# Improvement on Reproducibility of Flame Extinguishing Concentration Measured by Cup Burner Method

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## Abstract

The inter-apparatus deviations in the flame extinguishing concentrations are discussed from the point of statistical analysis and the instrumental error. for improving the reproducibility of flame extinguishing concentration measured by the cup burner method. The agent concentrations for the estinction of n-heptane flame are measured by three sets of the FRI glass cup burner. The good agreement is found among the extinguishing concentrations obtained by these cup burner apparatuses. when the measurements are carried out using the apparatuses with fised dimensions and employing the fixed test procedure. The influence of test operators on the extinguishing concentration was investigated using the FRI glass cup burner. The results show that there is no difference among the data obtained by different operators. The extinguishing concentrations were also measured by a FRI metal cup burner equipped with a cylindrical brass cup. There is the good agreement between the data measured by the glass cup burner and the metal cup burner.

## 1. Introduction

Up to now, there is no test methods which are standardized internationally for estimation of fire suppression efficiency of halogenated fire suppressants. However, a cup burner method has been widely employed as one of the most representative laboratory scale test methods of fire suppression efficiency [1]. Flame estinguishing concentration measured by the cup burner method is used as a basis for determination of a design concentration of total flooding fire extinguishing system. In U.S.A., the standard on clean agent fire extinguishing system, NFPA 2001 [2], has been already established in which the flame extinguishing concentrations of clean agents by the cup burner method reported by various organizations are summarized as shown in **Table 1.** The amount of difference in these data reaches approximately 30 % as a relative value for halon 1301, and over 10 % for some of the halon replacements reported. Since a design concentration of total flooding fire estinguishing system is determined by the flame extinguishing concentrations plus a 20 % safety factor, such magnitude of difference is beyond the acceptable range. It is desirable that an equal flame extinguishing concentration can be obtained by various organizations, for determination of the design concentration.

We previously studied about the scale effect of cup burner on flame extinguishing concentration, and reported that the flame extinguishing concentration measured by the cup burner method was changed significantly when the cup diameter or the chimney diameter of the

cup burner was varied [3]. It means that the amount of difference in flame extinguishing concentration can be reduced if the sizes of the cup burner apparatus are determined uniformly. However, the improvement in the reproducibility of flame extinguishing concentration by unifying the size of the apparatus and a test procedure, has not been verified yet. In the present study, the inter-apparatus deviation of the flame extinguishing concentrations and the deviation between operators are examined by measuring n-heptane flame extinguishing concentrations of halon 1301 and carbon dioxide using three cup burner apparatuses of the equal dimensions, to verify the improvement in the reproducibility of flame extinguishing concentration. Furthermore, this study seeks to resolve a difficulty in making the glass cups with complex curved shape, which is one of the important parts of the cup burner apparatus. A metal cup burner, which can be made with better accuracy than glass, is introduced and a comparison between the flame extinguishing concentrations measured by the metal burner and the glass burner is made. From the results, interpretation of the deviations will be discussed based on statistical analysis.

**Table 1 Cup burner heptane flame extinguishing data [2]**

| Investi-gator | Agent | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | FC-3-1-10 | HFC-134 | HFC-227ea | HBFC-22B1 | HFC-23 | HFC-135 | IG-541 | Halon 1301 |
| NRL | 5.2 | - | 6.6 | 4.1 | 13 | 9 | - | 3.1 |
| 3M | 5.9 | | | | | - | | 3.9 |
| NMERI | 5 | - | 6.3 | 4.4 | 13.6 | 9.4 | - | 3.9 |
| Fenwal | 5.5 | 6.4 | 5.8 | 3.9 | 12 | 8.1 | - | 3 |
| GLCC | | - | 5.9 | 3.9 | 13.7 | - | - | 3.5 |
| Ansul | - | | | - | - | | 29.1 | - |

NOTES: NRL - Naval Research Laboratory, NMERI - New Mexico Engineering Research Institute, GLCC - Great Lakes Chemical Company

## 2. Experimental

A diagrammatic sketch of the experimental set-up is given in **Fig. 1.** Three important parts of the set-up are the cup burner. the overflow type fuel reservoir with the fuel level control device, and the agent/air mixture supply system.

