Extinguishment of Natural Gas Pressure Fires

ARTHUR B. GUISE, *PE, SFPE*
Consulting Engineer

Several series of tests have been performed to compare the effectiveness of sodium bicarbonate-base and potassium bicarbonate-base dry chemicals in extinguishing natural gas fires. The author describes the methods used to analyze test data and recommends specific dry chemical application rates for extinguishing such fires.

ALTHOUGH the standard recommendation for handling gas fires is to "stop the flow of gas", there are circumstances in which extinguishment is desirable before the flow of gas can be stopped. Natural gas, being normally lighter than air, does not tend to flow over the ground in the manner of the higher molecular weight hydrocarbons so that the reignition hazard is less.

EXTINGUISHING TESTS

In 1951, the Texas Eastern Transmission Corporation and the Ansul Company cooperated in a series of 191 fire tests to determine the effectiveness of sodium bicarbonate-base dry chemical as an extinguishing agent for fires involving natural gas under pressure. The results have been briefly reported,[1,2] but more sophisticated techniques for analyzing fire extinguishment data have since been developed.

In 1963, the Safety First Products Corporation and the New York State Natural Gas Company conducted a series of 24 vertical jet fire tests using both sodium and potassium bicarbonate-base dry chemicals. The data are available from the manufacturer.[3]

In 1965, the Michigan Consolidated Gas Company and the Ansul Company cooperated in a more extensive series of 50 tests to determine quantitatively the relative extinguishing effectiveness of sodium bicarbonate-base, multipurpose monoammonium phosphate-base, and potassium bicarbonate-base dry chemicals.

Although the superiority of potassium bicarbonate-base dry chemical had been recognized with regard to liquid hydrocarbon fires since 1958,[4]

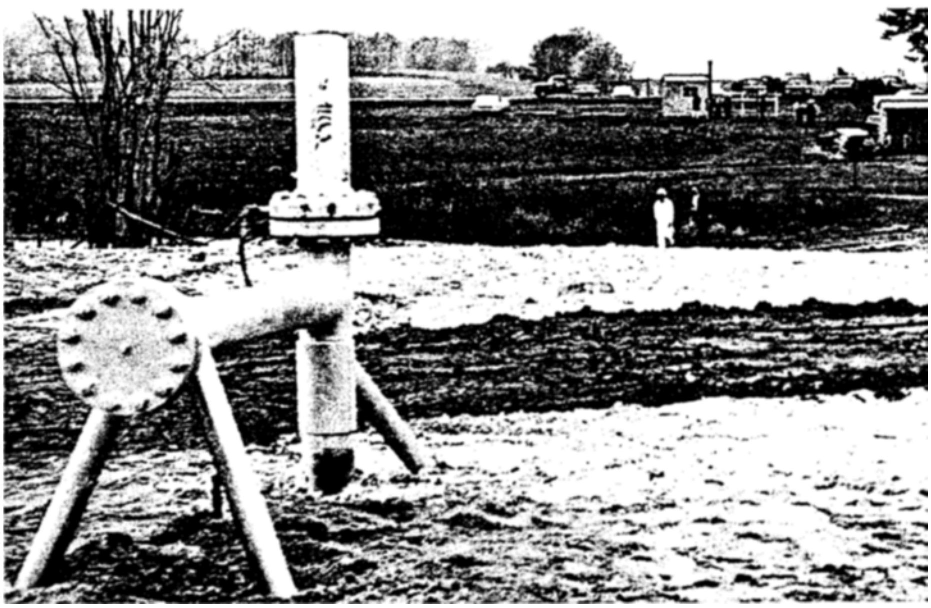
NOTE: Copies of the motion picture records of the tests may be borrowed from The Ansul Company and the Safety First Products Corporation.

tests with liquefied natural gas indicated that it was not superior to sodium bicarbonate-base dry chemical for the extinguishment of fires in this normally gaseous hydrocarbon.[5] A decision to use the more expensive potassium bicarbonate-base material could be economically justified only if quantitative fire test data showed it to be sufficiently more effective.

