가스계 소화설비의 제한사항 및 성능평가를 위한 배관 내 약제비율에 관한 연구

A Study on Percent Agent in Pipe as a Criterion to Evaluate Limitations and Performance of Gaseous Fire Extinguishing Systems

손봉세[†] · 김희우*

Bong-Sei Son[†] · Hee-Woo Kim*

경원대학교 소방방재공학과, *(주)SH엔지니어링

(2007. 11. 26. 접수/2007. 12. 14. 채택)

요 약

본 연구에서는 할론 1301 및 이산화탄소를 비롯한 가스계소화설비의 성능을 시험하고 평가하기 위한 가장 중요한 핵심 요소인 배관내 약제비율, 관경비 등 소화성능에 영향을 미치는 가스계소화설비의 제한사항 및 성능확보에 필요한 요소에 대하여 연구하였다. 또한 본 연구에서는 관련 국내외 기준 분석 및 국내 가스계소화설비의 성능평가에 관한 인정기준(KFIS 002)에 따른 시스템 성능시험을 실시하고 결과를 비교 분석하였다.

ABSTRACT

This study aims to investigate, review, and summarize the definition, development, and applications of "percent agent in pipe", "percent of agent in pipe" which is used as a key factor in testing and evaluating the performance of gaseous fire extinguishing agents, including Halon 1301 and CO_2. This study also analyzes and compares the local and international standards on testing and evaluating the performance of gaseous fire extinguishing systems, as well as the results of system performance tests conducted as a part of performance evaluation and approval programs for gaseous fire extinguishing systems, especially, Korean Gaseous Fire Extinguishing System Performance Approval Program called KFI Approval. Percent agent in pipe was defined first in NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems*, dating back to the 1970's. After the phaseout of Halon 1301 systems in 1994 in the developed countries, the percent agent in pipe has been widely used in Halon 1301 alternative clean agent fire extinguishing systems, both halocarbon clean agent systems and inert gas clean agent systems, as an essential criterion to assure the system design accuracy, determine the limitations and performance of a system, and to predict the system performance results accurately, especially, in association with their system flow calculations. Underwriters Laboratories has their own standards such as UL 2127 and 2166 applying percent agent in pipe in testing and evaluating the performance of clean agent fire extinguishing systems. As a part of a system performance test and approval program called KFI Approval System, Korea also has started to apply the percent agent in pipe as a key factor to test, evaluate, and approve the performance of gaseous fire extinguishing systems, including both high and low pressure CO_2 systems, from the early 2000's. This study outlines and summarizes the relevant UL and KFI standards and also describes the actual test resultant data, including the maximum percents of agent in pipe for gaseous fire extinguishing systems. As evidenced in lots of tests conducted as a part of the system performance test and approval programs like KFI Approval System, it has been proven that the percent agent in pipe may work as a key factor in testing, evaluating, and determining the limitations and performance of gaseous fire extinguishing systems, especially compared with the hydraulic flow calculations of computer design programs of gaseous fire extinguishing systems, and will remain as such in the future. As one thing to note, however, there are some difficulties in using the unified percent agent in pipe to determine the maximum lengths of pipe networks for gaseous fire extinguishing systems, because the varying definitions used by some of the flow calculations (not in accordance with NFPA 12A definition) make it impossible to do any direct comparison of pipe lengths based on percent agent in pipe.

Keywords : Percent agent in pipe, Gas extinguishing system, Evaluation, Pipe flow

---

[†]E-mail: bsson@kyungwon.ac.kr

1. Introduction

The concept of "percent of agent in pipe or piping" or "percent agent in pipe" was first introduced to the fire protection industry in early 1970's by H.V. Williamson and Tom J. Wysocki.[3] At that time, it was only applied to the "two-phase" flow of Halon 1301 to assure accuracy and determine the limitations of Halon 1301 systems, assuming that it was not practicable to predict the system performance results accurately beyond the limit on "percent agent in pipe" of the fire extinguishing agent. Until it was completely phased out as of January 1, 1994,[6] due to its ozone-depleting nature, Halon 1301 had been de facto the only gaseous fire extinguishing agent available worldwide for over 30 years since the early 1960's, which could be used in normally occupied areas, unlike CO_2 which can only be used in normally unoccupied areas due to its fatal nature even at low concentrations. That's partly why this concept was applied to Halon 1301 systems only before. This concept is explained in detail in NFPA 12A, *Standard on Halon 1301 Fire Extinguishing Systems.* Since the early 2000's after the completion of phaseout of Halon 1301 from the fire protection industry in the developed countries, this concept has been widely applied to clean agent Halon 1301 replacements, i.e. halocarbon liquefied compressed gas fire extinguishing agents such as HFC-227ea, HFC-23, HCFC Blend A, and HFC-125, as well as inert gas fire extinguishing agents such as IG-541, IG-01, IG-55, and IG-100,[5] as a criterion to evaluate and determine the limitations and performance of gaseous fire extinguishing systems, especially, in association with their system flow calculations.

As far as a limit on percent agent in pipe is concerned, the limits, which have been used for many liquefied compressed gas clean agent fire extinguishing agents rather recently, have been in general between 50 and 80%, while the limits used for inert gas fire extinguishing agents have been in general between 50 and 66%. More recently, the limits on percent agent in ipe for a couple of new clean agent fire extinguishing agent systems have been tested and found to exceed those established values. The maximum percents of agent in pipe are tested and found to be 99.5% for Novec 1230,[10] 95% for nitrogen, and 140% for piston-flow HFC-227ea systems. This study aims to investigate, review, and summarize the definition, history, development, and applications of "percent agent in pipe", "percent of agent in pipe" or "percent of agent in the piping" which is used as a key factor in testing and evaluating the system performance of gaseous fire extinguishing agents, including Halon 1301 and CO_2.