The cup and the chimney are illustrated in **Fig. 1** with those dimensions. Two types of the cup burner apparatuses whose cups are made of Pyrex glass tube and brass tube were prepared. The first one is named FRI glass cup burner and the other is named FRI metal cup burner. FRI glass cup burner shown in **Fig. 3** is designed on the basis of the ISO-type cup burner [1]. In the study, three FRI glass cup burners were used; FRI-0 as a prototype, FRI-1 and FRI-2 that are improved on FRI-0 to be handled easier. The dimensions of these burners indicated in **Fig. 3** agree one another. And two slight different shaped cups shown in **Fig. 4** were used. In **cup 1,** part of the cup between upper tube and lower tube is taper. In contrast, the same part of **cup 2** is curved gently.

Another type burner, FEU metal cup burner whose cup is made of brass tube, is shown in **Fig. 2** and its dimensions are described in **Fig. 5.** This brass tube stands straight and its outer diameter is constantly 30 mm not to disturb the stream line. To prevent an increase of fuel temperature, this burner is equipped with water-cooling part. Water temperature of the outlet is controlled to keep it 25°C.

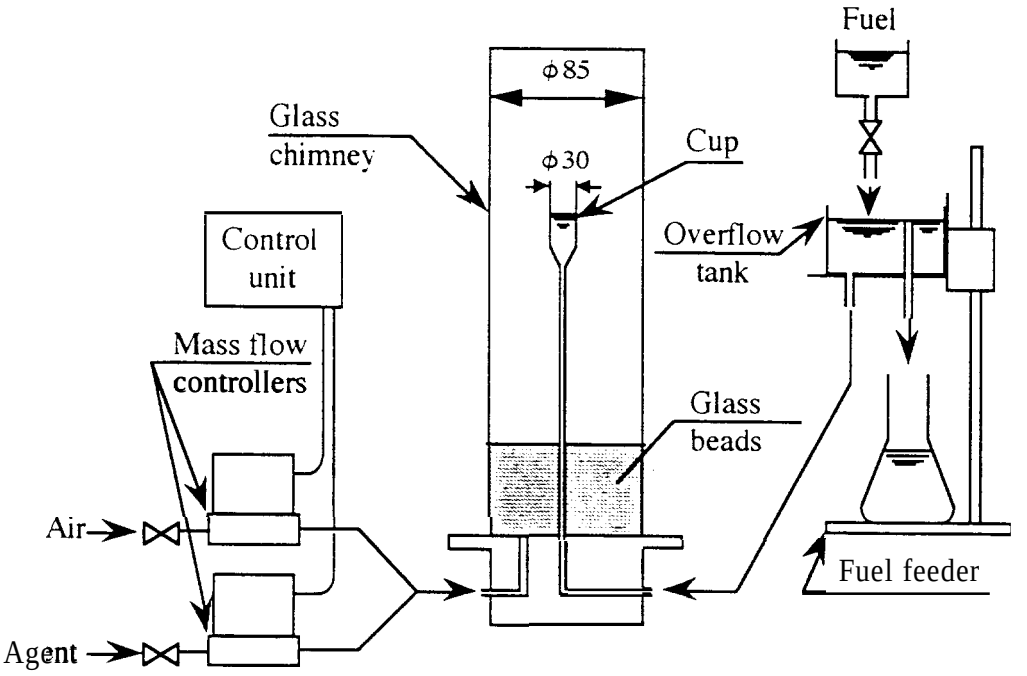
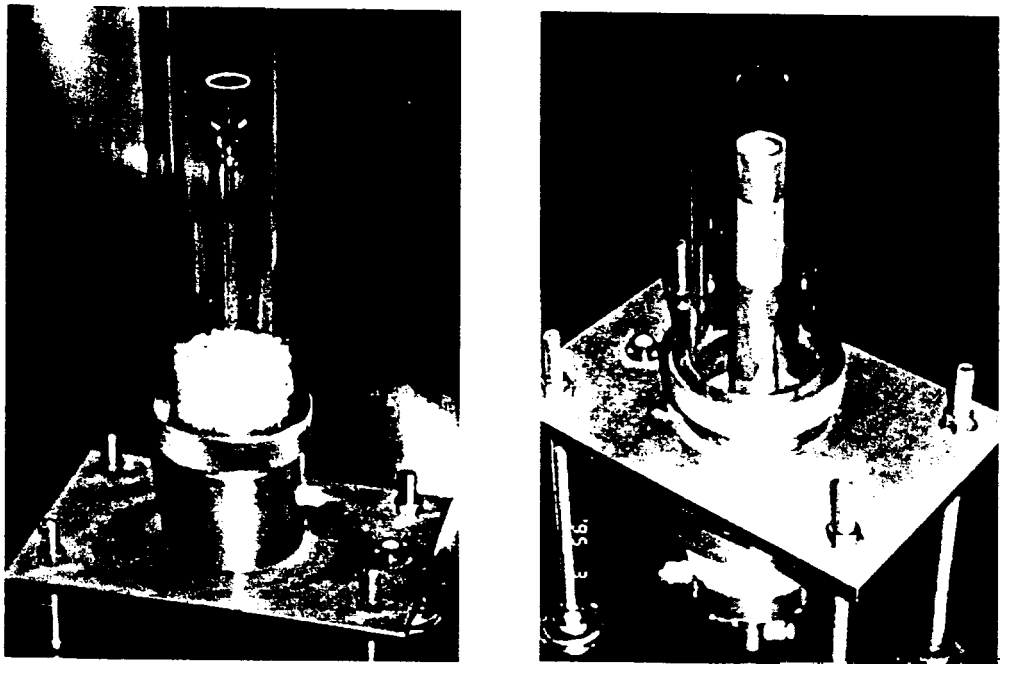



