SYSTEM CONCEPT

Designed to extinguish annular fires in a few seconds after ignition, the SNUFF system provides an increased margin of safety for operating personnel. The capabilities of the SNUFF equipment permit the extinguishment of fires in situations of various casing/drill pipe geometrics and gas fluid flow rates of up to 300 MMSCFM/day rates. Through its control system, which can function through periods of rig power loss, the fire will be extinguished in a few seconds. The system then automatically returns to a standby basis, immediately available for activation should reignition occur. This mode of operation can continue 40, 50 times or more depending upon the individual characteristics of the blowout.

It is anticipated that additional personnel reaction time is the major immediate contribution to drilling operations being made by SNUFF. Additional peripheral areas of equipment protection, improved conditions for rework and return of well control are anticipated to be positively affected by immediate fire extinguishment.

The system can also be of potential value where an extinguishment is not desired beyond the initial time for crew protection. As long as the SNUFF equipment has not been damaged either at the well head, or its interconnections, it can be activated later for the purpose of improving conditions for initiating repairs.

This system, operating within its design parameters, is expected to be very appropriate for all phases of drilling operations with possibly special emphasis in early drilling stages utilizing diverters.

The equipment is on-line and immediately available for activation at the time that an annular fire has been detected. The system consists of a custom multi-purpose spool piece installed in the BOP stack connected via rigid pipe spools to a remote inert gas pressurized vessel. Controls are located on the rig floor, at the pressure vessel and a third position to be specified by the drilling contractor or operator as appropriate. All hardware has been designed in accordance with applicable ASME and API standards. The multi-purpose spool piece contains necessary parts for SNUFF as well as choke and kill outlets. It serves the functions of both SNUFF and a drilling spool. Location of the spool piece in the BOP stack is a matter of contractor decision with the exception that Petro Safety recommends that the spool be installed with at least one set of preventers between it and the casing head. In diverter operation this spool would be installed upstream of the diverter lines.

SYSTEM DESIGN

GENERAL DISCUSSION

The basic consideration that the system must satisfy is the requirement for injection of the proper mass of inert gas into the casing annular area. The casing pressure which must be overcome is a function of two conditions within the BOP stack, or more properly, at the exit point of the well fluids; presuming a kick has occurred sufficient to result in a blow out. The first condition of interest results from a total lack of BOP functioning for whatever reason. The second results from partial functioning of the preventers.

With the recognition, for this discussion, that well control begins with closing one or more preventers it is clear that in this mode casing pressures will begin to build up towards a shut in pressure. The degree of closure is a resultant of the crew reaction and mechanical integrity of the closing valves. If something untoward occurs and the preventers are not able to do their job, then an emission of gas/hydrocarbons occurs. This flow is flammable in nature and its flammability limits as well as ignitibility points vary with composition of well fluids. In general, one can expect a fire of varying intensity to be created if a source of ignition of necessary strength is present in the area. The magnitude of this fire will be dependent upon the amount of fluid being discharged (a broad generalization taking into account the effects of fluid flow rate and other parameters not necessary to be discussed in this design synopsis). The well head exit pressures will vary from a low resulting from an open casing, without restrictions, to a high, approaching as a maximum, the full flowing reservoir pressure.

The system design constraints developed from the testing program reflect both considerations, i.e. an open hole and the effects of a partial closure of the BOP's. In addition, the design testing found that pressure of an obstruction such as the rig floor causes a flooding effect of the outflow on the underside of the rig floor. This effect changes the requirements for the quantity of inert gas necessary to extinguish the annular fire. The additional effects of temperature of the outflow as well as varying hydrocarbon mixtures have been surveyed and taken into account in the system design.

In the case of an open hole blow out, exit pressures are a function of the total fluid flow rate (including injection component). The system has been designed to be compatible with the BOP design for individual wells and gas flow rates of up to 300 MMSCFM/day. Various well geometries are shown in the accompanying charts as representative of the range of casing/drill pipe combinations which have been studied.

Specifically, scale testing at the LSU Blowout School provided a data base which could be used to extrapolate flow rates not easily attainable for the purposes of study. This data base, portions of which are included with this material, has authenticated the concept and its parametric limitations. As a result of this work the system was designed to consist of an inert gas (LCO_2) vessel under 850 psig maximum, 800 psig working pressure. The vessel is complete with refrigeration, all necessary gauges and all necessary safety devices. It has been designed, constructed, tested, inspected and stamped in accordance with the latest edition and revision of the ASME Code for Unfired Pressure Vessels and according to the State laws and regulations of the States of Ohio and Pennsylvania. The vessel has a National Board of Boiler and Pressure Vessel Inspectors Certification Number and has been inspected by the Hartford Steam Boiler Inspection and Insurance Company or equal.

