure (W.E.Baker, 1977).

$p_1$:Pressure
$\gamma_1$:Specific heat ratio
$a_1$:Sound speed
$V_0$:Volume

$p_s$:Side on pressure of blast wave

Atmosphere
$p_0$:Pressure
$\gamma_0$:Specific heat ratio
$a_0$:Sound speed

$$p_1 = p_s \left[ 1 - \frac{(\gamma_1 - 1)(a_0/a_1)(p_s/p_0 - 1)}{\{2\gamma_0[2\gamma_0 + (\gamma_0 + 1)(p_s/p_0 - 1)]\}^{1/2}} \right]^{\frac{-2\gamma_1}{\gamma_1 - 1}}$$

The pressure of blast wave decreased as propagating away. The decrease curve is correspond to that of high explosive using energy $E = \frac{p_1 - p_0}{\gamma_1 - 1} V_0$

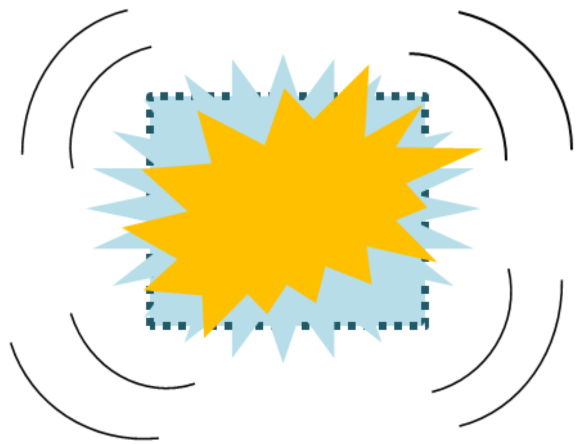
Please note that this model didn’t consider combustion reaction.

# Existing problem

**Flammable mixture**

Vessel bursted before ignition

Open space gas explosion



Vessel bursted during combustion

**Blast model？**

**Burned gas**

Vessel burst after all gas burned

High pressure Baker's model

There are little studies that examined the blast waves from bursting vessels, in which gas explosions happen, in detail.

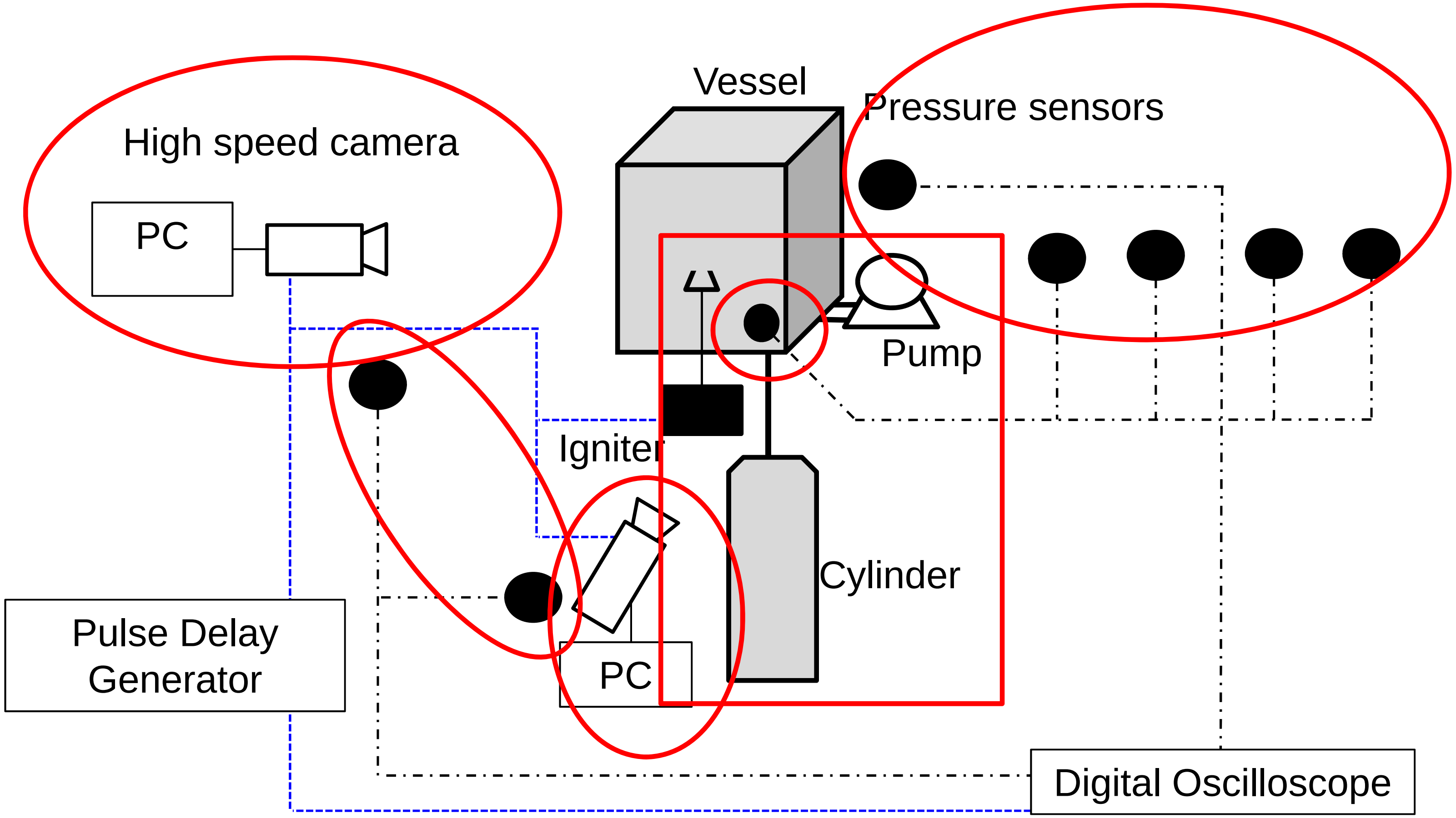
# Objective

To investigate the blast wave from bursting vessels with hydrogen-air deflagration,