NATURAL GAS SUPPLY

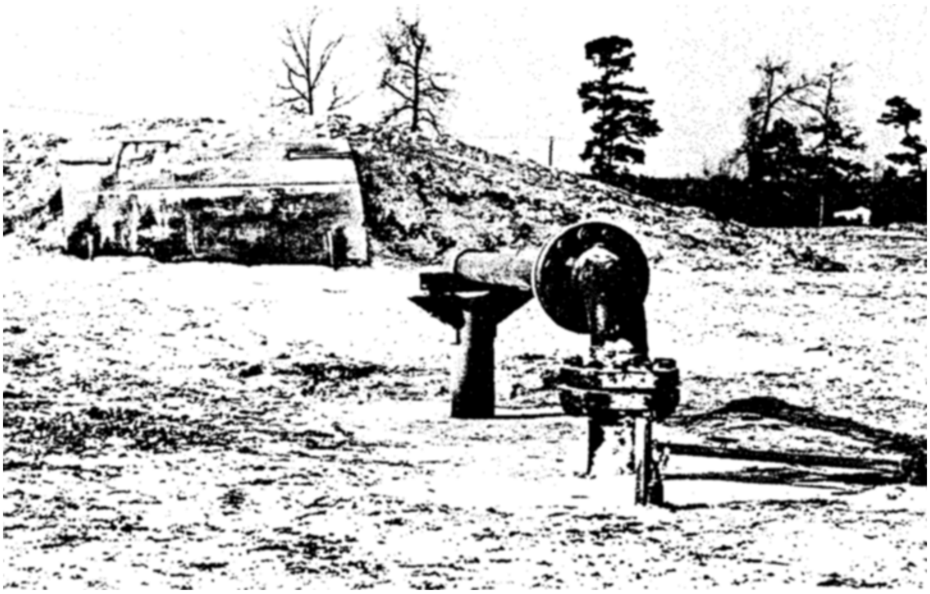
In each series of tests, the dry natural gas was supplied through about 500 ft of 6-in. pipe from large pipelines; in 1951, from a 24-in. line supplemented by a 16-in. line as necessary during high flows; in 1963, from a large pipeline connected to a large underground storage reservoir at 3,400 psig; and in 1965, from a 24-in. line supplemented by large underground storage. Main line pressure was about 850 psig in 1951 and slightly over 600 psig in 1965. The flow control valves were located about 450 ft from the fire test sites. In 1951, the gas flow rate was measured by an orifice meter; in 1963, by Pitot tube;[6] and in 1965, by side static pressure taken four pipe diameters from the outlet, using a dead weight pressure gage.[6]

At the 1951 and 1965 test sites, the 6-in. pipe terminated in a piping arrangement that permitted either vertical or horizontal jets and, in 1951, a downward jet from 20 in. above ground level. In each case, at least 7 tons of concrete were poured around the pipe at the terminus for anchorage against the thrust generated at high flow rates. Figure 1 shows the 1965 arrangement for vertical jets, and Figure 2 shows the 1951 arrangement for horizontal impingement.



Courtesy The Ansul Company

Figure 1. Arrangement for discharge of vertical jets in 1965.



Courtesy The Ansul Company

Figure 2. Arrangement for horizontal impingement against clay embankment faced with steel plate in 1951.

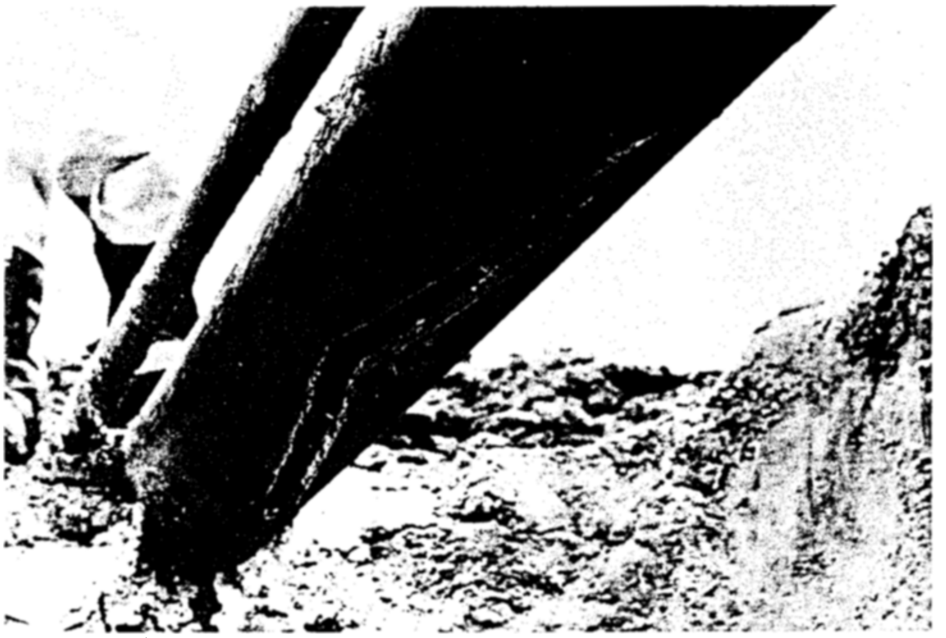
In 1951, tests were also made under conditions simulating a buried, split pipe with a break 1 in. wide by 28 in. long as shown by Figure 3.

In 1963 and 1965, a 6-ft long "nozzle" of 6-in. pipe was used in all tests. In 1951, nozzles 6 ft long of 2-in., 4-in., and 6-in. pipe were used, but not all sizes in all types of tests. The 2-in. nozzle was used only in the horizontal impingement tests, because at high flow rates the flame was blown away unless impinged to break the velocity of the gas stream. Even under critical flow (sonic velocity) conditions, the flames were not blown away when 4-in. and 6-in. nozzles were used in non-impinging jets.

Most of the vertical jet fires were in gas issuing at 5½ ft to 7 ft above ground level, but in some 1951 tests, gas issued from the riser pipe flange about 1 ft above ground level.