The vessel will feed LCO_2 into either a 4" or 6" Sch. 40 flanged (bolt through connection) carbon steel pipe of approximately 200' length. The exact length of the pipe will be worked out with the contractor as a function of the specific location available for the vessel. The pipe will feed into a spool piece which combines a drilling spool and the special requirements of SNUFF into one item to conserve space.

The system is controlled by 3 palm buttons, any one of which can energize the flow control valve. One palm button supplied with a protective stainless steel cover is suggested for the drilling station area. A second palm button with panel is attached to the gauge panel at the vessel also containing visual and audio cues indicating operational status of the SNUFF system. A third palm button with panel is supplied to be installed at another location to be specified by the contractor. The control system operates off rig electric power in the normal mode however at the two remote panels a mechanical override is available to manually operate the flow control valve. In the event of power loss, refrigeration of the LCO_2 and the ambient temperature. Pressure decrease in the vessel under a loss of power will result in some system degradation if repeated close interval activation of the SNUFF is necessary. Alternative power sources for standby ability are being investigated with the thought of future incorporation if field experience dictates a need.

INSTALLATION, MAINTENANCE & COST

Once an order has been received for a SNUFF system, a field crew will be dispatched to the well site with all of the equipment necessary for a field installation. Once on site it will be the responsibility of the Drilling Contractor to:

1) have the spool installed in the BOP stack or casing head for diverters

2) specify locations of the vessel and control boxes and

3) provide facilities for electrical connection with personnel to make the hook up between SNUFF and the power panel.

The SNUFF installation team will make up the interconnecting pipe, anchor if necessary, install the vessel where indicated, mount controls in desired location, have vessel filled, conduct system test and demonstrate system is functional to contractor personnel.

At the conclusion of drilling, the SNUFF installers will return to dismantle the system for transfer to another location or return to the warehouse. Again, the contractor will be responsible for removal of the SNUFF spool in good order for the installing team to transfer. Maintenance of the SNUFF is minimal and will normally be required if the system is activated, otherwise a routine check on a 30 day basis will be performed by SNUFF personnel.

The SNUFF system is available on a day rate basis for both on shore and off shore applications. The price is competitive with other well head components and is based upon a 15 day minimum for on shore and 30 day minimum for off shore. Installation, maintenance and periodic checks are separately priced one time for each installation.

EXCERPTED FROM LSU TEST DATA

Test Data included here has had some non pertinent, proprietary information removed. Essential test results have been left exactly as taken. All of the data deleted bears on engineering effort leading to other products in the general field of well control. If the information contained herein appears to be ambiguous please contact your Petro Safety representative and these areas will be dealt with on an individual basis.

3. TEST RESULTS

In order to evaluate the potential applications of the patented SNUFF system to well control in oil and gas drilling operations, approximately 200 experimental tests were run. About half of these tests were designed to determine the amount of Carbon Dioxide required to extinguish a burning blowout, or suppress ignition of a blowout.

3.1 FIRE SUPPRESSION RESULTS

The SNUFF system would be most easily applied to blowouts occurring on the well casing or annulus, because access to the casing would be possible through a casing spool or other spools located within the blowout preventer stack. Access to the drill pipe would generally be possible only by means of a hot tap made with the blowout in progress. Thus the majority of the experimental tests were conducted for conditions in which a blowout was occurring on the well annulus, or on the casing witn the drill pipe removed from the borehole. However, it is believed that these tests would also apply to conditions in which a blowout was occurring on a drill pipe and a hot tap could be made in order to inject Carbon Dioxide into the flow stream.

3.1.1 Blowout on Annulus

Two basic geometries were studied in the flame suppression studies. The first case was a blowout in which there was no obstructions above the burning wellhead. This geometry is generally present in the later stages of a blowout when all of the rig debris has been removed from the burning wellhead. This geometry would also apply to some producing wellhead situations. The second case was a blowout in which a platform was present above the burning wellhead. This would generally be the case during the initial stages of an annular blowout on a drilling well, when the well fluids are impinging upon the rotary table and rig floor.

3.1.1 Unobstructed Fire

Summarized in Table 3.1 are the results obtained by injecting various quantities of Carbon Dioxide into an annulus containing natural gas flow streams of varying magnitudes.