**Fig. 1 Diagrammatic sketch of the esperimental set-up**



FRI glass cup burner

FRI metal cup burner

**Fig. 2 Cup burner apparatuses**

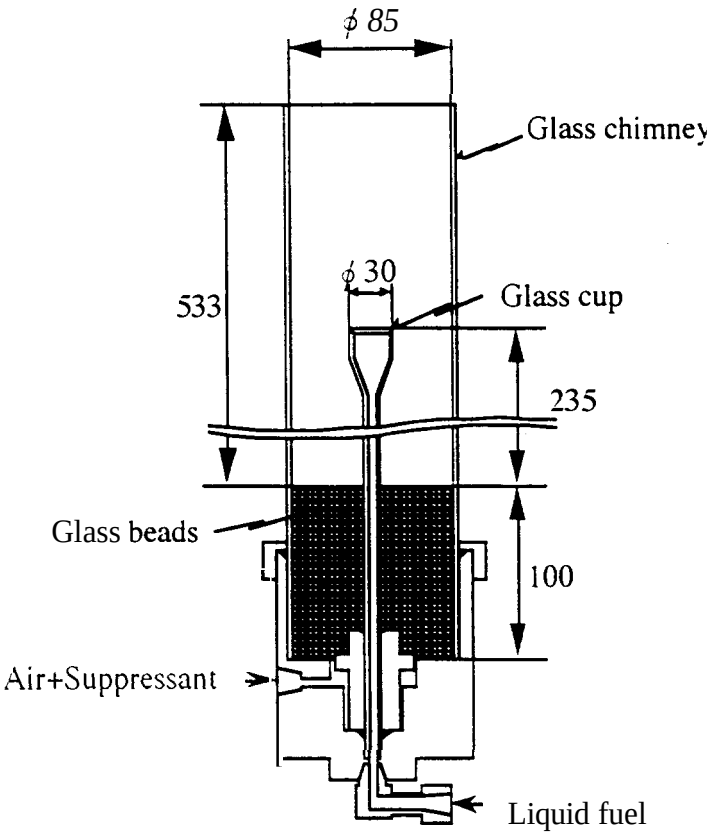



**Fig. 3 Schematic diagram of FRI glass cup burner**

To exhaust the burned gases. all cup burners are placed in the draft chamber. In the study, two draft chambers were used. The one is old and the other is new.

n-heptane and ethanol were used **as** the liquid fuels. The distance between the top edge of the cup and the surface of the fuel was adjusted using the fuel level control device, which was able to move the fuel reservoir vertically. The fuel was supplied continuously during the combustion to keep the fuel level constant. Carbon dioxide. nitrogen. halon 1301 and three halon replacements were used as the agents. The gases were supplied through mass flow controllers. The air and the agent were mixed in the bed of glass beads.