Although it is common gas transmission line practice to speak of flow rates in terms of thousands (M) of cubic feet per 24 hr day, in this paper the rates are cubic feet per second at 60° F and at atmospheric pressure, because time is expressed in seconds and dry chemical flow rate in pounds per second. To convert cu ft per sec into M cu ft per day, multiply by 86.4.

Because the method of measurement used in 1965 is valid only under critical flow rate conditions, all flow rates were at 400 cu ft/sec or greater. In 1951 and 1963, the gas flow rates were as low as 11 cu ft/sec from a 6-in. pipe, and the gas stream velocity was, therefore, an additional variable.



Courtesy The Ansul Company

Figure 3. Simulation of split pipe with cut 1 in. wide and 28 in. long in 1951.

EXTINGUISHING EQUIPMENT

In 1951, only sodium bicarbonate-base dry chemical was used. The potassium bicarbonate-base and the multipurpose dry chemicals had not yet been developed. Extinguishing equipment consisted of hand portable and wheeled extinguishers and 500, 1,000, and 2,000 lb capacity hose line units. The dry chemical flow rates used ranged from 1.4 lb/sec to 39.6 lb/sec. A maximum of 5 hose lines were used simultaneously. On large fires, the procedure frequently was to attack the fire with one hose line and, if the fire was not extinguished, to add streams until there was extinguishment or until it became evident that the fire was too large for the equipment available. The dry chemical flow time was measured only for the period of highest dry chemical flow rate.

It was quickly found in 1951 that only concentrated ("straight") high velocity dry chemical streams should be used manually on natural gas pressure fires. The data used for analysis in this paper do not include results obtained with "soft" or fan streams.

In 1963, sodium and potassium bicarbonate-base dry chemicals were applied from hand portable and wheeled extinguishers. Dry chemical flow rates ranged from 2.6 lb/sec to 5.2 lb/sec. The procedure used was to increase the size of the natural gas fires until, for a given dry chemical flow rate, extinguishment could not be effected. Instead of dry chemical flow time, extinguishing time was recorded. Based upon studies of the motion picture record of the 1965 tests, the extinguishing time is about 80 per cent of the dry chemical flow time.

In 1965, most of the fire tests were made with potassium bicarbonate-base dry chemical. Fire tests with sodium bicarbonate-base dry chemical were discontinued as soon as it was certain that there was good correlation with the results of the 1951 tests. Fire tests with multipurpose dry chemical were discontinued as soon as it became evident that it had about the same effectiveness as sodium bicarbonate-base dry chemical. Extinguishing equipment consisted of two 1,000-lb capacity skid-mounted units, each with two hose lines equipped with concentrated stream nozzles. The dry chemical flow rates ranged from 8.7 lb/sec to 47.9 lb/sec, and a maximum of four streams were used simultaneously. In general, the procedure was similar to that used in the 1963 tests; that is, the fire size was increased until there was failure to extinguish with a specific dry chemical flow rate. As in the 1951 tests, dry chemical flow time was recorded.

In all, 265 fire tests were carried out in 11½ days. Natural gas flow rates ranged from 11 cu ft/sec (950 M cu ft/day) to 2,610 cu ft/sec (225,500 M cu ft/day). Approximately 3,300,000 cu ft of gas, 49,000 lb of sodium bicarbonate-base, 6,000 lb of potassium bicarbonate-base, and 800 lb of multipurpose dry chemical were used during the tests.

Test Fires

The test fires were of two basic types — impinging and non-impinging — and there were several variations of each type. Non-impinging fires included horizontal jets (1951 and 1965) as well as vertical jets originating from 5½ to 7 ft above ground level (1951, 1963, and 1965) and from 1 ft above ground level (1951). Impinging fires included horizontal fires with short (1951 and 1965) and long (1951) preburn times, downward impinging fires (1951), and fires involving a split pipe in a trench (1951).

Non-impinging Fires: Although there are few vertical jet fires in practice, test fires of this type are of value for evaluating the relative extinguishing effectiveness of agents because there are fewer uncontrollable variables.

The vertical jet fires were the largest because they were the easiest to extinguish. A fire with the maximum available natural gas flow rate of 2,610 cu ft/ sec was easily extinguished by potassium bicarbonate-base dry chemical applied at the rate of 24 lb/sec from two hose lines. These fires were also the most spectacular.