The annular geometry studied in these tests was for 8.625-in. casing with 5.0-in. drill pipe. It was felt that this geometry would allow the determination of the effect of sonic velocity at significant wellhead exit pressures, without the need for excessive gas flow rates. Gas flow rates in the range of 2-32 MMSCF/D were included in the study. Also included in these tests were the effect of either natural produced water or water injected in the flow stream with the Carbon Dioxide.

Summarized in Table 3.2 are results obtained with the 5.0-in drill pipe removed. The results were thus obtained for a similar gas flow rate range but at lower exit wellhead pressures.

The results of both Table 3.1 and Table 3.2 have been displayed graphically in Figure 3.1, in which the inert to flammable gas ratio

TABLE 3.1 - Results of Flame Suppression Test for Annulus between 8.625-in. Casing for 5.0-in Drillpipe .

TEST NO.	NATURAL GAS RATE (MMSCF/D)	WATER RATE (lb/min)	GAS TEMP. (° F)	WELL EXIT PRESSURE (psia)	INERT TO FLAMMABLE GAS RATIO (by weight)	EXTINGUISH FLAME (?)	TIME REQ. (sec)
2	2.2	0	54	16	2.8	Yes	-
4	3.5	0	59	23	3.1	Yes	-
5	3.4	0	52	18	3.1	Yes	-
6	4.4	0	58	17	2.4	No	-
7	4.0	0	44	19	2.7	Yes	3
8	4.0	0	37	19	2.7	Yes	2
9	4.5	0	48	22	2.4	No	-
11	5.0	0	48	25	3.3	Yes	-
12a	4.8	0	59	23	3.5	Yes	1.5
12b	4.6	0	55	22	3.5	Yes	1.5
13	4.8	0	52	23	3.5	Yes	3.0
14a	5.4	0	49	26	3.0	Yes	3.1
14b	5.2	0	46	26	3.0	Yes	3.1
15	5.4	0	61	27	3.0	Yes	3.1
16	5.8	0	59	28	2.9	Yes	3.0
17	5.8	0	53	27	2.9	Yes	3.0
18	6.8	0	50	29	2.4	Yes	3.0
19	6.0	0	43	27	2.8	Yes	3.0
20	6.4	0	40	29	2.6	No	-
21	5.8	0	39	27	2.9	Yes	3.0
22	6.7	0	35	29	2.5	Yes	3.0
23	7.4	0	35	31	2.2	Yes	3.0
24	7.8	0	77	31	2.1	Yes	4.5
25	8.4	0	61	31	2.0	No	-
26	8.0	0	46	34	2.1	Yes	6.0
27	8.3	0	37	34	2.0	Yes	4.0
28	9.2	0	28	36	1.8	Yes	3.0
29	9.6	0	19	35	1.7	Yes	3.0
30	9.6	0	50	33	1.7	Yes	4.0
31	10.0	0	32	36	1.7	No	-
32	10.6	0	30	35	1.6	No	-

TABLE 3.1 - Results of Flame Suppression Test for Annulus between 8.625-in. Casing for 5.0-in Drillpipe . (Continued).

TEST NO.	NATURAL GAS RATE (MMSCF/D)	WATER RATE (lb/min)	GAS TEMP. (° F)	WELL EXIT PRESSURE (psia)	INERT TO FLAMMABLE GAS RATIO (by weight)	EXTINGUISH FLAME (?)	TIME REQ. (sec)
33	10.2	0	14	36	1.6	Yes	4.5
34	9.6	0	7	36	1.7	Yes	4.5
35	9.6	0	1	35	1.7	Yes	4.0
36	9.2	0	16	33	1.8	Yes	4.5
37	9.7	0	7	36	1.7	Yes	22.5
38	10.6	0	7	35	1.6	No	-
39	11.3	0	10	37	1.5	No	-
40	11.0	0	4	36	1.5	No	-
42	11.5	0	56	41	1.8	Yes	4.0
43	17.5	0	55	65	1.2	Yes	6.0
44	17.5	0	9	61	1.2	No	-
45	13.9	0	3	63	1.5	No	-
47	20.4	0	41	71	1.2	No	-
48	13.7	0	26	66	1.8	No	-
49	12.5	0	28	51	2.0	Yes	3.0
50	11.0	0	26	51	2.3	Yes	3.0
51	11.8	0	25	48	2.1	Yes	4.5
52	12.7	0	21	51	2.0	Yes	3.0
53	13.6	0	11	49	1.8	Yes	40.5
54	4.8	0	64	29	5.2	Yes	2.0
55	7.2	0	55	39	3.4	Yes	3.0
56	9.8	0	31	46	2.5	Yes	3.0
59	21.1	0	30	81	1.6	Yes	6.5
60	19.9	0	14	80	1.7	Yes	3.0
61	18.0	0	6	75	1.9	Yes	4.5
62	30.7	0	7	98	1.1	No	-
62	25.4	0	7	83	1.3	Yes	-
63	25.9	0	7	93	1.3	Yes	3.5
64	26.4	0	1	95	1.3	Yes	4.5
67	31.7	0	-9	105	1.1	No	-
67	17.3	0	-9	63	2.0	Yes	-

TABLE 3.1 - Results of Flame Suppression Test for Annulus between 8.625-in. Casing for 5.0-in Drillpipe . (Continued).

