

## Learning Equipment for the Flammability Limits of Liquefied Petroleum Gas

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**Abstract: Problem statement:** This article was developing learning equipment for flammability limit behavior which designed for study the relation of Liquefied Petroleum Gas (LPG) and combustion. The equipment can be use as an instructional media for obviously experiment of combustion. **Approach:** The test chamber was designed by using the stainless as a structure. The mirror with safety film was used for safety purpose to the tester. The mirror was the additional equipment for the ignition vision. The size of test chamber was 40×25×20 cm. The top of chamber can be opened when the ignition was occurred to reduce the inner pressure that can break the mirror or can be a cause of damage to other parts. The 2 of stainless plates with the size of 15×40 cm. were used and the hinges were attached at the upper edges of the chamber from both sides. The metal was closely attached at the chamber edge to reduce the leak of fuel to outer environment. The bottom structure of the chamber installs the control mainboard of electronics system and motor. The control of heat gain system inside the heat chamber. **Results:** The test chamber is designed to demonstrate the ignition. So, the size has to be suitably designed and large enough for convenience in monitoring. It can be seen that when the test is conducted in a real system, the result is extremely differed from the theory. The reason is the experimentation by the theory using the cup burner or a cylindrical glass cup. This cup has an outside diameter of 28 mm. and around the cup tunnel has an inside diameter of 8.5 or 9.5 cm with 53.5 cm. of height. The ratios of both testing equipments are extremely differed, so there is an opportunity that the accuracy is highly shifted. **Conclusion:** The test chamber shows that the flammability limit of LPG vary with temperature and can be compare with burgess-wheeler law. This law mentioned “LFL and UFL is relative with the chemical in Paraffin Hydrocarbon (Alkane) Group in any increasing of temperature” In addition, there are many flammability and backfire theory which interesting for experiment.

**Key words:** Learning equipment, flammability limit, upper flammable limit, lower flammable limit, liquefied petroleum gas, combustion, cup burner, Burgess-Wheeler Law

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### INTRODUCTION

The vapour of flammable substance, which is mixed with air, is able to launch the combustion when the mixture ratio between the concentration of the vapour of flammable substance and the air is mixed in certain range that is suitable for ignition. The ignition will be occurred when the energy is sufficient. The ratio of the mixture between fuel and air, that is flammable when the ignition is activated, is called “Flammability Limit”. The flammability limit is the flammable range fallen between the Lower Flammable Limit (LFL) and the Upper Flammable Limit (UFL) as shown in Fig. 1.

The Lower Flammable Limit (LFL) or Lower Explosion Limit (LEL) is the percentage of gas or smallest vapour of fuel that is mixed with air produces a suitable mixture for propagating flame. If the percentage of fuel that is mixed with air has less concentration, the propagating flame will not be occurred. The Upper Flammable Limit (UFL) or the Upper Explosion Limit (UEL) is the percentage of gas or highest vapour of fuel that is mixed with air produces a suitable mixture for propagating flame. In case the percentage of fuel that is mixed with air has more concentration, the propagating flame will not be occurred.

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A lot of researchers contributed to the liquefied petroleum gas such as, Adzimah and Anthony (2009); Bakar (2008); Lu and Li (2011); Meshkatoddini (2008); Ning and Chan (2007).

**MATERIALS AND METHODS**

**The related laws:** From the Le Chatelier's law, the concentration of the lowest flammability limits of fuel mixtures with the type of parafin hydrocarbon (C<sub>n</sub>H<sub>2n+2</sub>) relates to the concentration when the absolute combustion is occurred as proposed in Eq. 1-3:

$$\frac{1}{X_L} = \sum_{i=1}^{N_{fuel}} \left( \frac{X_i}{X_{Li}} \right) \tag{1}$$

$$X_L = 0.55X_{st} \tag{2}$$

$$X_U = 6.5X^{1/2} \tag{3}$$

Where:

X<sub>L</sub> = The % by mole of fuel at lower limit

X<sub>U</sub> = The % by mole of fuel at upper limit

X<sub>st</sub> = The % by mole of fuel at upper limit at standard state (25°C, 1 atm)

From earlier mentioned equation, the quantity of LEL and UEL can be calculated for fuel mixtures with the type of parafin hydrocarbon. The test substance used in this research is the liquefied petroleum gas or LPG, which has the compound of 40% of Propane and 60% of n-Butane, respectively. The characteristics of LEL and UEL are shown in Table 1.