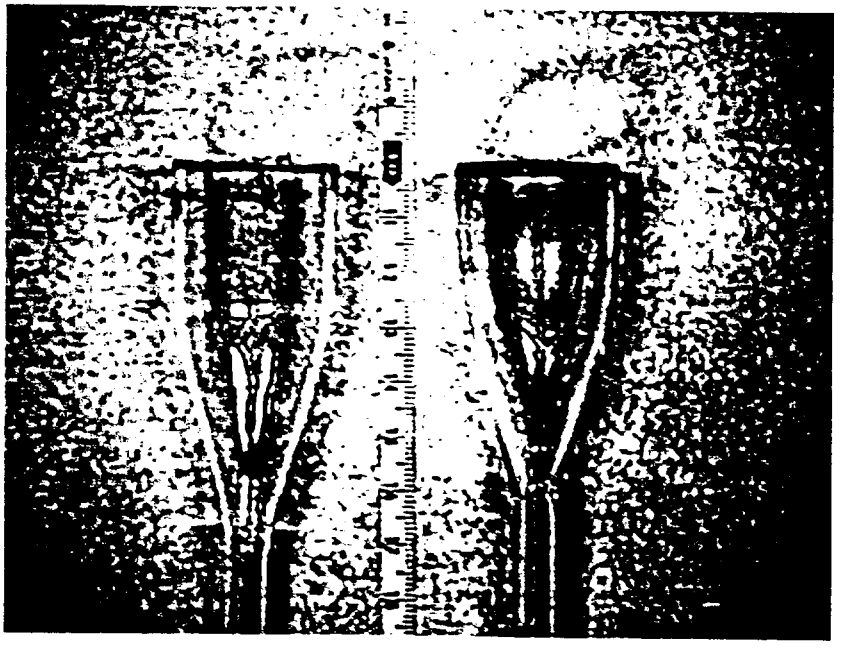
The pre-burn time was set at 8 minutes in the case of FRI glass cup burner **as** the air flow rate was adjusted to 40 l/min. In the case of FRI metal cup burner. the pre-burn time was set at **2** minutes after confirming that the flame extinguishing concentration was not affected by the difference of the pre-burn time which was **2** and S minutes. When the pre-burn time was

*hesurface position of the fuel was set at just the edge of the cup by adjusting the height overflow tank. Then. the addition of agent was started. The flow rate of the agent was ..sed in steps until the flame was extinguished. The flame extinguishing concentration ..(%) is calculated by the following equation.

$$C = \{Q / (Q+40)\} \cdot 100 \qquad (1)$$

where $Q$ (l/min) is the flow rate of the agent at extinction.

Using the three FRI glass cup burners. the flame extinguishing concentrations ware mesured by two ways in which the test period for flame extinguishing was set at *2.5* min or **5** min. Seven groups of operators participated in the test program on the measurement of the flame extinguishing concentrations **by** the same cup burner apparatuses and procedure.