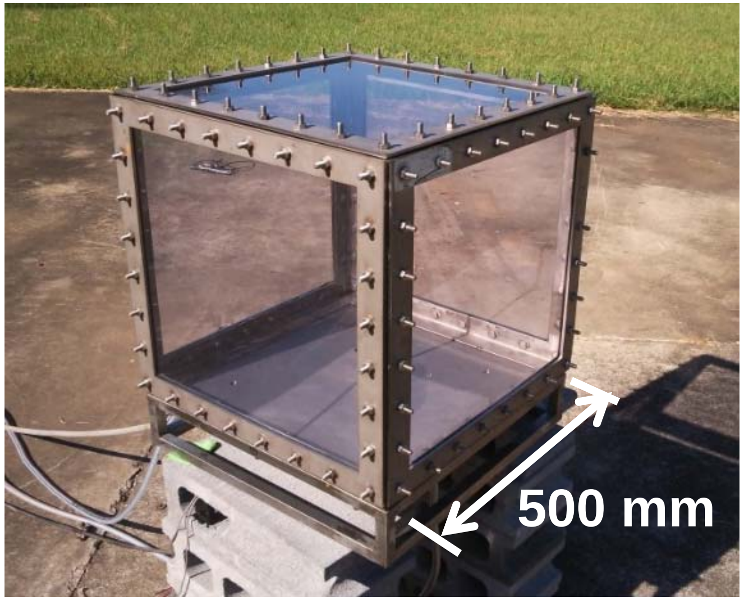
Experiments were performed various strength of the vessel and hydrogen concentration.

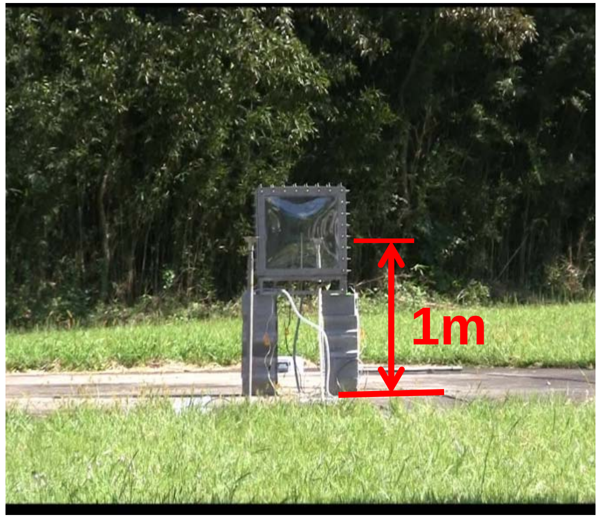
We focus the relation between the intensity of blast wave and the pressure in the vessel when vessel burst.