The calculation of X<sub>L</sub> and X<sub>U</sub> of LPG can be determined from the LFL of Propane at 2.1% and LFL of Butane at 1.8% by Eq. 1:

$$X_L(\text{LPG}) = \frac{100}{\frac{40}{2.1} + \frac{60}{1.8}} = 1.9\% \text{ (by volume)}$$

where, X<sub>L</sub> of LPG is 100. From Eq. 3, the value of X<sub>U</sub> can determine the X<sub>U</sub> as following:

$$X_U = 6.5\sqrt{1.9} = 8.9\% \text{ (by volume)}$$

From Burgess-Wheeler Law, the LFL and UFL are related to parafin hydrocarbon when the temperature is increased to certain point in which the temperature has the impact on the flammability limit.

Table 1: Shows the flammability characteristics of fuels

Fuel	LFL (%)	UFL (%)	AIT (°C)	T <sub>L</sub> (°C)
n-Butane	1.8	8.4	405	-72
Propane	2.1	9.5	450	-102

When the temperature is increased, the flammability limit will be increased in the same manner as proposed in Eq. 4 and 5.

$$X_{L,T} / X_{L,T 25^\circ\text{C}} = 1 - 0.000721 (T-25^\circ\text{C}) \tag{4}$$

$$X_{U,T} / X_{U,T 25^\circ\text{C}} = 1 - 0.000721 (T-25^\circ\text{C}) \tag{5}$$

**Equipment development:** the test chamber is designed by using the stainless as a structure. The mirror with safety film is used for safety purpose to the tester. The mirror is the additional equipment for the ignition vision. The size of test chamber is 40×25×20 cm. and the calculated volume is 20,000 cm<sup>3</sup>. The top of chamber can be opened when the ignition is occurred to reduce the inner pressure that can break the mirror or can be a cause of damage to other parts. The 2 of stainless plates with the size of 15×40 cm. are used and the hinges are attached at the upper edges of the chamber from both sides. The metal is closely attached at the chamber edge to reduce the leak of fuel to outer environment. The bottom structure of the chamber installs the control mainboard of electronics system and motor. The control of heat gain system inside the heat chamber is shown in Fig. 2 and 3.

The equipment to connect the LPG pipeline is installed from gas tank to the chamber through the regulator. The purpose is to reduce the gas pressure moving to the flow meter. The flow rate of LPG is adjusted to 30 L min<sup>-1</sup> or 0.0083 L sec<sup>-1</sup>, which is used as a constant flow rate in this research to calculate the LPG volume inside the test chamber (the flow rate is multiplied with the time duration of transferring LPG to the test chamber). When all equipments are already installed, the data of pressure and flow rate that is a constant control volume, is collected from all experiments.

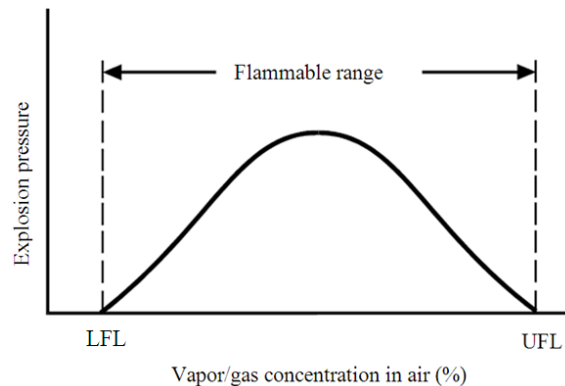


Fig. 1: Depicts the flammability limit



Fig. 2: Shows the test chamber

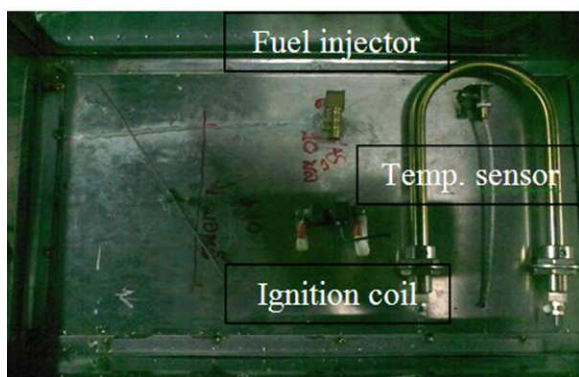


Fig. 3: Shows the locations of inner equipments

**The testing of equipment:** From the calculation, the determined LEL value of LPG is 1.9% and UEL value of LPG is 8.9%. The fuel quantity moving to the test chamber has a rate of 0.0083 L/sec. Then, the fuel quantity in the test chamber can be determined by Eq. 6.

$$\text{LPG quantity at \% LEL or UEL} = \frac{(\% \text{ LEL or UEL} \times \text{test chamber volume})}{100} \quad (6)$$