TEST NO.	NATURAL GAS RATE (MMSCF/D)	WATER RATE (lb/min)	GAS TEMP. (° F)	WELL EXIT PRESSURE (psia)	INERT TO FLAMMABLE GAS RATIO (by weight)	EXTINGUISH FLAME (?)	TIME REQ. (sec)
68	22.1	0	0	74	1.5	Yes	3.0
69	25.4	0	-9	88	1.3	No	-
70	22.6	0	-2	75	1.5	Yes	3.5
71	22.1	0	14	79	1.4	Yes	3.0
72	20.6	0	5	70	1.4	Yes	5.0
78	8.6	0	70	70	3.9	Yes	4.0
79	10.3	0	62	70	3.3	Yes	2.5
187	13.0	460	-	-	2.8	Yes	3.0
188	19.0	460	-	-	1.9	Yes	3.0
189	19.3	460	-	-	1.9	Yes	3.0
190	18.2	260	-	-	1.6	Yes	3.0
191	16.8	160	-	-	1.6	Yes	3.0
192	24.8	160	-	-	1.1	No	-
193	21.1	160	-	-	1.3	Yes	3.0
194	23.5	160	-	-	1.1	No	-
195	16.3	160	-	-	1.6	Yes	3.0

TABLE 3.2 - Results of Flame Suppression tests for 8.625-in. Casing with Drillpipe Removed.

TEST NO.	NATURAL GAS RATE (MMSCF/D)	WELLHEAD* PRESSURE (psia)	GAS TEMP. (° F)	GAS* EXIT PRESSURE (psia)	INERT TO FLAMMABLE GAS RATIO (by weight)	EXTINGUISH FLAME (?)	TIME REQ. (sec)
102	31.2	25	34	21	1.1	No	-
103	23.0	25	34	20	1.5	Yes	2.5
104	26.6	25	-4	21	1.3	No	-
105	23.5	25	10	20	1.5	Yes	3.6
106	23.0	25	-2	20	1.5	Yes	6.0
107	4.3	115	43	15.5	7.3	Yes	-
108	5.3	195	43	15.5	-	No	-
109	5.8	265	43	15.5	-	No	-
110	7.7	265	40	15.5	-	No	-
111	6.2	215	43	15.5	-	No	-
112	6.2	105	40	15.5	5.0	Yes	-
113	4.3	165	16	15.5	3.6	Yes	3.

*Prior to injection of CO_2.