2. Definition and Application

For gaseous fire extinguishing systems, the "percent agent in pipe" or "percent of agent in the piping" is defined as (1) mass of agent in pipe vs. mass of agent in container, (2) pipe volume vs. agent liquid volume, and (3) pipe volume vs. cylinder volume. For gaseous fire extinguishing systems like Halon 1301, as well as its alternatives like halocarbon liquefied compressed gas fire extinguishing agents more recently, the percent agent in pipe has been defined, mainly based on the mass of agent. It has simply been defined as "the mass of agent contained in the pipe during discharge divided by the total mass of agent initially contained in the agent storage containers".[4] The actual amount of agent contained in the pipe during discharge will be "the average density of agent like Halon 1301 in the pipe multiplied by the volume of pipe", though.

This concept has expanded its application to CO_2 systems as well, both high and low pressure CO_2 systems, and has been proven by tests to function as a key criterion to evaluate and determine the limitations and performance of the systems and to predict the system performance results accurately as a part of system approval. The concept has never been tried for CO_2 systems worldwide until recently when KFI has conducted a lot of CO_2 system testing, for both high and low CO_2 systems, as a part of their KFI approval program. As the CO_2, especially, low pressure CO_2, liquid leaves the storage unit at 2006 kPa (20.06 bar, 300 psi, 21.09 kg/cm^2),[3] the density is approximately 1016 kg/m^3 (64 lbs/ft^3), where "the density of a substance" is "the ratio of its mass to volume" (expressed as kg/m^3, or lb/ft^3). At the point in the pipe where the pressure has dropped to 1896 kPa (18.96 bar, 275 psi, 19.33 kg/cm^2), the density is 735 kg/m^3 (45.9 lbs/ft^3). Since the pressure continually drops in the pipe, the density of agent continually changes in each section of pipe. The actual amount of agent contained in the pipe

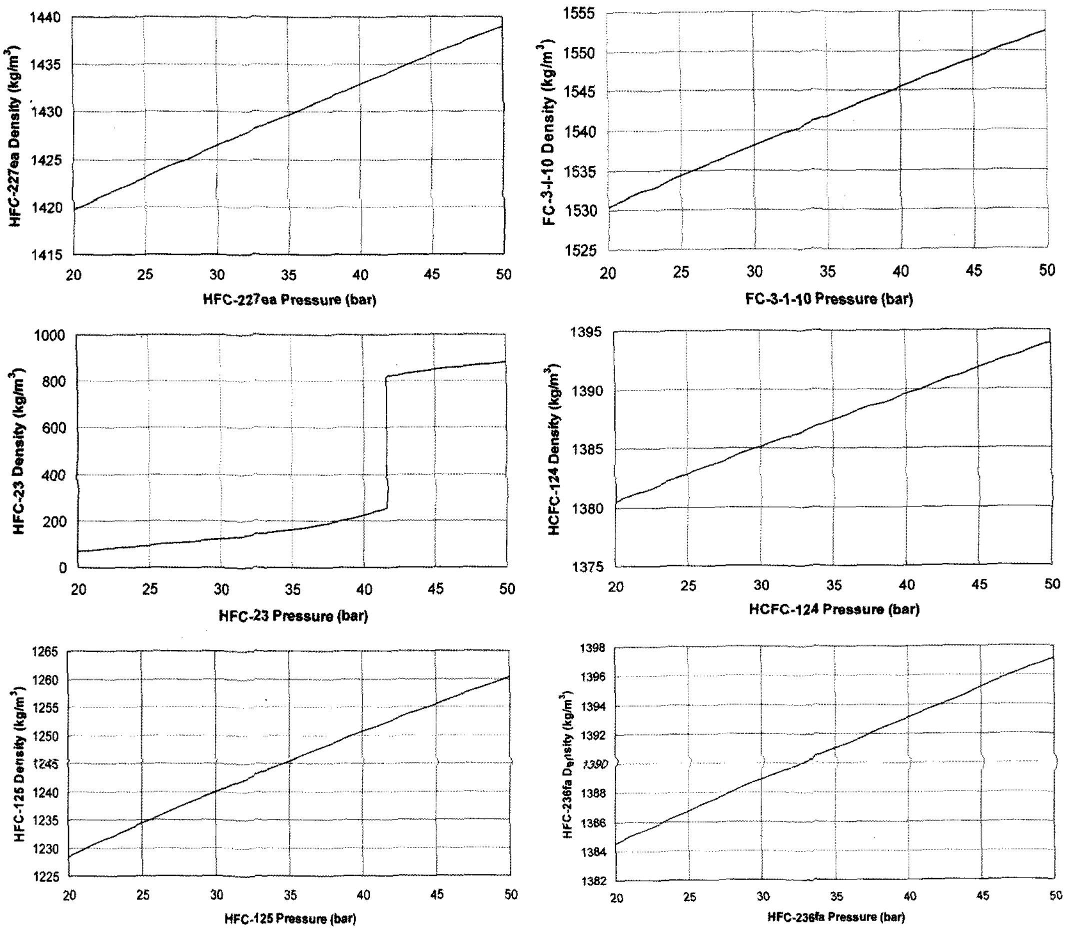


Figure 1. Pressures vs. Densities of Halocarbon Clean Agent Fire Extinguishing Agents.

during discharge will be "the volume of pipe multiplied by the average density of the CO_2" in the pipe.