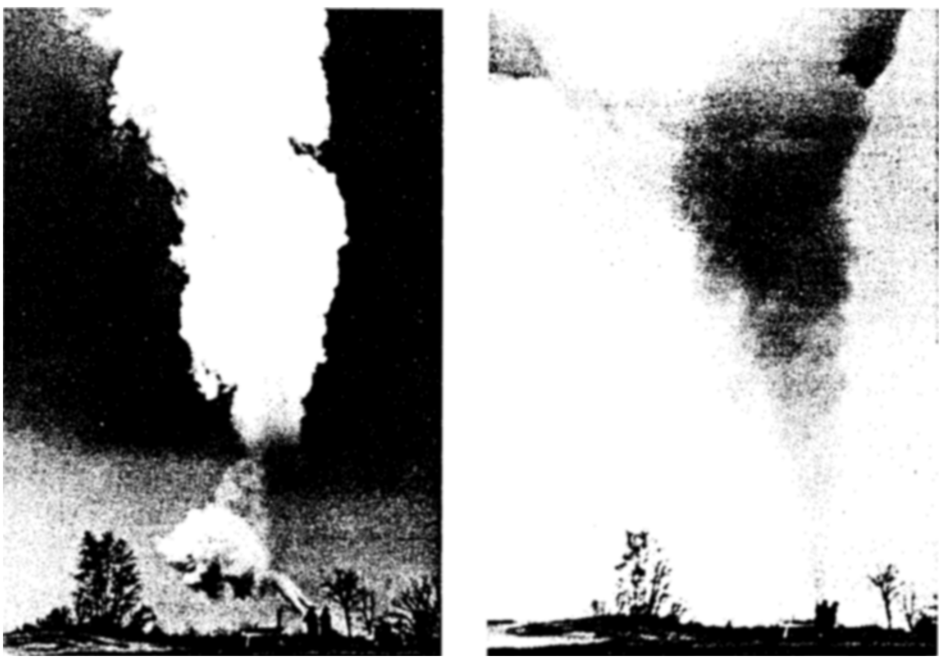
The ears were protected against damage by earplugs in 1951 and by earmuffs such as are used around jet aircraft engines, in 1965. Even so, the vibrations produced by the gas issuing at sonic velocity could be felt.

Because there are few opportunities to gather information on such gross gas diffusion flames, data from Reference 3, supplemented by data obtained by scaling photographs taken in 1951 and 1965, were studied and the following approximate relationships found applicable when the gas was discharged from 6-in. pipe:

- Height of flame, $h \sim 18V^{1/3}$
- Diameter of flame, $D \sim 2.5V^{1/3}$
- Area of flame, $A \sim 122V^{2/3}$

As the rate of gas flow is increased, an area of no flame or a faint blue flame appears at the base. This area is approximately equal in height to the diameter of the flame. About 25 per cent of the heat from a natural gas diffusion flame is radiated[5] so multiplying the gas flow rate by 250 will give the approximate heat radiation in Btu per sec. A fire fighter approaching such a fire passes through a region of high heat radiation. At the base of the flame, radiation is much less, and cool air rushes in at velocities as high as 13 mph. However, the radiant heat is not sufficiently intense at gas flow rates up to 2,600 cu ft/sec to char or ignite felt hats, dark woolen jackets, or canvas bunker suits if fire fighters pass quickly through the region of maximum radiant heat. A 600 cu ft/sec vertical jet fire is shown in Figure 4.

The foregoing comments apply to all vertical jet fires when the pipe terminates about 6 ft above ground level, and also to vertical jets when the pipe terminates about ground level and the gas velocity is near sonic. When the gas stream velocities are low and the pipe terminates near



Courtesy The Ansul Company

Figure 4. Extinguishment of 600 cu ft/sec vertical jet fire by sodium bicarbonate-base dry chemical. (a) First application of dry chemical. (b) Just before extinguishment of remaining flames.

ground level, the fire fighter directly faces a radiant flame, and special protective clothing and head gear of the aluminized type should be worn. A fire of this latter type occurred in New York City on January 13, 1967.[7]

Horizontal non-impinging jet fires are slightly more difficult to extinguish than vertical jet fires because the flame laps the ground. In the tests, the difference was not sufficient to include analysis of data from these fires.

Impinging Fires: Impinging jet fires are much more difficult to extinguish than the non-impinging fires. Figure 5 shows an attack on a horizontal impingement fire during the 1965 tests. The outline of the embankment is visible and, by comparison with Figure 2, it will be seen that in the 1965 tests the bank was considerably higher than the bank used in 1951. No steel plate was used in 1965.

In practice, impinging fires are more common, and it may be expected that such a fire could have been burning for a considerable time before fire fighting equipment and crews could try to extinguish it. Therefore, in 1951, a number of tests were carried out in which either the earthen (clay) embankment or the steel plate or both had been heated to red heat by prolonged preburns. In 1965, a preburn of about two minutes was used in one test, but the sandy earth did not reach red heat. There was no difficulty in extinguishing the fire. The higher gas flow rates required for limiting fires when potassium bicarbonate-base dry chemical is used impose an economic limit on the length of time that such flow rates are continued.

Courtesy The Ansul Company

Figure 5. Initial application of dry chemical on horizontal impingement fire in 1965.

Fire fighters encounter severe heat radiation in approaching all impingement fires, but this is quickly reduced as soon as dry chemical reaches the gas jet. The natural gas, itself, carries the dry chemical to the flames. However, reflashes do occur from pockets of flame that do not immediately receive sufficient dry chemical for extinguishment. Eventually, the flames in the pockets are extinguished if the rate of dry chemical application is sufficiently high.

In the long preburn impingement tests, it was found that although continuous reflashes occurred initially, the continued application of dry chemical to prevent general combustion served to allow the gas itself to cool the hot steel and earth.