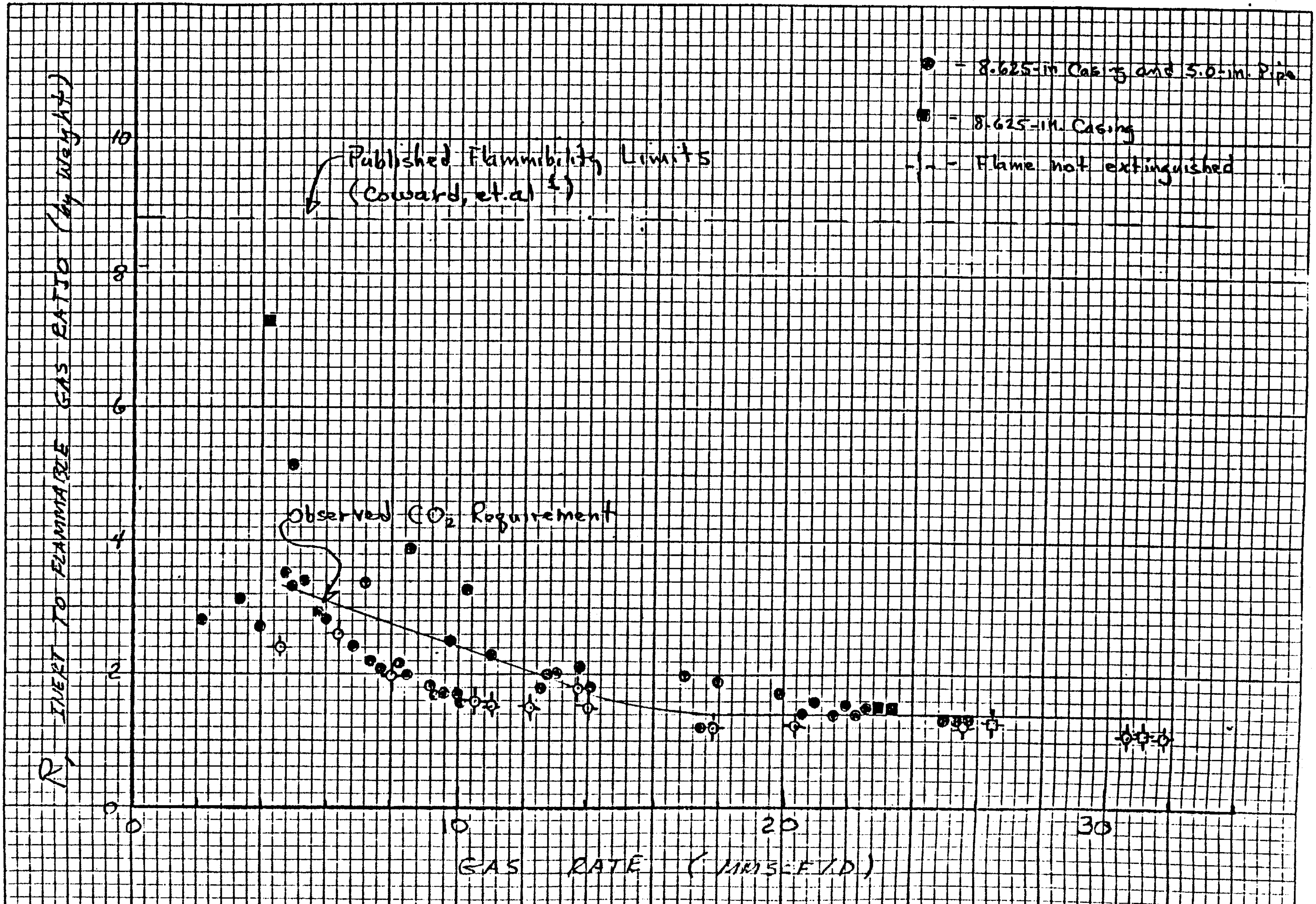

Fig. 31 - Carbon Dioxide Requirements for Flame Suppression of an Unobstructed Natural Gas Fire

(by weight) is plotted versus gas flow rate. Note that for gas rates above 16 MMSCF/D, in every test for which the inert to flammable gas ratio (by weight) was above 1.4, the fire was extinguished. At lower gas rates, the required ratio increases. A ratio of about 3 is required at 5 MMSCF/D. Note that the same trend line applies for both (1) the 8.625-in. by 5.0-in annulus and (2) th 8.625-in. casing a with the drill pipe removed.

Shown for comparison in Fig. 3.1 is the minimum value of the inert to flammable gas ratio reported by Coward, et. al.[1] for mixtures of methane and Carbon Dioxide. The ratio of 8.1, which is shown in Fig. 3.1, corresponds to the upper limit of 3.2 inert to flammable gas mixture (by volume) shown for the methane/CO2 envelop in Fig. 3.2. Since the average molecular weight of the natural gas used was about 16, and since the molcular weight of Carbon Dioxide is 44, then

$$(3.2)\ (44)/16 = 8.8$$

Note that the value of 1.4 obtained experimentally is well below this published valve. Thus, the experimental flame produced was much less stable for this experimental geometry than standard flammability tests would suggest.

The time required to extinguish the fire was generally about 3 seconds from the time the switch was closed to activate the automatic valve. Since valve actuation was not instantaneous, the time of extinguishment was even less. A few cases were observed when much longer time intervals were required to extinguish the fire, but these cases were generally at or below the trend line drawn in Fig. 3.1, such that an almost stable flame was present.