From Eq. 6, the LPG quantity by proportions of LEL and UEL can be calculated as following:

$$\begin{aligned} \text{Quantity of LPG at \% LEL} &= 1.9 \times 20 \text{ L} / 100 = 0.38 \text{ L} \\ \text{Quantity of LPG at \% UEL} &= 8.9 \times 20 \text{ L} / 100 = 1.78 \text{ L} \end{aligned}$$

When the quantity of LPG is determined at LEL and UEL points, the time to release LPG can be calculated by constant flow rate of 0.0083 L/sec as Eq. 7.

$$\begin{aligned} \text{Time} &= \frac{\text{Quantity of LPG at \% LEL or UEL}}{\text{flow rate}} \quad (7) \\ \text{Then, Time at LEL} &= 0.38 / 0.0083 = 46 \text{ sec} \end{aligned}$$

$$\text{Time at UEL} = 1.78 / 0.0083 = 214 \text{ sec}$$

So, this test sets the release time of LPG to the test chamber by the calculated value of %LEL and %UEL at 46 and 214 sec, respectively. From the relationship in Eq.4 and 5, the flammability limits will be increased when the room temperature in the test chamber is increased. There are 4 cases of experimentations as followings:

- The 1st case: Test at room at normal temperature (25°C)
- The 2nd case: Test at 80°C
- The 3rd case: Test at 100°C
- The 4th case: Test at 120°C
- The 3 repeated experimentations are conducted for each case

**The 1st case:** The normal temperature (25°C) is used in which the heater is closed. Then, the flammability limits are tested at normal temperature. The experimentation starts with releasing the fuel through the test chamber below calculated %LEL for a small quantity. After that, the fuel volume is slightly increased whereas the flow rate is set to be constant at 0.0083 L sec<sup>-1</sup>. Each time of increasing uses 5 sec or the volume is 0.0415 L in which the total is 21. The concentration level of fuel by each case will be repeated for 3 times. The calculated result will be determined as in Eq. 6. The result shows that the LPG quantity at %LEL is 0.38 L and at %UEL is 1.78 liters. After that, the time duration to release the fuel by constant flow rate can be determined by Eq. 7. The time at %LEL is 46 sec and at %UEL is 214 sec.

**The 2nd case:** The heater is opened to make the room temperature closed to 80°C. The calculated result as in Eq. 6 can be determined. The LPG quantity at %LEL is 0.36 liters and at %UEL is 1.87 L. Then, the time duration to release the fuel is calculated at constant flow rate by Eq. 7. The time at %LEL is 43 sec and at %UEL is 225 sec.

**The 3rd case:** The heater is opened to make the room temperature closed to 100°C. The calculated result as in Eq. 6 can be determined. The LPG quantity at %LEL is 0.34 liters and at %UEL is 1.94 liters. Then, the time duration to release the fuel is calculated at constant flow rate by Eq. 7. The time at %LEL is 40 sec and at %UEL is 232 sec.

**The 4th case:** The heater is opened to make the room temperature closed to 120°C. The calculated result as in Eq. 6 can be determined. The LPG quantity at %LEL is

0.3 L and at %UEL is 2.01 L. Then, the time duration to release the fuel is calculated at constant flow rate by Eq. 7. The time at %LEL is 38 sec and at %UEL is 250 sec.

### RESULTS

The test of the 1st case uses the normal temperature in which the heater is closed. The flammability limits were also tested in normal temperature. From the calculation, the flammability should occur in the test chamber from 46-214 sec. The test result shows that the flammability starts at 45 sec. whereas the volume is 0.37 L or the fuel is 1.87% of air in the test chamber from the 2nd and the 3rd tests. The flammability limits continue to expand until the time is 145 sec. in which the volume is 1.20 L or the fuel is 6.03% of air in the test chamber. The test results are shown in Fig. 4 and Table 2.

The test in the 2nd case uses 80°C in which the flammability should occur in the test chamber from 43-225 sec. In this test, the temperature is increased in the test chamber leading to the flammability limits expansion, which starts the fire at 45 min. The volume is 0.37 L or the fuel is 1.87% of air in the test chamber from 3 tests. The flammability limits continue to expand until the maximum level at 165 sec in which the volume is 1.37 L or the fuel is 6.87% of air in the test chamber. The test results are shown in Fig. 5 and Table 2.

The test in the 3rd case uses 100°C in which the flammability should occur in the test chamber from 40-232 sec. In this test, the temperature is increased in the test chamber leading to the flammability limits expansion, which starts the fire at 45 min. The volume is 0.37 L or the fuel is 1.87% of air in the test chamber from 3 tests. The flammability limits continue to expand until the maximum level at 170 sec in which the volume is 1.41 L or the fuel is 7.08% of air in the test chamber. The test results are shown in Table 2.