The downward impingement fires were more difficult to extinguish than the horizontal impingement fires. The flames spread around the point of gas impact and greater skill in applying the dry chemical was required for extinguishment. In addition to facing severe heat radiation, the fire fighter had to be careful not to step into an area where there was unburned gas that could reflash. Although the best way of fighting any gas fire is to try to get the dry chemical into the jet of gas issuing from the pipe so that the agent will be carried by the gas to the point of combustion, the ball of flame prevented the fire fighter from easily reaching the target of his stream.

These downward impingement fires were extinguished with the same dry chemical flow rates that were successful on horizontal impingement fires, but the extinguishing times were approximately five times longer.

The most difficult fires to extinguish were those in which the gas issued downwards from the split pipe in a trench. It was necessary for the fire fighter to go to the edge of the trench in order to project the dry chemical downwards into it against the resistance of the upward flow of gas. As the flow rates increased, so did the gas velocity, and on the larger fires, pebbles and dirt spewed from the trench. For protection against those missiles as well as against the severe exposure to radiant heat at such close range, fire fighters wore face masks. In addition, extra dry chemical streams were used solely as shields against heat radiation.

ANALYSIS OF EXTINGUISHMENT DATA

The earlier analysis of data from natural gas fire tests was based only on dry chemical and gas flow rates.[1,2] Examination of the data from the 1965 tests indicated that the extinguishing time should also be included as a variable. Extinguishing times had not always been taken in either series of tests, but dry chemical flow times had been recorded and were used instead.

The basic method of analysis used in this paper has been previously described in terms of flammable liquid fires.[3] Reviewing briefly: for a given fire condition, fuel, extinguishing agent, and method of agent application, the relationship between extinguishing time and agent application rate is hyperbolic as shown graphically by Figure 6-I. Curve C represents the relationship for a fire that is extinguished with more difficulty because of larger size, type of fuel, less effective agent, or less effective method of agent application. In these tests, there are only two types of agent but many fire sizes, and insufficient data for similar curves to be drawn for any one size. Fuel and method of agent application were the same in all tests included in this analysis.

The equation* for any one of the curves in Figure 6-I is

$$T = \frac{R}{aR - b}. \tag{1}$$

Rewriting Equation 1 as

$$\frac{1}{T} = a - \frac{b}{R} \tag{2}$$

gives a straight line equation as shown graphically by Figure 6-II. From experience, it was known that the variable of fire size modified Equation 2 to give

$$\frac{V^m}{T} = a - \frac{bV^n}{R} \tag{3}$$

and it was found by testing that, for these natural gas fires, m equals n.

Introducing the third variable, gas flow rate, modified Equation 1 to

$$T = \frac{RV^n}{aR - bV^n}. \tag{4}$$

The quantity of dry chemical to extinguish, Q, was obtained by multiplying both sides of the equation by R. The graphical relationship between Q and R is shown by Figure 6-III and the mathematical relationship is

$$Q = \frac{R^2V^n}{aR - bV^n} \tag{5}$$

Differentiating Equation 5 to get the rate of change in Q with respect to R, dQ/dR, and taking $dQ/dR = 0$, gave the minimum quantity of dry

---

* See list of nomenclature on page 193.

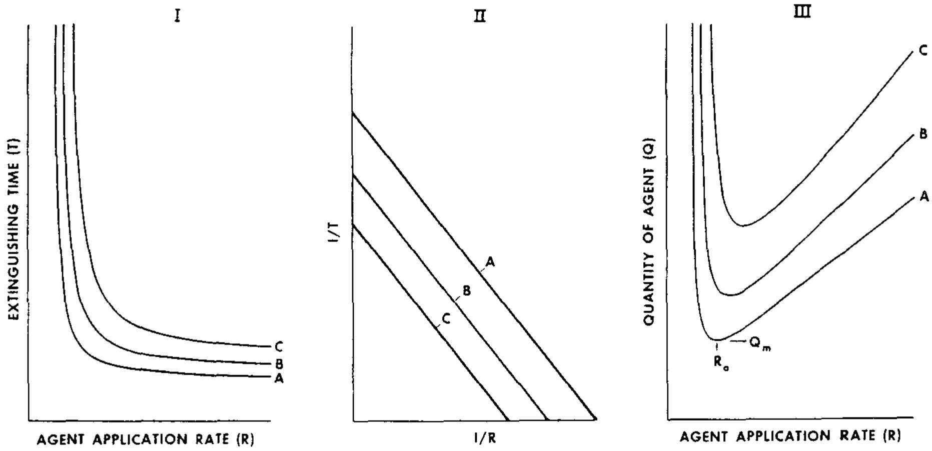


Figure 6. Graphical representation of relationship among extinguishing time, agent flow rate and agent quantity in the extinguishment of flammable liquid and combustible gas fires. Fire C represents a fire more difficult to extinguish than Fire A.

chemical required for extinguishment, Q_m, and the corresponding optimum dry chemical flow rate, R_o.

$$R_o = \frac{2bV^n}{a} \tag{6}$$

$$Q_m = \frac{4bV^{2n}}{a^2}. \tag{7}$$

It was found that the easiest way to get a first approximation of the numerical value of n was to plot Q against V on full-logarithmic paper. The lowest values for Q would approach Q_m and n could be calculated. The constants a and b were then obtained by least squares solution of Equation 3, regressing V^n/T on V^n/R. If there was doubt as to the true value of n, several values bracketing the first approximation would be tested and the apparent true value selected on the basis of the minimum standard deviation. An excellent discussion of least squares estimations will be found in Reference 9.