Based on the volume of expanded agent which the pipe contained, the percent agent in pipe for halocarbon clean agent fire extinguishing agents can be obtained, calculating "the volume of pipe multiplied by the average density of agent in the pipe". Say we have 100 kg of agent in the cylinder and the density of the agent as it exists in the cylinder before discharge is 80 kg/m^3. Let us say we have a single pipe of 200 meter length and 100 mm internal diameter. The volume of the pipe is then calculated as $(0.01\ m/2) \times (0.01\ m/2) \times 3.14 \times 200\ m = 1.57\ m^3$. For sake of example, let us say that the 100 kg of agent expands to an average density of 20 kg/m^3 as it flows through the pipe (NFPA 12A definition). The percent agent in the pipe will be calculated as $20\ kg/m^3 \times 1.57\ m^3/100\ kg = 32\%$ agent in pipe. The following graphs show the pressures vs. densities of halocarbon clean agent fire extinguishing agents.

For liquefied compress gas fire extinguishing agents, the percent agent in pipe is also defined as "the total pipe volume/agent liquid volume" ratio. The total pipe volume can be calculated by summing up the internal pipe volume of a distribution piping network of a system, while the agent liquid volume is as per the manufacturer's listed or approved value. The agent liquid volume varies, depending on the temperature and pressure. The following table, of which data have been obtained from NIST Chemistry WebBook, shows the agent liquid densities and volumes of gaseous fire extinguishing agents at 20 °C.[11)]

Table 1. Agent Liquid Volume of Gaseous Fire Extinguishing Agents (@20 °C)

Agent	Agent liquid density, kg/m^3	Charging pressure, psig (bar)*	Agent liquid volume, m^3/kg	Remark
HFC-227ea	1423.0	360 (24.82)	0.00070274	GLCC
	1433.7	600 (41.37)	0.00069748	Dupont
FC-3-I-10	1534.2	360 (24.82)	0.00065183	3M
HCFC Blend A	1218.5	360 (24.82)	0.00082071	Safety Hi-Tech
	1226.9	600 (41.37)	0.00081507	
HFC-23	820.99	608.9 (41.98)	0.00121800	Dupont
HCFC-124	1382.7	360 (24.82)	0.00072320	Dupont
	1390.2	600 (41.37)	0.00071933	
HFC-125	1234.2	360 (24.82)	0.00081025	Dupont
	1252.0	600 (41.37)	0.00079874	Safety Hi-Tech
HFC-236fa	1386.6	360 (24.82)	0.00072117	Dupont
	1393.7	600 (41.37)	0.00071753	
FK-5-1-12	1610.0	360 (24.82)	0.00062111	3M
HP CO_2	778.04	850 (58.6)	0.00128530	
Halon 1301	1575.0	360 (24.82)	0.00063492	
LP CO_2	1420.2	300 (20.7)	0.00098382	

Meanwhile, for inert gas fire extinguishing agents, the percent agent in pipe is defined as "pipe volume vs cylinder volume" ratio. The pipe volume can be calculated by summing up the internal pipe volume of a distribution piping network of a system, while the cylinder volume is the total capacity of a bank of cylinders connected together to protect a specific single hazard area.

3. Test Standards

There are both local and international standards for testing and evaluating the system performance of gaseous fire extinguishing systems. Such international standards are represented by the relevant UL standards, while local standards are represented by the relevant KFI standards. UL or Underwriters Laboratories is an international testing and evaluation agency which tests, evaluates, approves, or disapproves fire protection products, including gaseous fire extinguishing systems, while KFI or Korea Fire Equipment Inspection Corporation is a Korean Government agency which tests, evaluates, approves, or disapproves fire protection products, including gaseous fire extinguishing systems.

For system performance tests with percent agent in pipe as its essential factor, UL has its own system test and approval standards such as UL 1058 for Halon 1301 systems, UL 2166 for halocarbon clean agent extinguishing systems, and UL 2127 for inert gas clean agent extinguishing systems.[1,2] UL tests, verifies, and approves Halon 1301 and its alternative clean agent fire extinguishing agent systems and their flow calculations in accordance with those respective standards. The UL tests are largely divided into fire extinguishment tests, flow calculation method verification tests, and nozzle distribution verification tests. The nozzle distribution verification test includes minimum room height/nozzle area coverage tests and maximum room height test. Results of UL fire extinguishment tests are shown in the following table.

One of the most rigorous approval procedures used in verifying design or flow calculation methods is outlined by Underwriters Laboratories (UL). UL 1058, Halogenated Agent Extinguishing Systems Units, was used for evaluating engineered Halon 1301 systems, but the same approach is taken for all clean agent alternatives. Design method limitations are described by ten parameters, and tests are required to verify the

Table 2. Fire Test Data for Clean Agents: Maximum Percent Agent in Pipe

Agent	Test laboratory	Percent of agent in pipe	System manufacturer	Remark
FM-200/FE-227	UL, FM	80%	Kidde-Fenwal	
FM-200/FE-227	UL, FM	140%	Kidde-Fenwal	Piston Flow
HFC-227ea	KFI	625%	Local System	Piston Flow
FE-125(a)	FM		Fike	ECARO-25
FE-13/HFC-23	UL, FM	80%	Kidde-Fenwal	
Triodide			Ajay North America	
NAF S-125(b)		100%	Safety Hi-Tech	
NAF S-III	HAI	80%	Safety Hi-Tech	
NAF S-III	KFI	95%	Safety Hi-Tech	
Novec 1230	UL, FM	99.5%	Kidde-Fenwal	
Argotec/IG-01			Minimax	
SN-100/IG-100	KFI	95%	SHE	
Argonite/IG-55	UL, FM	60%	Kidde-Fenwal	
ProInert/IG-55	FM		Fike	
Inergen/IG-541	UL, FM	66%	Ansul	
Inergen/IG-541	KFI	50%	SHE	
Halon 1301	UL, FM	80%	Kidde-Fenwal	
HP CO_2	KFI	27%	NK	
LP CO_2	KFI	50%	SHE	