cup 1 cup 2

**Fig. 4 Glass cups**

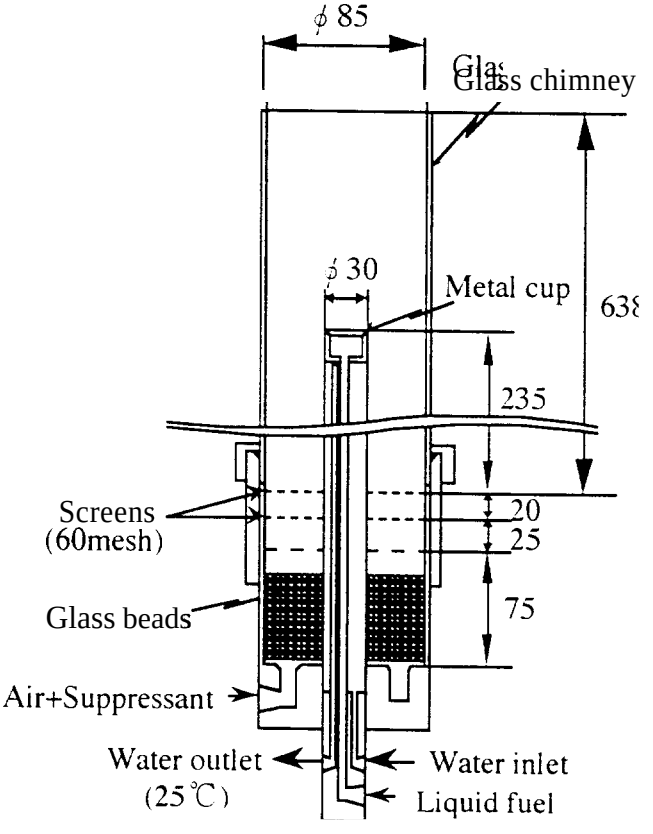



**Fig. 5 Schematic diagram of FRI metal cup burner**

## 3. Results and discussion

### 3.1 Extinguishing concentrations of carbon dioxide measured by three FRI glass cup burners against heptane flame

The flame extinguishing concentrations of carbon dioxide against n-heptane flame are measured by three different sets of the FRI glass cup burner. These apparatuses are equipped with the same cup, and labeled FRI-0, FRI-1 and FRI-2. The FRI-0 apparatus is the prototype of the cup burner in the study. The FRI-1 and FRI-2 apparatuses have the same design, but they were made in different factories. In the experiment, an old draft chamber installed the cup burner apparatus was exchanged by another new chamber for checking the affection of the draft chamber.

**Table 2** shows the extinguishing concentrations measured in four different cases, the averages of the data, and their standard deviations. The cases of **A** and **B** are the experiments on the effect of draft chamber. The cases of **B, C,** and **D** demonstrate the influence of burner system without changing the glass cup. The averages of the flame extinguishing concentrations about all the cases are in the range from 31.7 % to 22.0 %, and the average value and the standard deviation over all the data in **Table 3** are **31.8** % and 0.30 %, respectively.

**Table 3** is the result of t-test to accept the hypothesis on the existence of differences between every pair of the averages in **Table 2**. The equation used for t-test is as follows.

$$t = |\ (\langle x_1 \rangle - \langle x_2 \rangle)/\{(1/n_1 + 1/n_2)(n_1 s_1^{\,2} + n_2 s_2^{\,2})/(n_1 + n_2 - 2)\}^{1/2}\ | \qquad (2)$$

Where $\langle x \rangle$ represents average of data, $n$ is numbers of data, $s$ means standard deviation and suffix denotes case.

**Table 2 Extinguishing concentrations of $CO_2$ for n-heptane flame**

| Draft | Old | New | | |
|---|---|---|---|---|
| Burner | FRI-0 | FRI-0 | FRI-1 | FRI-2 |
| CUR | 1 | 1 | 1 | 1 |
| Case | A | B | C | D |
| (1) | 31.8 | 22.0 | 31.8 | 31.5 |
| (2) | 22.1 | 22.0 | 22.3 | 22.0 |
| (3) | 33.3 | 21.4 | 21.9 | 32.4 |
| (4) | 31.8 | 31.4 | 31.5 | 22.2 |
| (5) | 21.5 | 31.5 | 31.7 | 31.9 |
| Average (%) | 21.9 | 21.7 | 21.8 | 22.0 |
| Std. dev. | 0.30 | 0.30 | 0.27 | 0.32 |

According to the t-distribution table, the $t_{0.05}$-value at significant at 5 % level to accept the difference is *2.306* in these cases. All the t-values on the any couples of the cases in **Table 3** are less than 2.306, thus it is recognized that there are no differences among the average values of the extinguishing concentrations in **Table 2.** The fact shows that the extinguishing concentrations were not affected by the difference of the cup burner apparatus and the draft chamber in this study.

**Table 3 t-test result on differences between averages in Table 2**

| | A | B | C | D |
|---|---|---|---|---|
| A | ---- | 1.007 | 0.335 | 0.474 |
| B | | ---- | 0.833 | 1.466 |
| C | | | ---- | 0.717 |
| D | | | | ---- |

## 3.2 Reproducibility of extinguishing concentration of halon 1301 against n-heptane flame measured by FRI glass cup burners

The maximum difference of the flame estinguishing concentrations of halon 1301 is about 30 %, and it is the largest one in **Table 1**. We can use, therefore, the extinguishing concentration of halon 1301 for n-heptane flame as an index to understand whether the improvement of the reproducibility is achieved in the cup burner method.