# Experimental setup



# Details of vessel

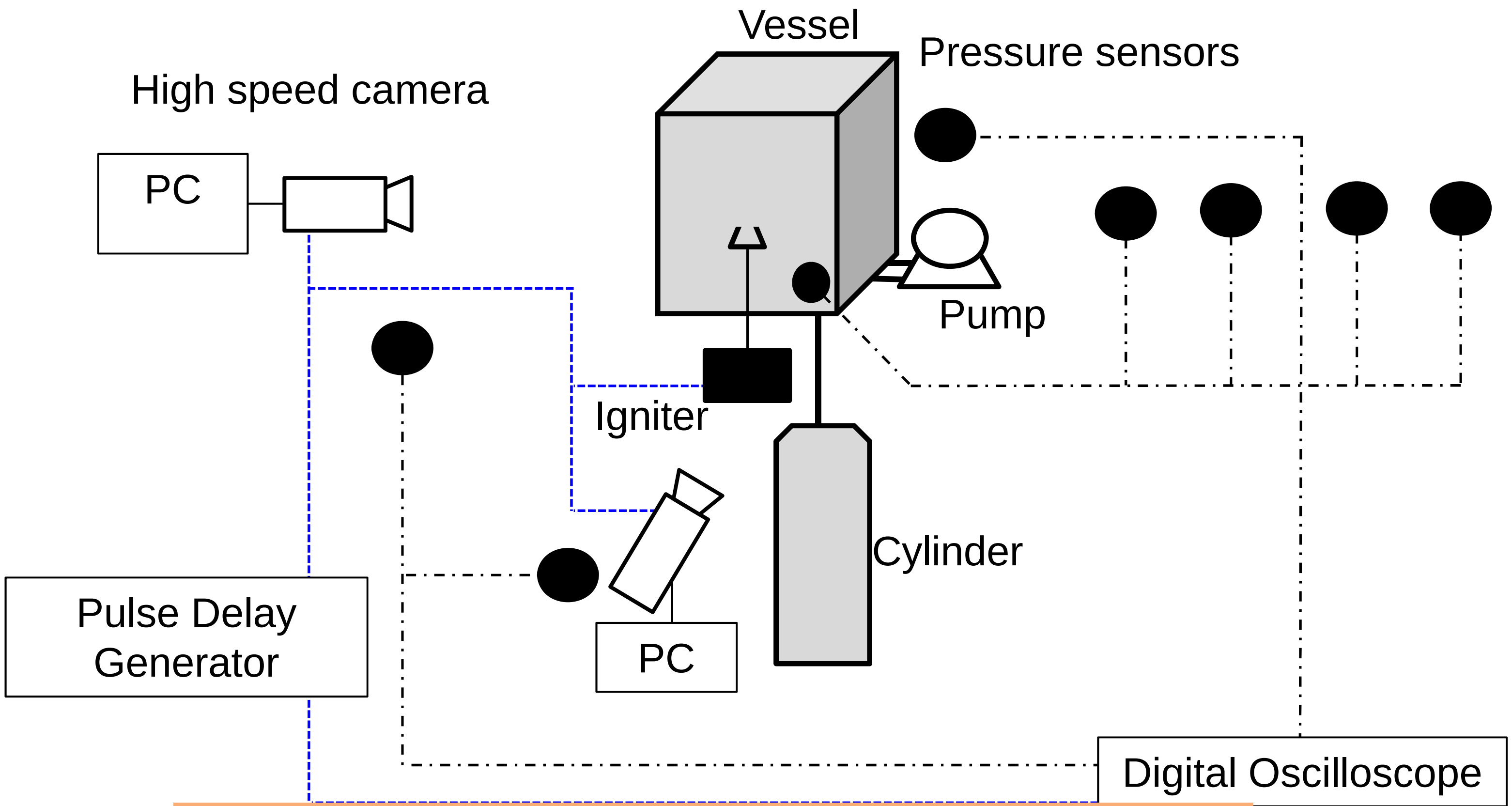



Volume 0.125 $m^3$ (125L)

Wall condition(except bottom)
Poly vinyl chloride (PVC)
Thickness 0.5 mm～6 mm
and
Polyethylene(unconfined)

# Experimental setup




Hydrogen-air mixture were used.
Equivalence ratio was 0.5, 1.0, 1.8 and 2.5.
Cf. Methane-air mixture $\phi = 1.0$