HAI = Hughes Associates Inc.; HAE = Hughes Associates Europe; UL = Underwriters Laboratories; NMRI = National Maritime Research Institute of Japan; DIFT = Danish Institute of Fire Technology; FM = Factory Mutual; SHE = SH Engineering.

accuracy of the calculation procedure at all of these limits. Full-scale testing is performed to evaluate the performance of the design method. The limits on flow calculation method performance are as follows:

1. Actual versus predicted discharge time ±10 percent
2. Actual versus predicted nozzle pressure ±10 percent

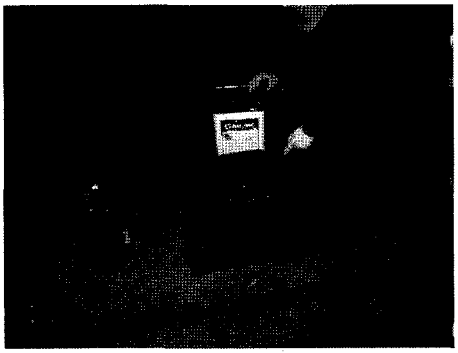
Results of UL flow calculation method tests are shown in the following table.

Meanwhile, for system performance tests with percent agent in pipe as its essential factor, Korea Fire Equipment Inspection Corporation, KFI, has its own system performance test and approval standard for gaseous fire extinguishing systems called KFIS 002, *Standard on Certification of Gaseous Fire Extinguishing System Performance*, which includes, especially, both high and low pressure carbon dioxide systems as well. The standard contains the minimum requirements for maintaining the performance of gaseous fire extinguishing systems in an effective manner by verifying whether the systems are designed and configured properly in accordance with the National Fire Safety Code on Carbon Dioxide and Halocarbon Fire Extinguishing Systems and National Fire Safety Code on Clean Agent Fire Extinguishing Systems.[9]

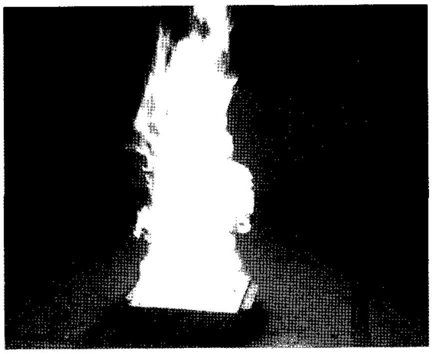
Like UL standards, the KFI standard applies to tests for verifying major performances of systems such as discharge pressure, discharge time, discharge quantity, and fire extinguishment performance, which aims to verify the suitability of the discharge routes of gaseous fire extinguishants of total flooding systems.

4. Test Results

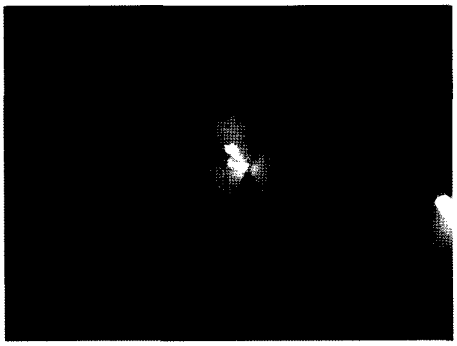
As a part of KFI system performance approval program, fire extinguishment tests and discharge tests are conducted to check and evaluate the system performance of gaseous fire extinguishing systems, including both high and low pressure CO_2 systems, by KFI



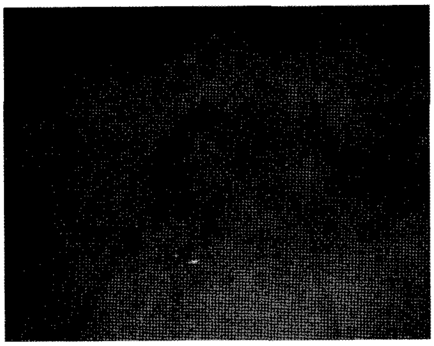
Preparation of Class B Fire Extinguishment Test