Using three sets of apparatuses of the FRI glass cup burner, the flame extinguishing concentration of halon 1301 against n-heptane were measured, and the reproducibility of the data was tested. In the espenment. the variable conditions are cup burner apparatus. glass cup. and test period for the flame estinction. The cup burner apparatuses are the same as in the section **3.1**. The effect of shape of the cup was also esamined, since all the glass cups used were 'hand made,' and the shape of each cup is a little different from others'. The shapes of the **cup 1** and **cup 2** are shown in **Fig. 4**. The effect of rate in increasing agent concentration was tested, too, because it is supposed easily that there is a little difference of test procedure, especially in the method of addition of the-agent. In the experiment, we used an electronic program unit to control the augmentation of agent concentration stepuise, and employed 2.5 min or 5 min as the test **period.**

The result is shown in **Table 4**. The average and the standard deviation of all the flame extinguishing concentrations of halon 1301 against n-heptane in **Table 4** are 3.36 % and 0.11 %, respectively.

**Table 4 Extinguishing concentrations of halon 1301 for heptane flame**

| Test period | 5 min | | | | | 2.5 rnin | | |
|---|---|---|---|---|---|---|---|---|
| Burner | FRI-0 | FRI-1 | | FRI-2 | | FRI-0 | FRI-1 | FRI-2 |
| cup | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 |
| Case | E | F | G | H | I | J | K | L |
| (1) | 3.37 | 3.48 | 3.18 | 3.37 | 3.37 | 3.33 | 3.22 | 3.41 |
| (2) | 3.41 | 3.52 | 3.33 | 3.41 | 3.33 | 3.32 | 3.41 | 3.22 |
| (3) | 3.29 | 3.44 | 3.44 | 3.41 | 3.39 | 3.14 | 3.37 | 3.33 |
| (4) | 3.33 | 3.56 | 3.41 | 3.37 | 3.25 | 3.14 | 3.48 | 3.29 |
| (5) | 3.33 | 3.56 | 3.44 | 3.44 | 3.41 | | 3.29 | 3.37 |
| **Average (%)** | **3.35** | **3.51** | **3.36** | **3.40** | **3.33** | **3.18** | **3.35** | **3.32** |
| **Std. dev.** | **0.046** | **0.052** | **0.110** | **0.030** | **0.063** | **0.046** | **0.102** | **0.073** |

**Table 5** is the result of the t-test on the difference between the averages in **Table 4**. **All** the t-values for the cases **F** and **J**, which is represented in bold type in **Table 5**, are larger than 2.306 as the $t_{0.05}$-value at significant at 5 % level to accept the hypothesis on the existence of the difference between the averages. On the other cases labeled **E, G, H, I, K** and **L**, the t-

values are smaller than *9.306.* Therefore. we have to understand that there is the different of the extinguishing concentration between the group of cases F and **J** and the group of cases ***E,*** **G, H, I, K** and **L** from the point of statistical analysis. However, we could not find any reasons on the instrument and the procedure to explain the difference in the estinguishing concentrations.

**Table 5 t-test on differences between averages of extinguishing concentration data obtained under various conditions**

| | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|
| **E** | ---- | **4.792** | 0.235 | 1.978 | 0.410 | **4.758** | 0.144 | 0.509 |
| **F** | | ---- | **2.493** | **3.733** | **4.440** | **8.802** | **3.766** | **4.178** |
| **G** | | | ---- | 0.700 | 0.472 | **3.697** | 0.080 | 0.544 |
| **H** | | | | ---- | 2.000 | **7.600** | **0.868** | **1.918** |
| **I** | | | | | ---- | **3.502** | 0.401 | 0.124 |
| **J** | | | | | | ---- | **3.797** | **3.017** |
| **K** | | | | | | | ---- | 0.479 |
| **L** | | | | | | | | ---- |

The mass flow controller has the error of 1 % in setting of flow rate. In the case of the cup burner apparatus, it is supposed that there is the error of about 1 % due to the instability of estinction phenomena So, the error by the two mass flow controllers and the apparatus is at most about 3 %. On the other hand. the standard deviation of the data in **Table 4** is about 3 % of the mean value. Thus it is concluded that the tlame estinguishing concentration measured by FRI glass cup burner is 3.4 % and its standard deviation becomes 0.1 % **as** the average and the standard deviation calculated with all the flame estinguishing concentrations in **Table 4.** Since the average and the standard deviation of the data about halon 1301 in **Table 1** are 3.3 % and 0.4 % respectively. our data are better than the data cited in NFPA 2001 [2] on the reproducibility.