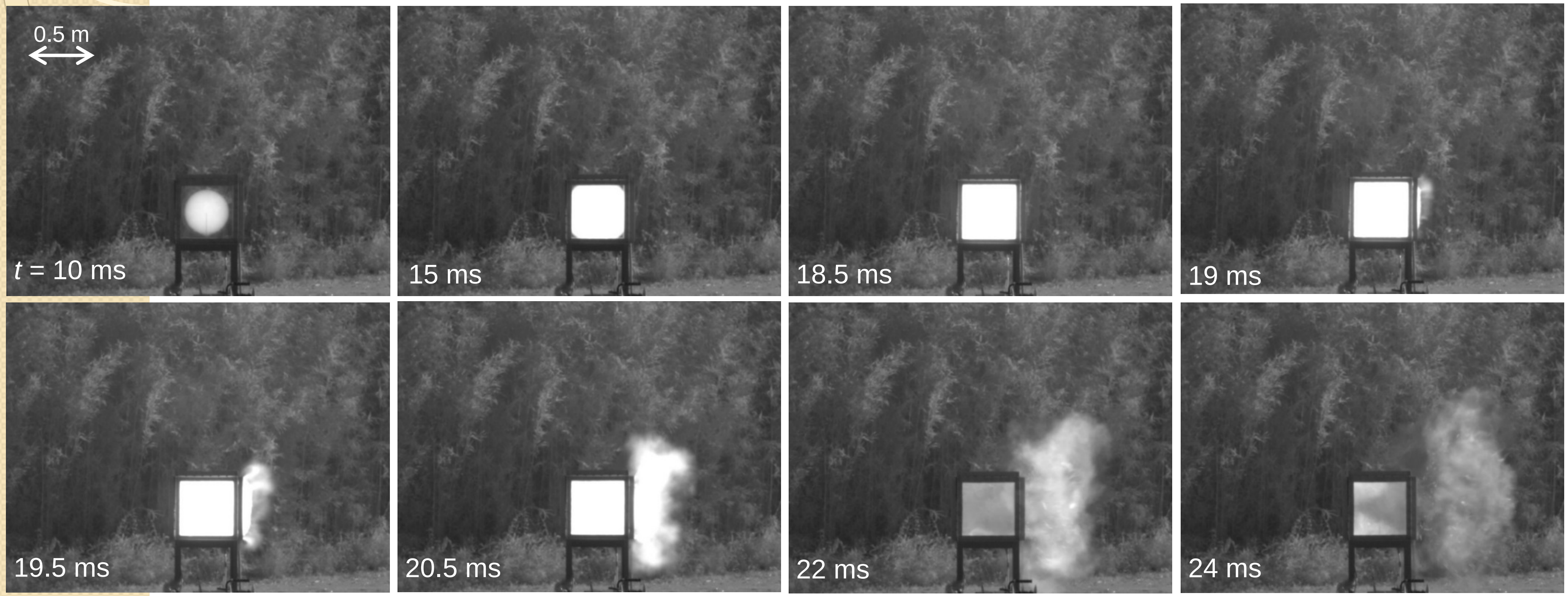
# Explosion phenomena

High speed video movie

$H_2$-air mixture $\phi$ =1.0, 1wall, $P_b$ = 399 kPa

# Explosion phenomena

## Pictures of frame capture



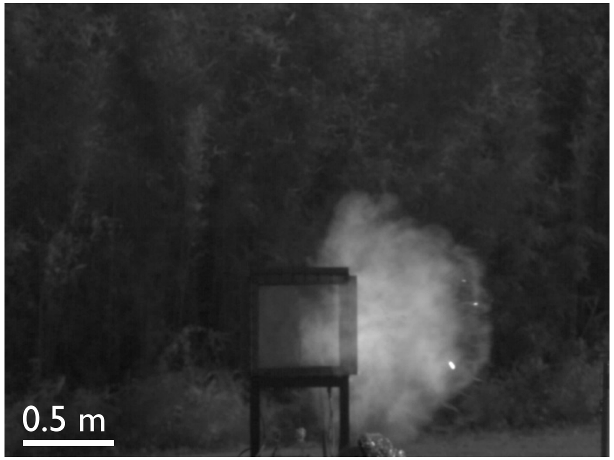

$H_2$-air mixture $\phi$ = 1.0, 1wall, $P_b$ = 399 kPa

① Flame propagates spherically in the vessel.
② The vessel burst when the flame propagate to approach the wall.
③ When the vessel burst, the mixture in the vessel suddenly jet out.

# Flame behavior

5 ms after one wall vessel burst


$H_2$ $\phi$ = 0.5, $P_b$ = 246 kPa

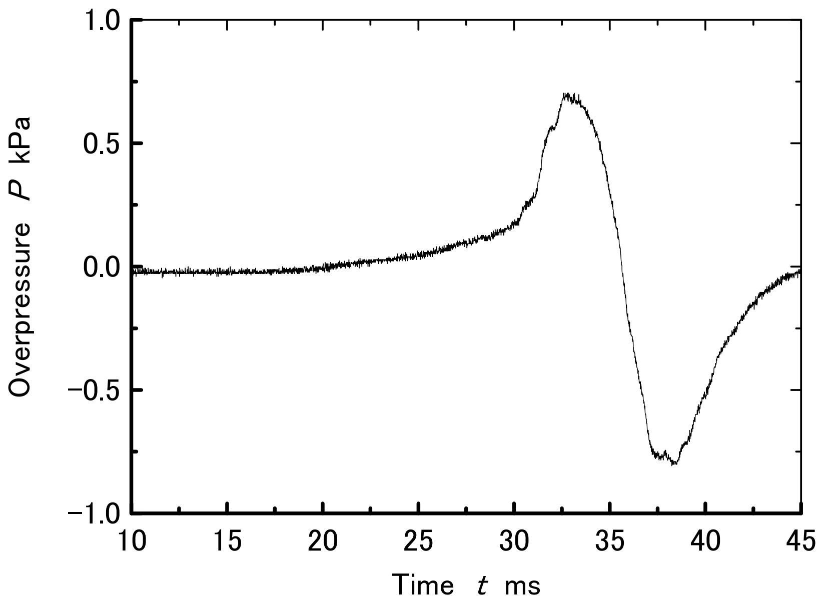



$H_2$ $\phi$ = 2.5, $P_b$ = 183 kPa

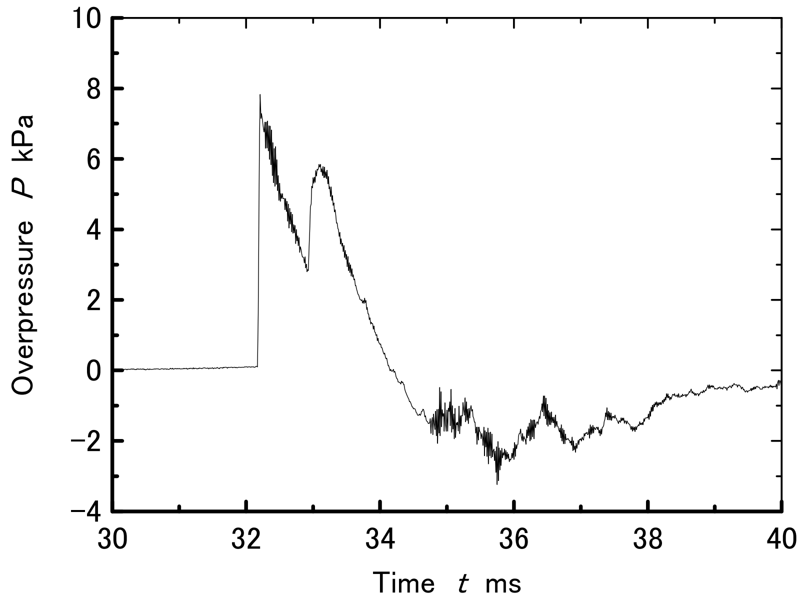

$CH_4$ $\phi$ = 1.0, $P_b$ = 264 kPa

- Lean concentration : flame luminescence is weak
- Rich concentration : flame propagate far away
  (combustion reaction continue for long time)

# Pressure histories of blast wave (1/3)




$H_2$ $\phi$ = 1.0, sheets
(Unconfined space)