Pan in the Center of Test Enclosure

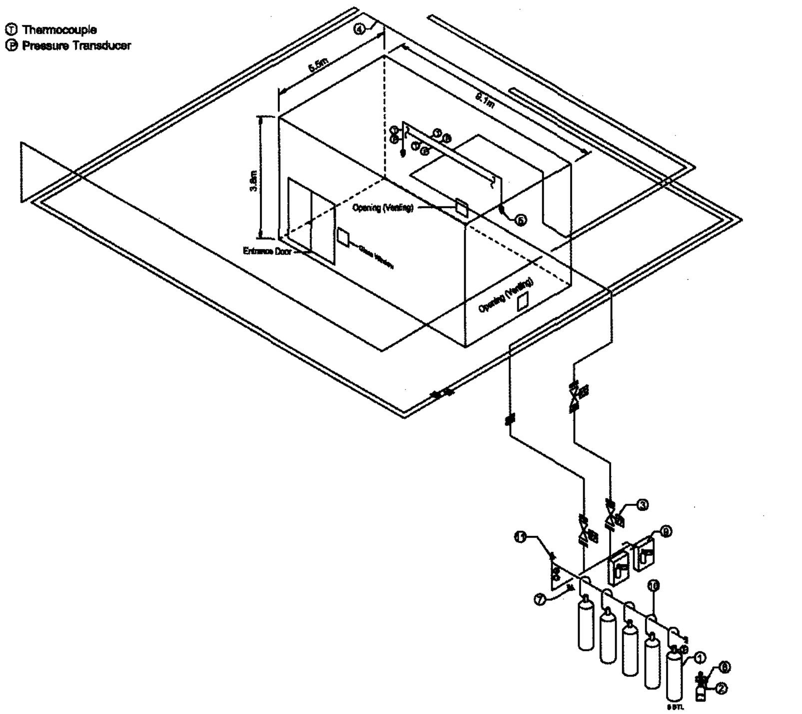


8 Cans on the Corners of Enclosure



Pan After Class B Fire Extinguishment

Figure 2. KFI class B fire extinguishment tests.



1) Test Room
- Volume : 5.5(W) X 9.1(D) X 3.8(H)m = 190.19m³
- SN-100 Quantity : 190.19 X 0.47 = 89.3893m³
89.3893m³/ 20.3 = 4.4 = 5 Bottles

2) Entrance Door : 1.89m²

3) Glass Window : 1

4) Interior : 9.5t Plywood

5) Opening (Venting) : 290mm X 290mm X 1EA (Backdraft Damper)

No.	Description	Size	Q'ty
1	N2 Cylinder	83L/20.3m³	5BTL
2	Pilot Cylinder	5L/0.65kg	1EA
3	Selector Valve	50A	2EA
4	Pipe	Max.	176.0m
		Min.	16.6m
5	Nozzle (PN)	32A	2EA
6	Orifice Plate	32A	-
7	Line Control Valve	LCV4A	1EA
8	Manual Releaser	PH10-N3	1EA
9	Pressure Switch w/CO2 Cylinder, Solenoid, Actuating Cylinder Set	1L/0.6Kg	2SET
10	Loop pipe (w/Check V/V)	14QSU	5EA
11	Safety Valve	15A	1EA

Figure 3. System arrangement with maximum percent agent in pipe (Test Room 3).

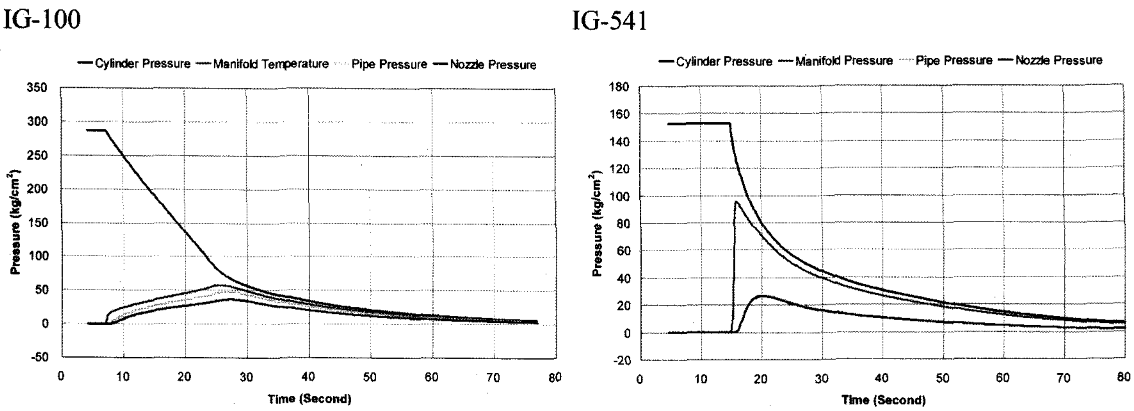


Figure 4. Discharge test results of inert gas clean agent systems.