### 3.3 Difference between flame extinguishing concentrations measured by several groups of operators

It is very interesting to know the deviation in the flame extinguishing concentrations measured by different operators tor checking the reproducibility. Seven groups of operators who have never measured the flame extinguishing concentrations participated in the test. They learned about a cup burner system and the procedure for measurement, then they measured the flame extinguishing concentration of halon 1301 for n-heptane flame using the same apparatus of the FRI glass cup burner.

**Table 6** shows the data obtained by the seven groups of operators, these averages, and the standard deviations. The mean value and the standard deviation of all the data in **Table 6** are 3.39 % and 0.06 % respectively. The t-test results for checking the difference between the averages of the data are demonstrated in **Table 7.** In this case, all the t-values in **Table 7** are also smaller than the $t_{0.05}$-value of 2.306. Thus, it can be concluded that there is no difference in the estinguishing concentrations obtained by the different operators.

It is also nesessary to confirm whether the data shown in **Table 4** and **Table 6** are equivalent or not. According to the t-test about the difference between the averages of the flame extinguishing concentrations measured in sections **3.2** and **3.3**, the t-value is given 1.633 by the equation (3)for all the data in **Table 4** and **Table 6.** On the other hand, the $t_{0.05}$-value at significant at 5 % level to accept the difference becomes about 2.0 in the case. Therefore we

can conclude that the averages of flame extinguishing concentrations in **Table 4** and **Table 6** are equivalent. That is, the extinguishing concentration of halon 1301 for n-heptane is 3.4 % , and the standard deviation is 0.1 % , when the extinguishing concentrations are measured by the FRI glass cup burner apparatus.

**Table 6 Operators and flame extinguishing concentrations of halon 1301 for n-heptane**

| Operators | Observed data (%) | | | | | Average | Std. dev. |
|---|---|---|---|---|---|---|---|
| **M** | 3.43 | *3.46* | 3.42 | 3.35 | 3.39 | **3.41** | **0.041** |
| **N** | 3.36 | 3.40 | 3.36 | 3.51 | 3.39 | **3.38** | **0.081** |
| **O** | 3.44 | 3.40 | 3.30 | 3.37 | 3.44 | **3.39** | **0.059** |
| **P** | 3.44 | 3.30 | 3.37 | 3.33 | 3.37 | **3.36** | **0.053** |
| **Q** | 3.33 | 3.30 | 3.40 | 3.40 | 3.44 | **3.37** | **0.057** |
| **R** | 3.37 | 3.44 | 3.56 | 3.37 | 3.44 | **3.44** | **0.078** |
| *S* | 3.42 | *3.46* | 3.42 | 3.35 | 3.39 | **3.41** | **0.041** |

**Table 7 t-test on differences between averages of extinguishing concentrations measured by various operators**

| | M | N | *O* | P | *Q* | R | *S* |
|---|---|---|---|---|---|---|---|
| **M** | ---- | 0.530 | 0.399 | 1.381 | 0.967 | 0.638 | 0.000 |
| **N** | | ---- | 0.105 | 0.456 | 0.202 | 0.928 | 0.530 |
| **O** | | | ---- | 0.583 | 0.324 | 0.823 | 0.399 |
| **P** | | | | ---- | 0.309 | 1.578 | 1.381 |
| **Q** | | | | | ---- | 1.285 | 0.967 |
| **R** | | | | | | ---- | 0.638 |
| **S** | | | | | | | ---- |

## 3.4 Flame extinguishing concentrations measured with FFU metal cup burner

The glass cup is an important part of the glass cup burner system. and it is fairly difficult to make the glass cup nith the fixed dimension and shape. Thus a cylindrical metal cup was developed and employed in the new FRI cup burner apparatus. We call it "FRI metal cup burner." The extinguishing concentrations were measured about two inert gases, halon 1301, and three halon replacements for n-heptane and ethanol by the new burner.

The results are shown in **Table 8** comparing with the data measured by the FRI glass cup burner apparatus. The relation between the extinguishing concentration measured by the metal cup burner ($C_M$) and that about glass ($C_,$) is demonstrated in **Fig. 6.** In the figure, the linear equation of the regression line and $R^2$-value are shown too. These results mean that the data obtained by the metal cup burner are equal to the data by the glass cup burner, and that the flame extinguishing concentration is insensitive to the matenal ot the cup used in this study. Thus, we can employ the metal cup burner which can be made with better accuracy than the **glass** cup burner to measure the flame extinguishing concentrations.