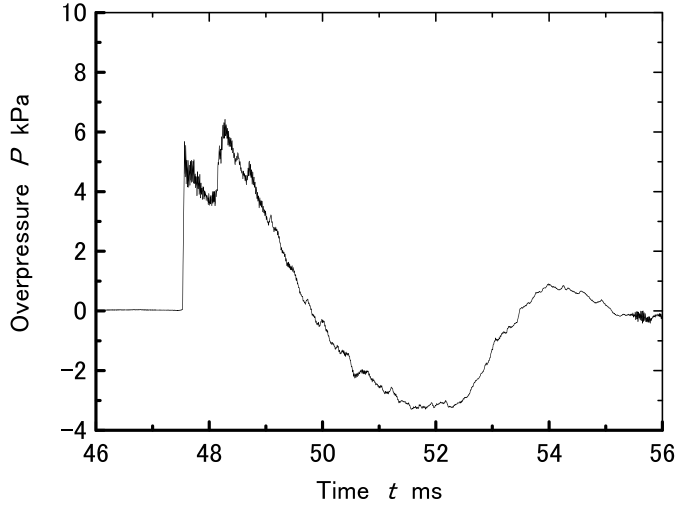



$H_2$ $\phi$=1.0, 5 PVC wall, $P_b$=268kPa
(Confined space)

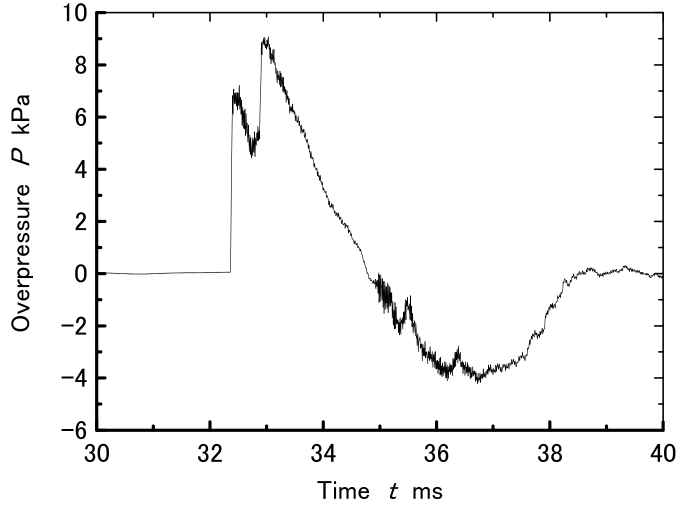
Increase gradually
One peak

Increase suddenly
Two peaks

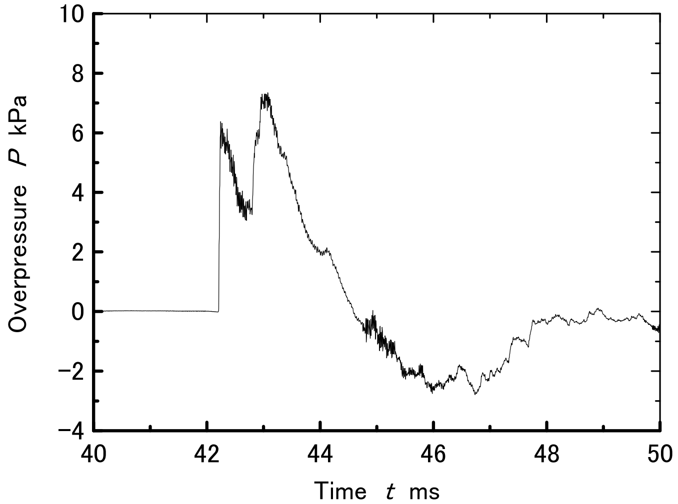
# Pressure histories of blast wave (2/3)