Even when the flame was not extinguished, the flame changed

DETERMINATION OF LIMITS

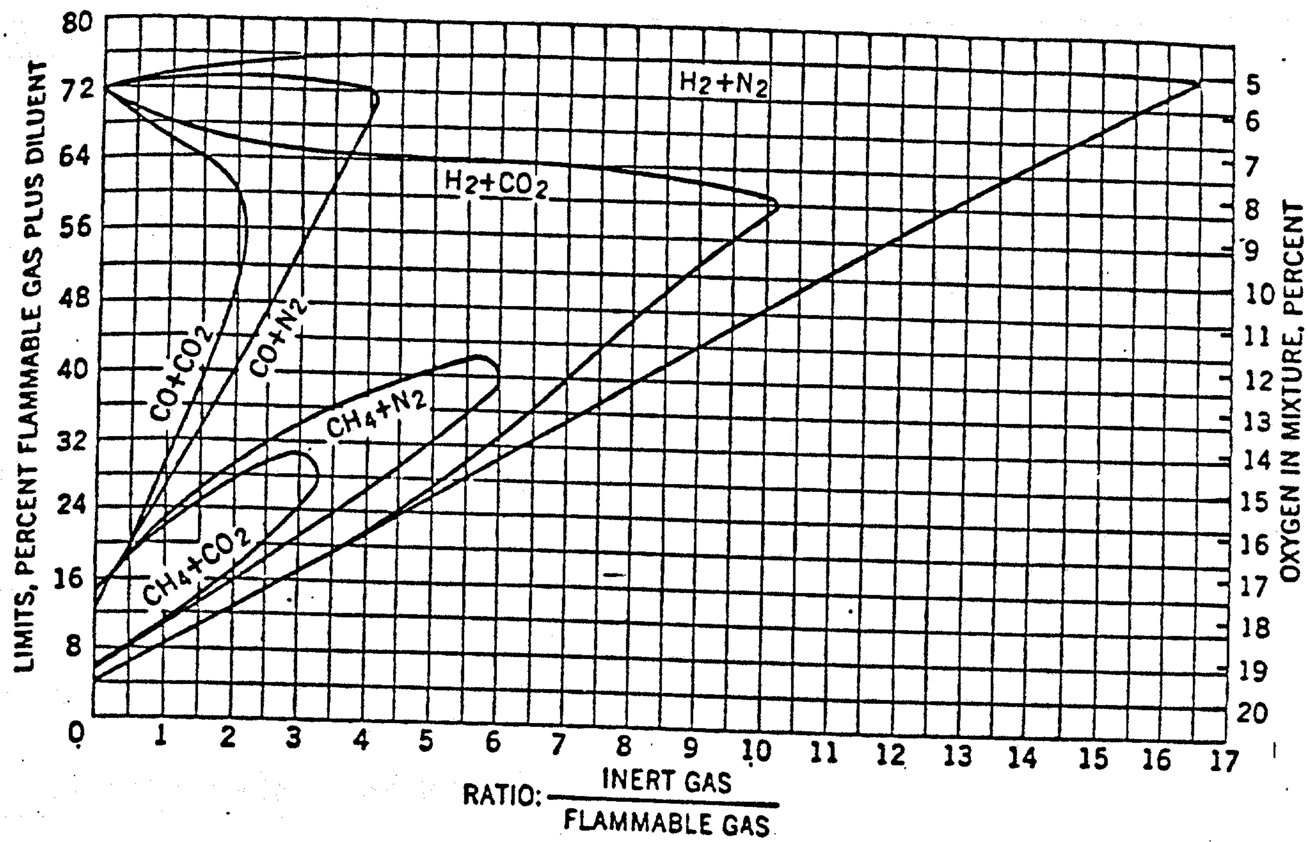

FIG. 3.2 - Limits of Flammability of Hydrogen, Carbon Monoxide, and Methane Containing Various Amounts of Carbon Dioxide and Nitrogen. After Coward et. al.[1]

greatly in appearence, changing to an almost invisible blue/white flame. In daylight, it was often easier to determine by sound rather than sight if the flame was still present after injection of Carbon Dioxide was started.

3.1.1.2 Obstructed Fire

The results of the flame suppression tests when an obstruction was present 8 ft. above the well exit are given in Table 3.3. Results for an open wellhead with an obstruction present 3 ft above the well exit are given in Table 3.4.

Note that the inert gas requirements are greatly increased by the presence of an obstruction,and becomes even greater as the obstruction is moved closer to the well exit. At low gas rates, the inert gas requirements are approaching the flammability limits published by Coward, et. al. when an obstruction is near the well exit.

TABLE 3.3 - Results of Flame Suppression Tests for Annulus between 8.625-in. and 5.0-in. Drill Pipe with Obstruction Present 8 ft. above Well Exit.