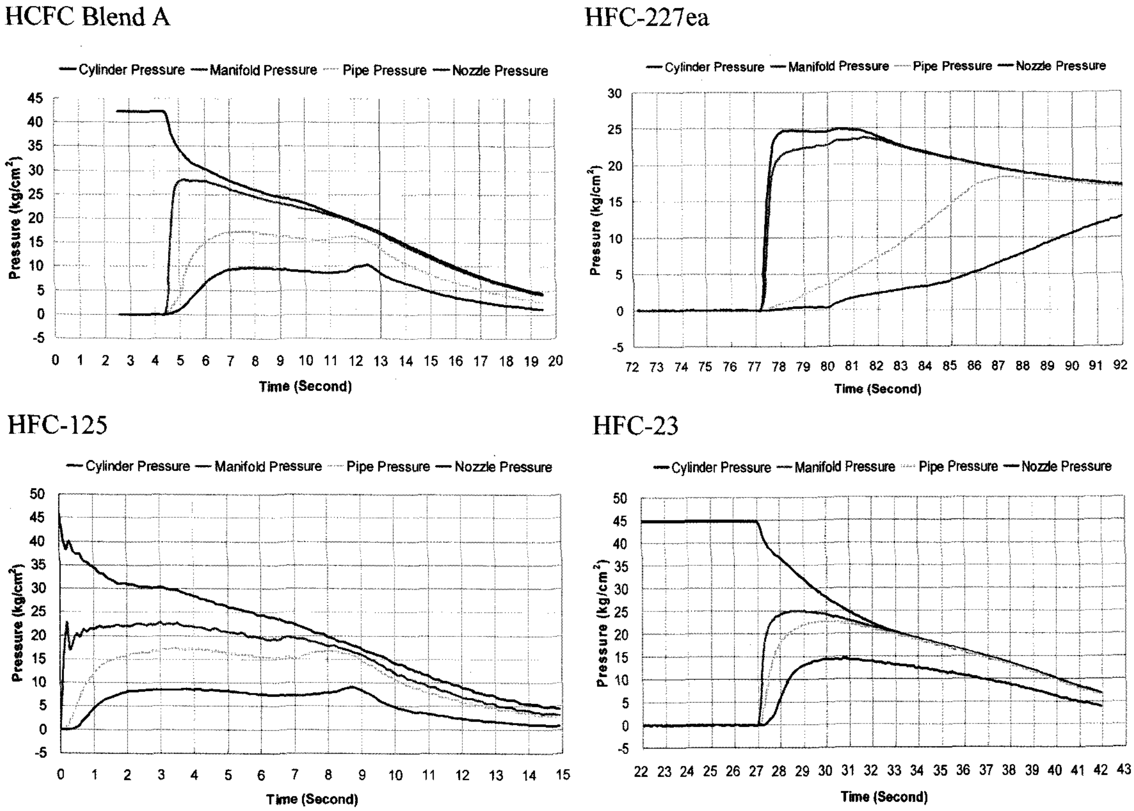


Figure 5. Discharge test results of Halon alternative clean agent systems.

testing personnel with the help of the applicants. KFI testing personnel carry out all the testing procedures, check and analyze the test results, and approve or disapprove the systems, based on the requirements and specifications of KFIS 002, *Standard on Certification of Gaseous Fire Extinguishing System Performance*. System manufacturers conduct their own tests at their own testing laboratories sufficiently prior to the official KFI tests.

Fire extinguishment tests for Class A fuel, i.e., wood crib, and Class B fuel, n-heptane, are conducted as a part of KFI Approval of gaseous fire extinguishing

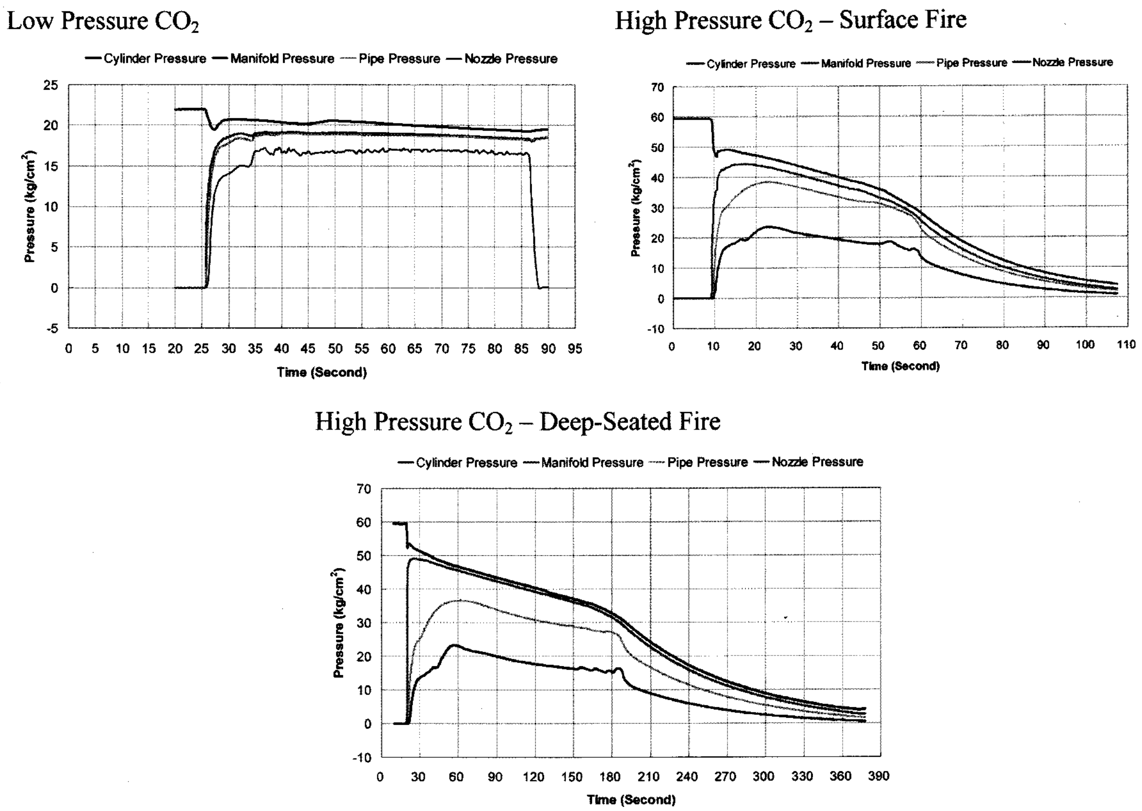


Figure 6. Discharge test results of CO_2 systems.