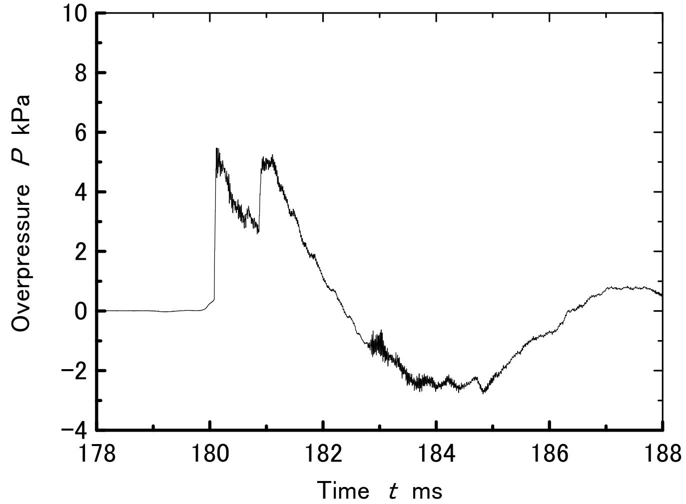

$H_2$ $\phi$=0.5, 1wall $P_b$=246kPa




$H_2$ $\phi$=1.0, 1wall $P_b$=255kPa

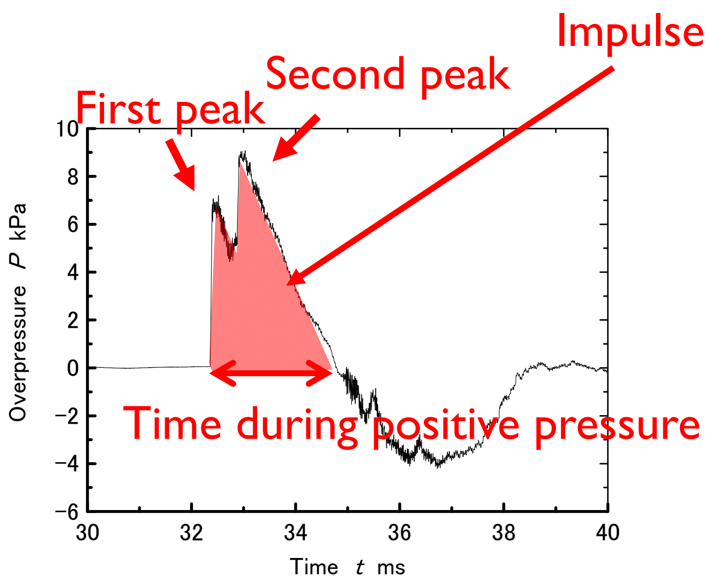



$H_2$ $\phi$=2.5, 1wall $P_b$=183kPa




$CH_4$ $\phi$=1.0, 1wall $P_b$=264kPa

# Pressure histories of blast wave (3/3)




$H_2$ $\phi$=1.0, 1wall $P_b$=255kPa

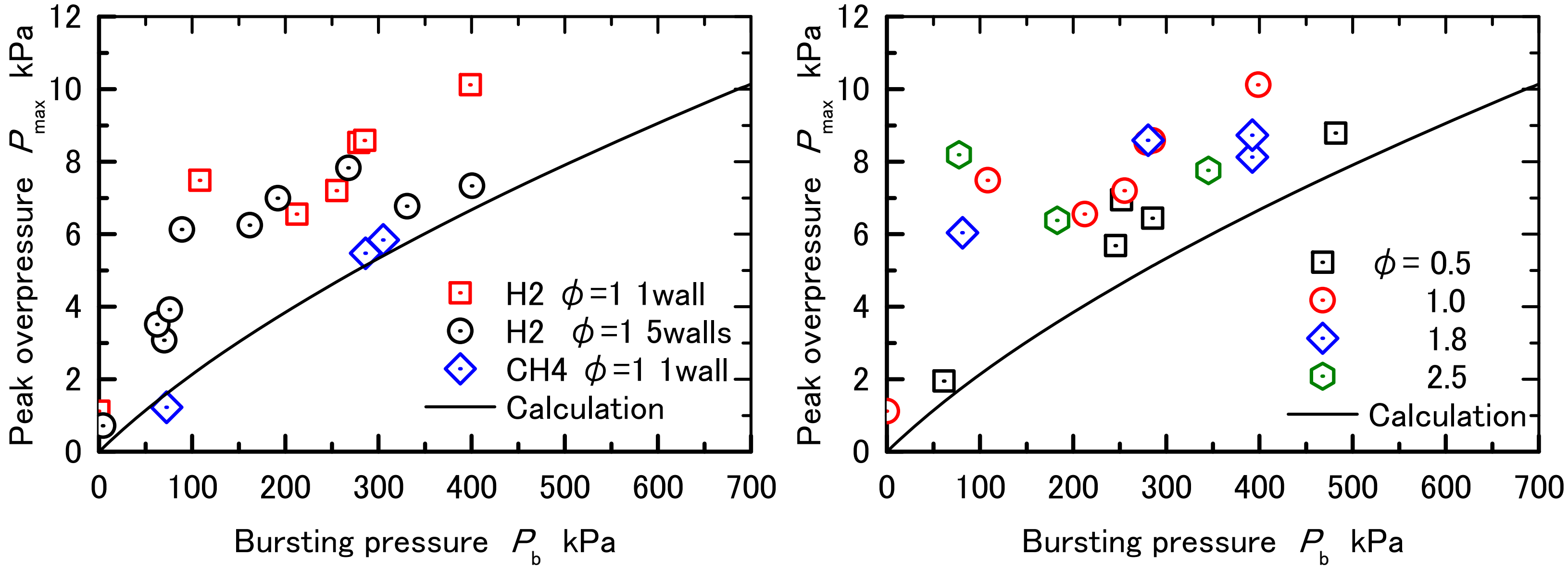
- The pressure increase sharply and first peak generated when the vessel burst.

- It seems that the main cause of the first peak generation is sudden jetting out of high pressure mixture in the vessel.

- After vessel burst, it seems that combustion reaction is continued near the bursting walls.

- it is considered that second peak on the pressure histories of the blast wave is caused by turbulent flame propagation.

# First peak overpressure




- These peak overpressure were measured at 5 m away from the center of the vessel.
- Bursting pressure means the pressure in the vessel when the vessel burst.
- The curve in the graphs shows calculated value by based on Baker's model and Yellow Book..