An alternative procedure for determining the value for n is to plot R against V on full-logarithmic paper. The lowest values of R approach $R_o/2$, and a first approximation of n can be calculated. Unless an adequate amount of data from limiting fires is available, the use of either procedure may give grossly erroneous values for n.

It was necessary to use knowledge of the fire test conditions to reject certain data. As an example, Figure 7 shows the linear relationship for horizontal impingement fires using potassium bicarbonate-base dry chemical. It will be noted that the first two tests gave very poor results. The data from those two tests were not included in the calculations of the empirical equations because it was obvious that they did not represent what should have been obtained. Table 1 gives the data for the first three fire tests.

The first fire should have been extinguished more quickly than the third fire. The explanation is simple: neither the writer nor the fire fighting crew chief, Anthony Gill of The Ansul Company, the only participants in the 1965 tests who had also participated in the 1951 tests, anticipated the ease with which potassium bicarbonate-base dry chemical extinguished the first two fires. When extinguishment takes place so quickly and unexpectedly, human reactions are seldom fast enough to enable obtaining meaningful time data. There is the further possibility that the time recorders were also surprised and did not stop the watches quickly enough. On the basis of the calculated relationship, the dry chemical flow time for Test No. 1 should have been 1.0 sec.

From the example given, it is clear that precise measuring of extinguishing or discharge time is a necessity if data are to be used for the derivation of empirical equations. Only when the dry chemical flow rates were in the

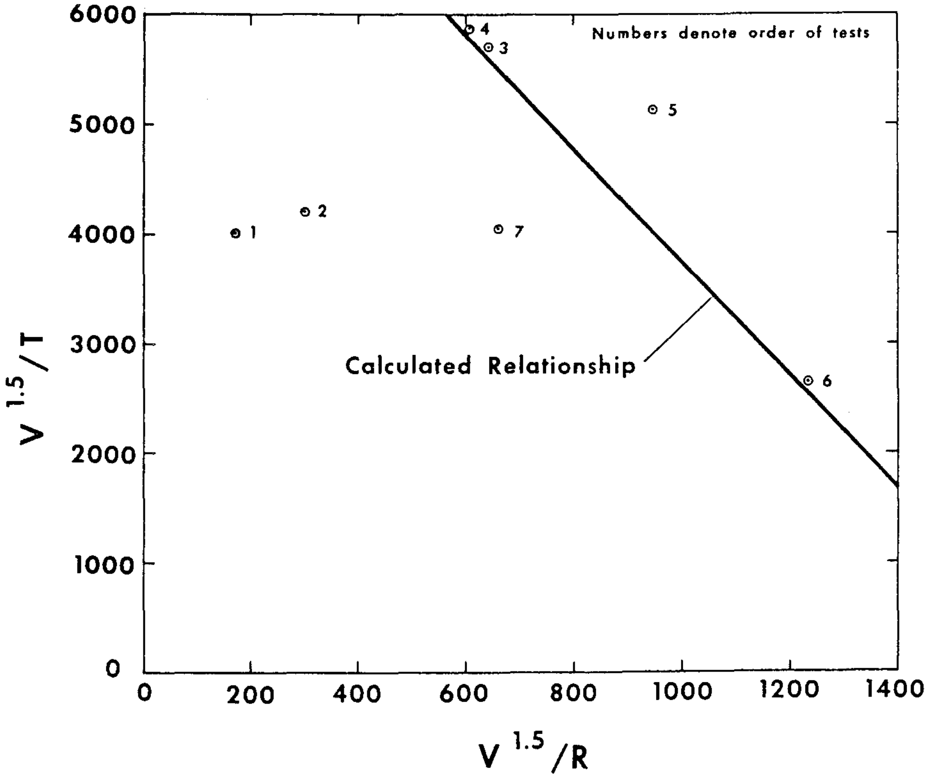


Figure 7. Typical linear relationship for natural gas pressure fires. Data are from extinguishment of horizontal impingement fires by potassium bicarbonate-base dry chemical.

TABLE 1. *First Three Tests on Extinguishment of Horizontal Impingement Fires with Potassium Bicarbonate-base Dry Chemical*

		Dry Chemical			
Test No.	*Gas flow, V (cu ft/sec)*	*Flow, R (lb/sec)*	*Flow time, T (sec)*	$V^{1.5}/T$	$V^{1.5}/R$
1	400	47.3	2.0	4,000	167
2	400	26.8	1.9	4,211	299
3	400	12.5	1.4	5,714	640

limiting ranges did the discharge time exceed 10 sec in tests where there was extinguishment.