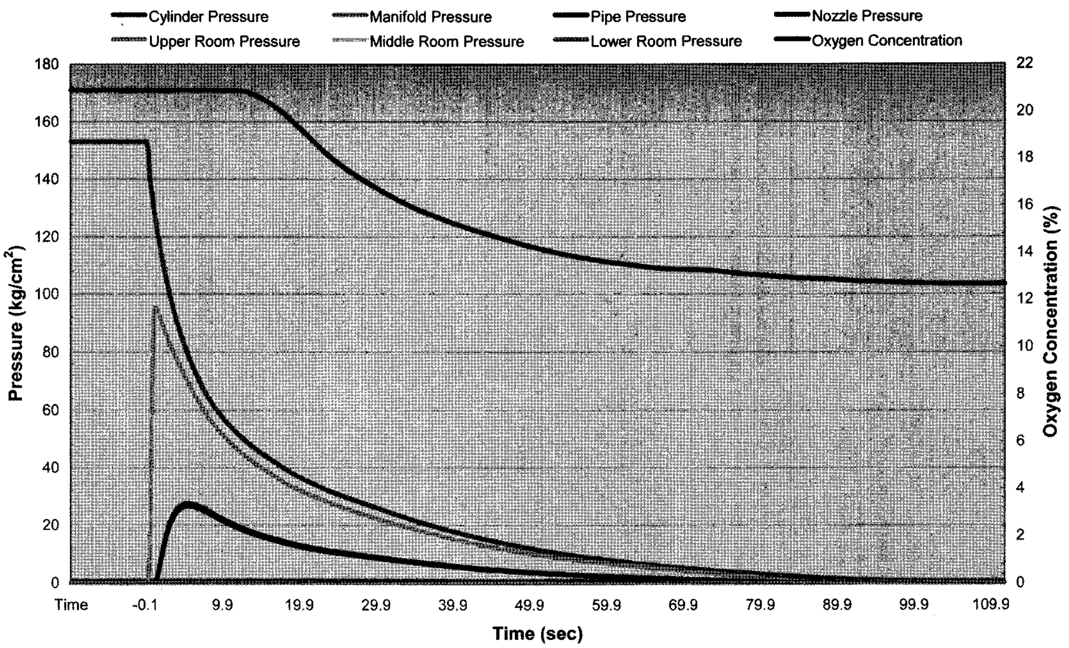


Figure 7. IG-541 KFI discharge test result with maximum percent agent in pipe at test room 3.

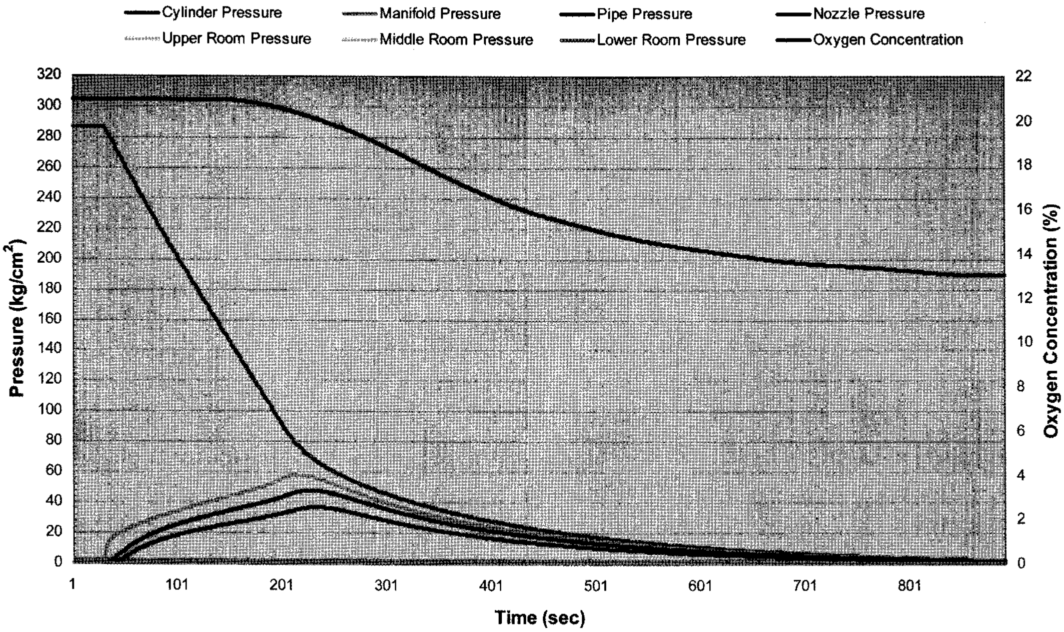


Figure 8. IG-100 KFI discharge test result with maximum percent agent in pipe at test room 3.

systems such as clean agent systems and CO_2 systems with the pipe networks having the maximum possible percents of agent in pipe which the specific gaseous fire extinguishing system manufacturer and applicant chooses. The tests are conducted at Test Rooms 2 and 3. Part of the actual fire extinguishment tests are shown as below.

For Class A fire extinguishment tests, the heptane is ignited and the wood crib burns freely for 6 minutes outside the test enclosure. Less than 15 seconds before the end of the total pre-burn period of 6 minutes, the wood crib is moved into the test enclosure and placed on a stand above the floor. The time required to position the burning wood crib within the test enclosure and the initiation of system discharge does not exceed 15 seconds. Except for the pressure relief, the vents are closed and the system is actuated. After the end of system discharge, observations shall be made for crib extinguishment. The enclosure remains sealed for a total of 10 minutes. After the 10 minute soak period, the crib is removed from the enclosure, observed to determine whether fuel remains to sustain combustion, and observed for signs of re-ignition.

The Class B fire extinguishment tests are conducted using commercial grade heptane. For the first test, a total of eight (8) round test cans are installed within 50 mm of the corners of the test room and 300 mm of the top or bottom of the test room. For the first test, the heptane of the test sample is ignited and burn for 30 seconds. Openings are quickly closed and the extinguishing agent is discharged. For the second test, a 0.25 m^2 (2-1/2 ft^2) square pan is located in the center of the room. The test pan contains at least 5 cm (2 inches) of heptane with the heptane 5 cm or more below the top of the pan. For each test, the heptane is ignited and burns freely for 30 seconds. Just prior to discharging agent into the enclosure, the vents, except for the pressure relief, are quickly closed and the extinguishing system is manually operated. Observations are to be made for the time of fire extinguishment. All fires must be extinguished within 30 seconds for Class B fire extinguishment tests.