  → spherical symmetry

  → ignore the effect of reflection from the ground

- Hydrogen-air mixture → larger than calculated value.
- Methane-air mixture → almost agree

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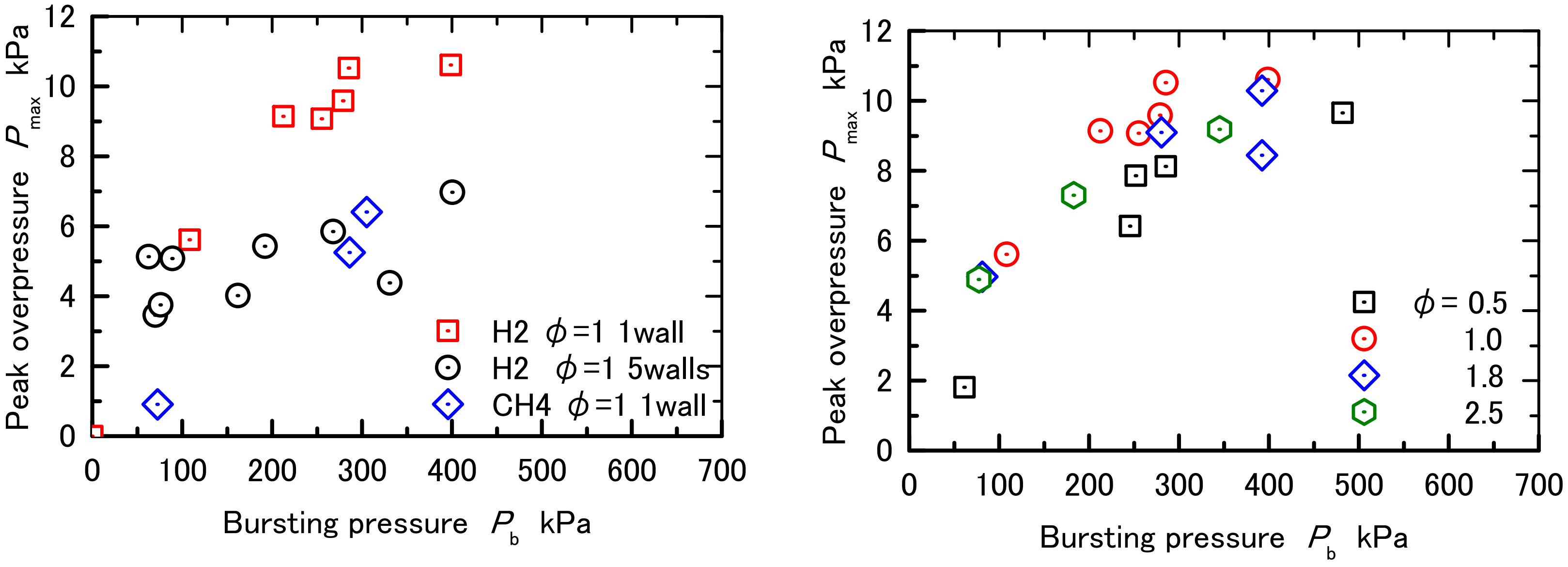
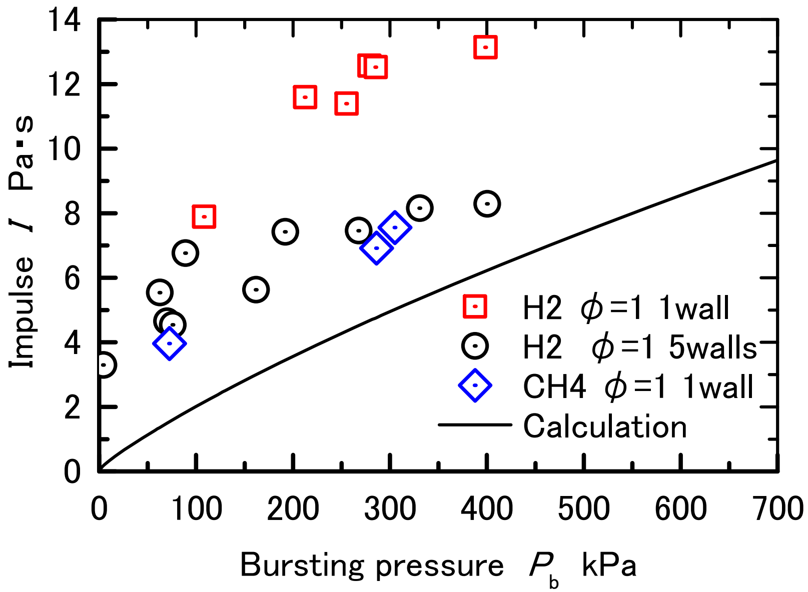
# Second peak overpressure

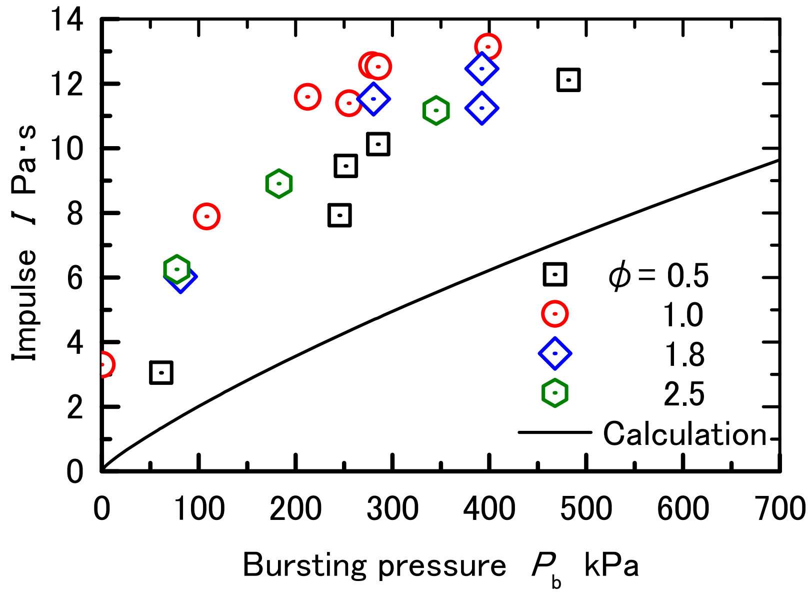



- The main difference from first peak is influence of the number of bursting wall.