Because of the large amount of data collected under comparable conditions, the results of the 1951 and 1965 tests were used to obtain empirical equations. However, the 1963 data were mathematically analyzed and, making allowance for the use of extinguishing time instead of discharge time, were found to have good correlation with the 1965 vertical jet data. Because of the wide range of gas flow rates from 6-in. pipe, the 1963 data were valuable for study of the possible effect of gas stream velocity. Although there were insufficient data to allow quantitative expression of the effect of gas stream velocity, there are indications that it is easier to extinguish a vertical jet fire when the velocity is near, or in, the sonic range (approximately 1,460 ft/sec).

The 1951 vertical jets issuing from about 1 ft above ground level also were in a wide range of gas flow rates and velocities. Although again not easily expressed in quantitative terms, there are indications that the fires were more easily extinguished when the gas stream was issuing at sonic velocity.

Gas velocity was a most important factor in the split-pipe-in-trench tests, and it was possible to incorporate this variable into the empirical equation. The equivalent of Equation 6 is

$$R_o = 1.43(V + 0.714 \times 10^{-12} V^{6.73})^{1/2}. \quad (8)$$

It will be quickly seen that, at low gas flow rates, the velocity is not a factor but the large exponent, 6.73, shows that the difficulty of fire extinguishment is eventually due more to the gas velocity than to the gas flow rate as the latter increases.

The correlation coefficients for the derived empirical equations ranged from 0.77 to 0.96, except for an unsurprising 0.19 for the long preburn horizontal impingement tests, 0.57 for the split-pipe-in-trench tests, and a surprisingly low 0.30 for the vertical jet tests with sodium bicarbonate-base dry chemical.

DISCUSSION

A high percentage of the fires were fought by experts in the handling of dry chemical extinguishing equipment, and the remainder, by well-trained men. Because the tests were made specifically to determine the limitations of commercially available equipment and dry chemicals, in a majority of tests $R \lhd R_o$ and examination of Figure 6-III shows clearly that probable success in extinguishment in practical fire fighting would require $R \geqq R_o$. To simplify the graphical presentation of the results, R_o is used as one ordinate and V as the other. R_o is, then, the recommended *minimum* rate of dry chemical flow for a given type and size of fire. The lines in the graphs are not extrapolated beyond the ranges of natural gas flow rates actually used in the tests.

The emphasis on dry chemical flow rates does not mean that the quantity of dry chemical available for fire fighting can be overlooked. However, dry chemical fire extinguishing equipment is commercially available in fixed capacities with application rates proportioned. In general, the quantities of dry chemical are more than adequate, with good safety factors. There are, however, complicating factors that are discussed in detail later in this paper.

Figure 8 shows that potassium bicarbonate-base dry chemical is somewhat over twice as effective as sodium bicarbonate-base dry chemical, measured in terms of dry chemical flow rate required to extinguish the same size fire. This correlates excellently with data obtained in tests with flammable liquids.[4]

In Figure 9, it will be seen that potassium bicarbonate-base dry chemical has an even greater superiority over sodium bicarbonate-base dry chemical in short preburn horizontal impingement tests. In such tests, the dry chemical is carried by the natural gas to the point of combustion, the flames. It is probable that the much greater effectiveness of the potassium bicarbonate-base dry chemical in extinguishing impingement fires is due to the smaller particle size, which would permit a higher concentration of the agent to be more readily carried to hidden flames.

In the United States, the physical characteristics of all potassium bicarbonate-base dry chemicals are generally based on military specifications[10] for competitive reasons. In other countries the usual 2 to 1 advantage over sodium bicarbonate-base dry chemical is sometimes not found. The only conclusion that can be drawn is that the particle size of those less effective potassium bicarbonate-base dry chemicals is larger than in American practice. If such is the case, those dry chemicals would not be expected to have the unusually great effectiveness found in the impingement tests.

Figure 9 also shows that, when an impingement fire has been burning long enough to heat earth and metal in the area to red heat, it is necessary to use a much greater dry chemical flow rate to obtain extinguishment.

Since such conditions are more likely to occur in rural areas, it may be expected that only relatively small fires of this type can be extinguished in practice because of the difficulty of getting very large equipment to the scene of the fire.

In one respect, Figure 10 can be misleading. It shows that both downward impingement fires and horizontal impingement fires can be extinguished by applying dry chemical at the same rate of flow for fires having identical gas flow rates. However, as previously remarked, it takes