TEST NO.	NATURAL GAS RATE (MMSCF/D)	WATER RATE (lb/min)	WELL EXIT PRESSURE (psia)	INERT TO FLAMMABLE GAS RATIO (by weight)	EXTINGUISH FLAME (?)	TIME REQ. (sec)
166	12.7	0	51	2.3	No	-
166	4.4	0	26	6.7	Yes	-
167	7.0	0	39	3.8	No	-
167	4.3	0	26	6.2	Yes	-
168	3.9	0	20	7.0	Yes	3.0
169	5.2	0	30	5.2	Yes	3.0
170	6.7	0	35	4.0	No	-
171	5.8	0	33	4.7	No	-
172	5.8	280	-	6.2	Yes	-
173	8.9	280	-	4.0	Yes	-
174	9.6	280	-	3.8	No	-

TABLE 3.4 - Results of Flame Suppression Tests for 8.625-in. Wellhead with Obstruction Present 3 ft. above Well Exit.

TEST NO.	NATURAL GAS RATE (MMSCF/D)	WATER RATE (lb/min)	INERT TO FLAMMABLE GAS RATIO (by weight)	EXTINGUISH FLAME (?)
202	13.0	0	1.3	No
203	10.8	0	1.6	No
204	5.4	0	3.2	No
205	1.0	0	17.5	Yes
206	6.5	150	3.4	No
207	3.4	150	6.5	No
208	2.5	150	8.8	No
209	1.7	150	13.1	Yes
210	5.8	400	5.2	No
211	5.3	400	5.7	Yes
212	5.8	400	5.2	No
213	7.2	670	4.9	No
214	5.8	670	6.0	Yes
215	6.2	670	5.6	No
216	5.3	670	6.6	Yes

3.1.3 Effect of Well Fluid Composition

An exhaustive study of the effect of hydrocarbon composition on the Carbon Dioxide requirements for flame suppression was not felt to be feasible. However, the effect of Carbon Dioxide concentration on flammability limits for certain hydrocarbons has been studied previously and data are available in the literature. These data can be used to allow comparisons of the Carbon Dioxide requirements for natural gas and for other hydrocarbons.

Shown in Fig. 3.9 are flammability envelopes for mixtures of Carbon Dioxide with Ethane, Ethene, and Benzene. Note that the minimum inert to flammable gas ratios (by volume) vary considerably for these different hydrocarbons. However, as shown in Table 3.7, if these ratios are put on a weight basis, the percentage variations are greatly reduced. If the Carbon Dioxide requirements are based on hydrocarbons mass rate, and a large safety factor is applied, then the effect of a variable hydrocarbon composition should not cause a major problem with flame extinguishment.

3.1.4 Effect of Well Fluid Temperature

Because of limits imposed by the experimental test apparatus, the effect of the temperature of the hydrocarbon flow stream could not be studied experimentally over a wide range.

The hydrocarbon temperature range entering the test welhead varied from about 20 to 60 degrees F. A large effect of this temperature range on the Carbon Dioxide requirements was not evident from a review of the experimental results.

The temperature of the well fluids in an actual blowout could be significantly higher than those studied in this tests. Coward[1] points out that the internal energy of the flammable gas does affect flammability limits. Although a major effect is not anticipated, the effect of temperatures of the order of 200 degrees F should be