- When only one wall burst, the unburned mixture in vessel jet out only one direction.
- The combustion reaction after vessel burst is enhanced in the case of one wall bursting more significantly than in the case of five wall bursting.

# Impulse

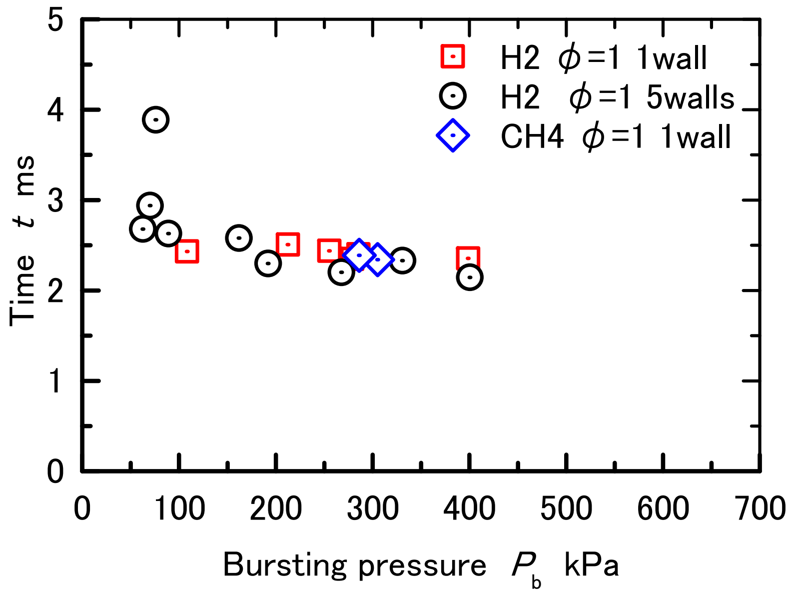


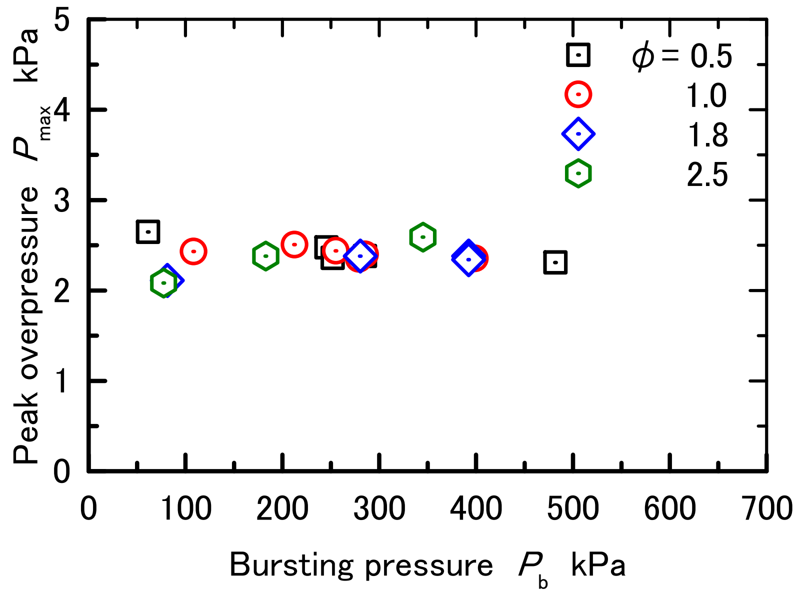




- The curve in these figures shows the calculated values of bursting vessel by high pressure mixture of hydrogen-air presuming that combustion reaction stops at vessel bursting.
- Experimental values are larger than the calculated values.

- Second peak is generated by combustion reaction after vessel bursting.
- The dependence of impulse on the condition of explosion phenomena tends to be same as that of second peak.

# Time during positive pressure of blast wave




- If the bursting pressure is over about 100 kPa, the time during positive time is almost constant although bursting pressure increases.
- The time is independent of the condition of flammable mixture.

- It is suggested that the impulse can be determined only by the peak value.

# Concluding remarks

- There are two peaks on the pressure histories of blast waves. The first peak was generated from sudden jetting out of high pressure mixture at vessel bursting and the second peak was generated from combustion reaction after vessel burst.
- The first peak overpressures increased as bursting pressure increased and were larger than that from open space gas explosions because of the first peak was generated by the effect of venting high pressure mixtures. However, the measured first peak values were larger than the calculated values of high pressure bursting without combustion reaction. It is inferred that the combustion reaction made some effect on the generation of first peak.
- The intensities of blast wave which include the first peak, second peak and impulse were larger in case of hydrogen-air explosions than in case of methane-air explosions. However, the effect of equivalence ratio of hydrogen-air mixture on the intensities was small.

# Acknowledgment

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Thank you for your attention

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