The test in the 4th case uses 120°C in which the flammability should occur in the test chamber from 38-250 sec. In this test, the temperature is increased in the test chamber leading to the flammability limits expansion, which starts the fire at 40 min.

Table 2: Shows the test results of flammability limits at various temperatures comparing with the calculated values

Temperature	Calculated values		Tested values	
	%LEL	%UEL	%LEL	%UEL
Normal (25°C)	1.90	8.90	1.87	6.03
80°C	1.78	9.39	1.87	6.87
100°C	1.70	9.69	1.87	7.08
120°C	1.60	10.10	1.67	7.50



Fig. 4: Shows the test of flammability at 145 sec



Fig. 5: Shows the test of flammability at 165 sec

The volume is 0.34 L or the fuel is 1.67% of air in the test chamber from the 3rd test. The flammability limits continue to expand until the maximum level at 180 sec in which the volume is 1.49 L or the fuel is 7.5% of air in the test chamber. The test results are shown in Table 2.

From Table 2, the result from the test has different values compared with the theory calculation by certain levels. The % LEL differs from theory approximately 5% and the %UEL differs from theory approximately 28%.

### DISCUSSION

The differentiation of the experiment compared with the theory calculation, especially %UEL, is extremely high. The researcher notices this result and then the determination of the cause are further conducted. The variation should relate to the fuel quantity that is released into the test chamber. The flow meter, Agilent Flow meter ADM2000, is then used in which the equipment can measure the flow rate from 0.5-1,000 mL min<sup>-1</sup> or 0.83×10<sup>7</sup> to 0.0167 L sec<sup>-1</sup>. The flow meter is used to test the flow rate of the fuel. The test is conducted by releasing the fuel into the test chamber whereas the flow meter is adjusted to 0.0083 L sec<sup>-1</sup>. The flow meter is checked in details for 3 times and the results of flow rate are concluded in Table 3 and Fig. 6.



Fig. 6: Shows the measurement of flow rate of fuel through the test chamber by using the flow meter

Table 3: Shows the flow rate of fuel releasing to the test chamber and is measured in details by the flow meter

Tests	The 1st test	The 2nd test	The 3rd test
Flow rate (mm./minute)	567.0000	570.0000	566.0000
Flow rate (liter/second)	0.0094	0.0095	0.0094

The conclusion is made that the true flow rate is higher than the observed flow rate that is monitored from the flow meter attached at the side of the test chamber. From the calculation, the %LEL is differed from the theory approximately 17.5% and the %UEL is differed from the theory approximately 16.3%.

### CONCLUSION

From 4 cases of experimentations, it can be concluded that the flammability limits has a relationship with a change in temperature. When the temperature in the test chamber is increased by the heater installed inside the chamber, the %LEL is found to be lower compared with the experimentation at normal temperature and %UEL is also increased. The true experimentation provides different result compared with the theory. The reason is the test chamber is larger than the cup burner used in the theory's experimentation and the efficiency of the chamber. Because of the limitation of the resources, the test chamber is not a 100% closed-system.

However, the experimentation result can explain the relationship as proposed by the Burgess-Wheeler Law in that the increasing in the temperature relates to the %LEL and %UFL of Paraffin Hydrocarbon or Hydrocarbons (Alkanes). The learning equipment for testing in this research is developed as a learning tool to investigate the relationship between the temperature and a change in flammability limits of the gas. The test result shows that the equipment can be efficiently used in a laboratory lesson. The student can monitor the ignition phenomenon at a real time. However, some flaws are found that has to be further efficiently improved.

The test chamber is designed to demonstrate the ignition. So, the size has to be suitably designed and large enough for convenience in monitoring. It can be seen that when the test is conducted in a real system, the result is extremely differed from the theory. The reason is the experimentation by the theory using the cup burner or a cylindrical glass cup. This cup has an outside diameter of 28 mm. and around the cup tunnel has an inside diameter of 8.5 or 9.5 cm with 53.5 cm. of height. The ratios of both testing equipments are extremely differed, so there is an opportunity that the accuracy is highly shifted.

The calculation of fuel quantity by using the timer can affect the test in that the time to release a gas to a chamber will be longer. The opportunity of the increasing in gas leak can be occurred. The top of the chamber can be opened to release the pressure. The side of the chamber also is not perfectly sealed, so the fuel or air cannot be controlled as a 100% closed-loop system.

The flow meter of fuel in the test chamber has minor scale and the meter uses a red ball. The problem is the adjustment of flow rate can be shifted.

In addition, there is a single point to measure the temperature in the chamber. The air that contacts with the heat from heater can has different temperature levels from all sides in the test chamber, although the propeller is installed. The location for measurement should be increased to determine the average result. The result will provide more accuracy.

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