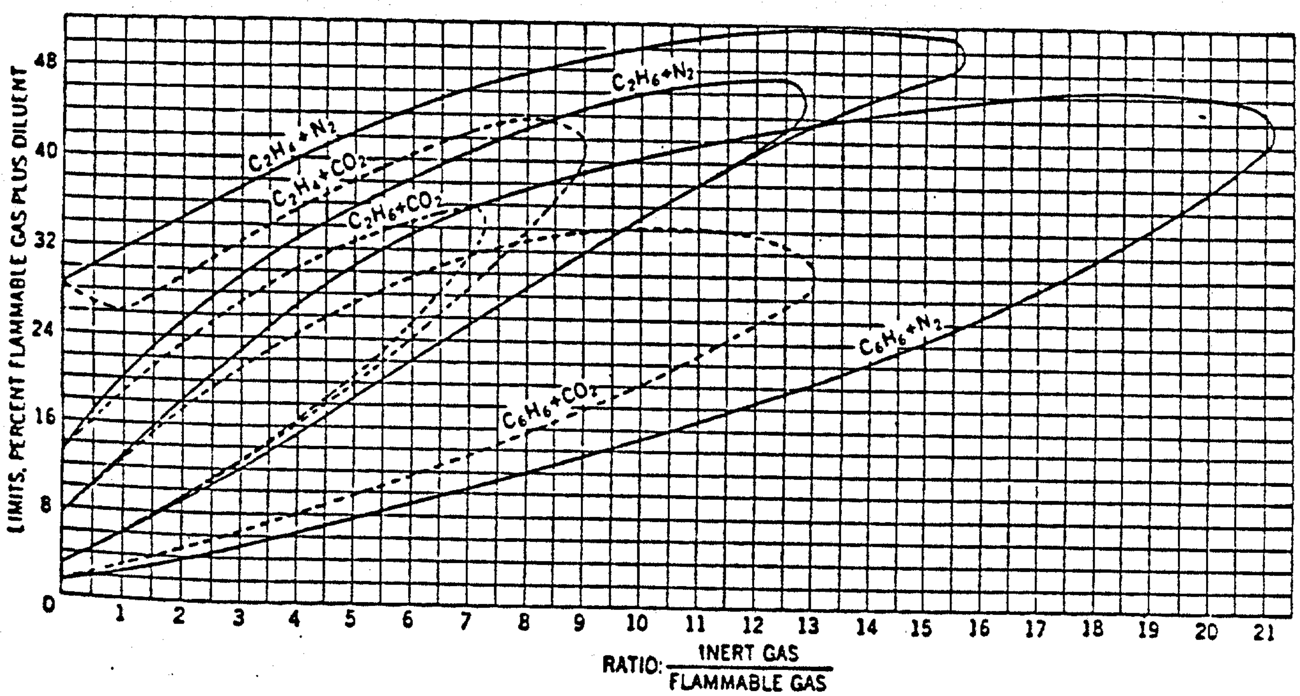

FIG. 3.9 - Limits of Flammability of Ethane, Ethylene, and Benzene Containing Various Amounts of Carbon Dioxide and Nitrogen.

HYDROCARBON	MOLECULAR WEIGHT	CO2/FLAMMABLE GAS RATIO (by volume)	CO2/FLAMMABLE MOLECULAR WEIGHT RATIO	CO2/FLAMMABLE GAS RATIO by weight)
Methane	16	3.2	2.75	8.8
Ethane	30	7.2	1.47	10.5
Ethene	28	9.0	1.57	14.1
Benzene	78	13.0	0.56	7.3

TABLE 3.7 - Published Carbon Dioxide Flame Suppression Requirements for Several Hydrocarbons.

determined either by a literature search or experimentally on a small scale.

4. EVALUATION OF POTENTIAL APPLICATIONS

Based on the results of the experimental test program, the potential applications the of SNUFF system studied are in the area of fire suppression or extinguishment rather than freeze plug formation. Possible applications in the oil and gas industry could include:

(1) Fire extinguishment or suppression in ruptured process piping on and between offshore oil and gas production platforms.

(2) Fire extinguishment or suppression in oil and gas well blowouts.

In offshore oil and gas operations, the available platform space is greatly limited by the high cost of platform construction, making it necessary to maintain a large amount of process equipment in a small space. The safety of personnel working on these structures are of major concern. Also, the economic investment at risk in case of fire can be quite high, making the economics of fire suppression systems most favorable.

Potential blowouts of oil and gas wells during drilling, producing, or workover operations also continue to be a major concern for operators involved in these activities. The SNUFF system could have possible applications in providing additional protection to rig personnel during those first moments when well control is lost and a blowout occurs. It could also find applications with wild well fighters and aid them in bringing the blowout under control.

The objectives of this study were directed primarily towards the consideration of the SNUFF system for application as a blowout safety device during drilling operations. Thus, this will be the primary application discussed in this chapter. Included in the evaluation of this application will be a discussion of the potential advantages of the system, the potential problems and limitations of the system, and the requirements for sizing the system.

4.1 POTENTIAL ADVANTAGES

The potential advantages to be gained by the SNUFF system are in the area of increased personnel safety. In the event of blowout preventer equipment failure, followed by a release of hydrocarbons, activation of the SNUFF system could allow additional time for rig personnel to evacuate the rig floor area. Also, when a shallow gas blowout is encountered which requires the use of the diverter system, the SNUFF system could be activated to provide additional time for rig personnel to safely evacuate the area.

5. CONCLUSIONS AND RECOMMENDATIONS

As a result of the experimental test program conducted, the following conclusions can be drawn:

1. An unobstructed natural gas fire burning at a rate above 16 MMSCF/D can be extinguished for a Carbon Dioxide to natural gas ratio by weight of 1.4.

2. A natural gas fire with an obstruction above it requires more Carbon Dioxide for extinguishment than an unobstructed fire. The Carbon Dioxide requirements increase as the obstruction moves closer to the wellhead exit and approaches the flammability limits of 9 pounds of CO_2 per pound of natural gas for the most unfavorable conditions.