Table 8 Comparision of flame extinguishing concentrations measured by FRI glass and metal cup burners

| Agent | Fuel | Burner | | | |
|---|---|---|---|---|---|
| | | FRI metal cup | | FRI glass cup | |
| | | $C_M$ (%) | Std.dev. | $C_G$ (%) | Std.dev. |
| Halon 1301 | Heptane | 3.5 | 0.08 | 3.4 | 0.10 |
| HFC-23 | | 12.7 | 0.08 | 12.9 | 0.03 |
| HFC-227ea | | 6.5 | 0.07 | 6.6 | 0.12 |
| FC-3-1-10 | | 5.5 | 0.09 | 5.3 | 0.08 |
| $N_2$ | | 33.0 | 0.03 | 33.6 | ***0.28*** |
| $CO_2$ | | 22.8 | 0.18 | 21.8 | 0.30 |
| Halon1301 | Ethanol | 4.2 | 0.0 1 | 4.3 | 0.07 |

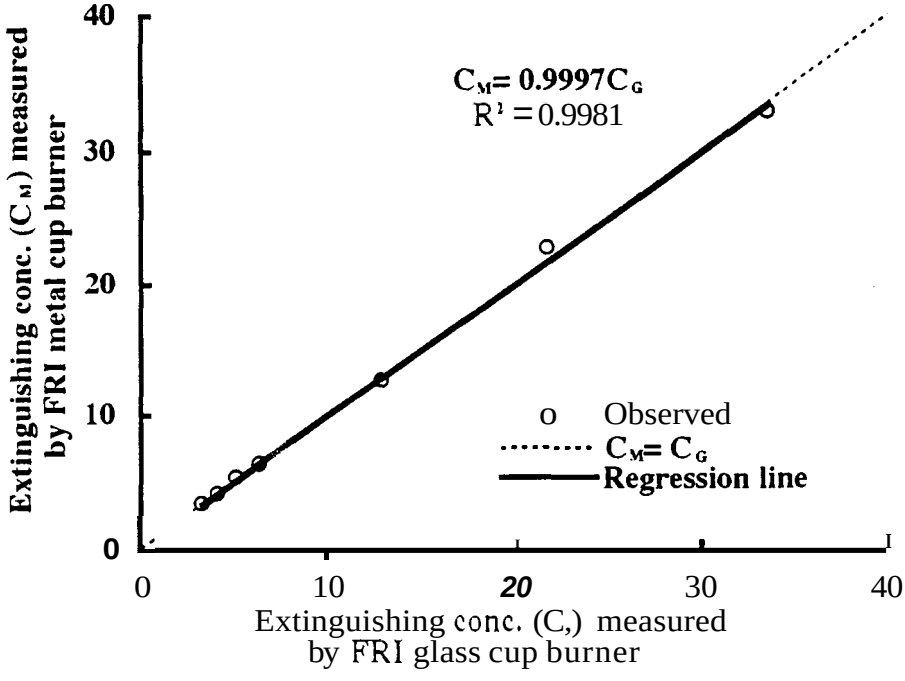



Fig. 6 Comparison of flame extinguishing concentration with glass cup and metal cup

## 4. Conclusions

Our previous study indicated that the amount of difference in the flame extinguishing concentration measured by the cup burner method could be reduced if the burner dimensions and the test procedure nere unified. This study has verified the improvement on the reproducibility of flame extinguishing concentration by employing the cup burner apparatuses with same dimensions. The results ot this study are summarized as follows.

(1) For a specific agent, an equal flame extinguishlng concentration is obtained by different cup burner apparatuses of equal dimensions under an equal test procedure .

(2) For a specific agent, an equal flame extinguishing concentration is also obtained by different operators under an equal test procedure.

(3) The flame extinguishng concentration is insensitive to the kind of material used for a cup. The FRI metal cup burner gives flame extinguishing concentrations equal to those obtained by the FRI glass cup burner.

## References

[1] ISO/DIS *7075*-1 *Fire protection equipment - Automatic fire-extinguishing systems using halogenated hydrocarbons* - ( 1989)

[2] NFPA *200* 1 *Standard on Clean Agent Fire Extinguishing svstern* ( 1994)

*[3]* Y. Saso, N. Saito, and Y. Iwata, *Fire Technology*, **29**, 22 (1993)