The most rigorous tests during KFI tests are discharge tests, which are conducted with the pipe networks having the minimum and maximum percents of agent in pipe which the system manufacturer and applicant chooses for Test Rooms 1, 2, and 3, respectively. During the discharge tests at the three (3) test rooms, pressure transducers are installed at four (4) node points of pipe network, i.e., the storage container, the upstream pipe section of a selector valve, the downstream pipe section of a selector valve, and the inlet to discharge nozzle to record the agent discharge pressures at those node points of each test room, while thermocouples are also installed at those node points and the inside of the test room to record the temperatures at those node points and the upper, middle, and lower sections of the test room as well.

An oxygen metering device is installed on the lower side of the wall to measure the oxygen concentrations achieved in the test enclosures during discharge. The test results are compared with the flow calculations of computer design software, and are judged to be acceptable when the test values fall within ±10 percent (%) tolerance of the design values. A system arrangement with maximum percent agent in pipe is shown on the following figure.

The following graphs show the pressure changes at the four node points, i.e., cylinder, manifold, pipeline, and discharge nozzle for gaseous fire extinguishing systems as results of discharge tests.

Samples of KFI discharge test results with pressure transducers and, oxygen metering devices, and thermocouples installed are shown in the following graphs.

5. Conclusion

This study has tried to investigate, review, and summarize the definition, history, development, applications, and limitations of the "percent agent in pipe" for gaseous fire extinguishing systems. This study has also tried to compare UL and KFI standards on gaseous fire extinguishing systems and has summarized the actual KFI test results of gaseous fire extinguishing systems, including clean agent systems and CO_2 systems.

Especially, KFI tests include tests of discharge pressures at least four (4) node points, i.e., cylinder pressure, manifold pressure, pipe pressure, and nozzle pressure, and allow a plus or minus 10 percent tolerance only, comparing the actual test resultant pressures at those four node points with the predicted pressures obtained from hydraulic flow calculations of system design computer programs. Fire extinguishment tests and discharge tests are conducted with the pipe networks having minimum and maximum percent agent in pipe, respectively. Summarized below are the results of this study on percent agent in pipe.

Firstly, it has been confirmed that there are lots of similarities between UL and KFI standards on testing and evaluating the limitations and performance of gaseous fire extinguishing systems. Both standards consider the percent agent in pipe as one of the key factors in testing and evaluating the system performance of gaseous fire extinguishing systems.

Secondly, as evidenced in lots of tests conducted as a part of system performance test and approval programs like UL and KFI Approval Programs, via such tests as fire extinguishment tests and discharge tests, especially, flow calculation method verification tests, percent agent in pipe has been found to be a critical factor in testing and evaluating the performance of gaseous fire extinguishing systems, compared with the predicted pressures obtained from hydraulic flow calculations, especially, as a part of KFI Approval of gaseous fire extinguishing systems.

Thirdly, it has been confirmed that there are still some difficulties in using the unified percent agent in pipe to determine the maximum length of pipe network for gaseous fire extinguishing systems, due to a few different definitions of percent agent in pipe. The varying definitions used by some of the flow calculations make it impossible to do any direct comparison of pipe lengths based on percent agent in pipe. Furthermore, there are still some misunderstandings among system manufacturers about the exact definitions of percent agent in pipe, which cause erroneous programming of computer design software.

Nevertheless, percent agent in pipe seems to be a useful and important factor in testing and evaluating the system performance of gaseous fire extinguishing systems and will remain as such in the future as well.

References

1. "UL 2127 - Standard for Inert Gas Clean Agent Extinguishing System Units", Underwriters Laboratories Inc.(1999).
2. "UL 2166 - Standard for Halocarbon Clean Agent Extinguishing System Units", Underwriters Laboratories Inc.(1999).
3. "NFPA 12 - Standard on Carbon Dioxide Extinguishing Systems", National Fire Protection Association(2000).

4. "NFPA 12A - Standard on Halon 1301 Fire Extinguishing Systems", National Fire Protection Association(1997).
5. "NFPA 2001 - Standard on Clean Agent Fire Extinguishing Systems", National Fire Protection Association(2004).
6. Philip J. DiNenno, "Direct Halon Replacement Agents and Systems", Fire Protection Handbook, 19th Edition, Section 11, Chapter 2(2003).
7. Philip J. DiNenno, "Halon Replacement Clean Agent Total Flooding Systems", The SFPE Handbook of Fire Protection Engineering 3rd Edition, Chapter 4-7(2002).
8. Thomas J. Wysocki, "Single Point Flow Calculations for Liquefied Compressed Gas Fire Extinguishing Agents", Guardian Services, Inc.(2003).
9. "KFIS 002 – Standard on Certification of Gaseous Fire Extinguishing System Performance", Korea Fire Equipment Inspection Corporation(2000).
10. Kidde-Fenwal, "Kidde Engineered Fire Suppression System Design and Flow Calculation Software For use with Software Versions 1.0.X Designed for use with 3M™ Novec™ 1230 Fire Protection Fluid, User's Guide", February(2005).
11. NIST Chemistry WebBook, NIST Standard Reference Database Number 69, June 2005 Release.