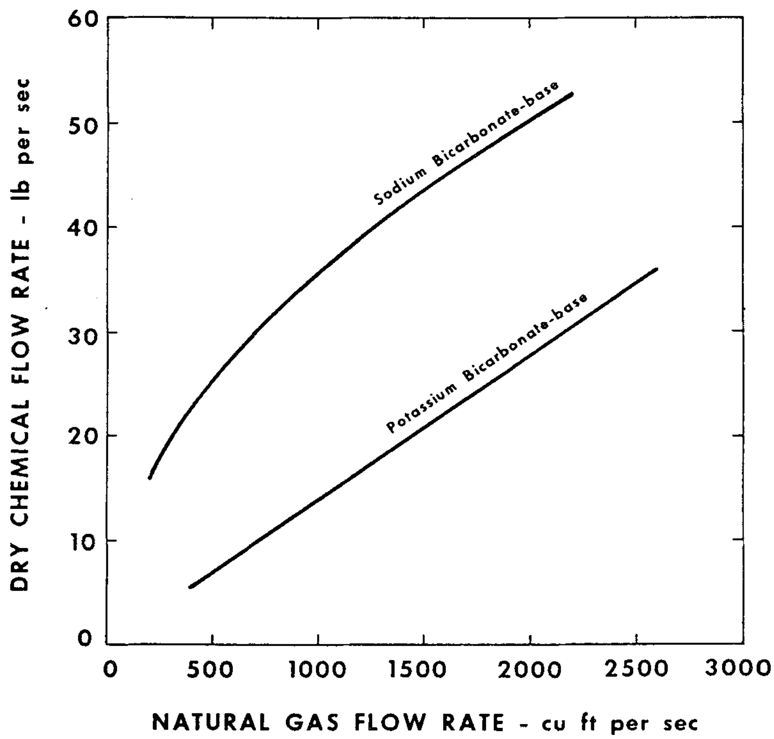


Figure 8. Recommended minimum dry chemical flow rates for extinguishment of vertical jet natural gas fires.

longer to extinguish downward impingement fires; therefore, the amount of dry chemical required to obtain extinguishment is five times greater than is required for extinguishment of a horizontal impingement fire.

The effect of the higher velocity at high gas flow rates in the split-pipe-in-trench fires is obvious in Figure 10. The cross-sectional area of the gas discharge opening was the same for downward impingement and the split-pipe-in-trench, 28 sq in. In these tests, there was only a short preburn. The difficulty in obtaining extinguishment if the surrounding earth were heated to red heat can only be estimated.

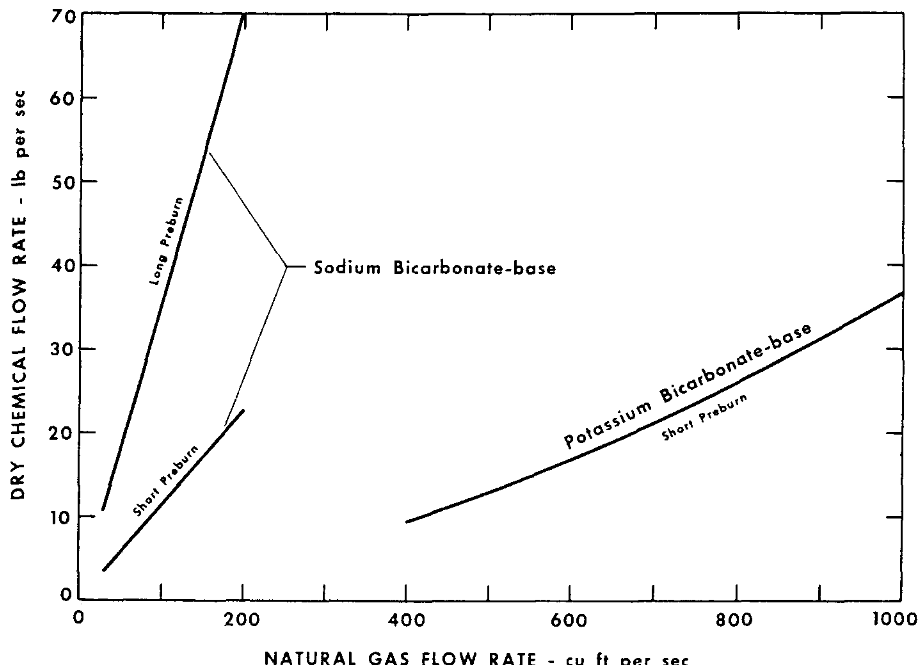


Figure 9. Recommended minimum dry chemical flow rates for extinguishment of horizontally impinged natural gas fires.

Flow rates can be chosen that will approximate what may be manually applied to any of the natural gas fires that have been discussed: 2.5 lb/sec from hand portable extinguishers, 5 lb/sec from small wheeled extinguishers, 10 lb/sec from large wheeled extinguishers or from one hose line from large mobile equipment, and 20 lb/sec from two hose lines from large equipment. Except for the hand portable extinguishers, the equipment should have sufficient dry chemical for a minimum 25 sec effective discharge time. Using those dry chemical flow rates as the minimum recommended for the type and size of fire, that is $R = R_o$, the maximum size fire of each type that can be expected to be extinguished by the two types of dry chemical are given in Table 2. Where experimental data were not available or extrapolations are needed, estimates have been provided and are noted in the table.

The asterisked values in Table 2 are extrapolated by calculations using empirical equations. The 1963 data were received after calculations had been completed on the basis of the 1951 and 1965 data, and the graphs were in final form for publication. Two limiting fires were extinguished in 1963, one flowing at 46 cu ft/sec extinguished by sodium bicarbonate-base dry chemical applied at 2.8 lb/sec, and the other, flowing at 392 cu ft/sec, by potassium bicarbonate-base dry chemical applied at 2.6 lb/sec.

From the empirical equations, it was known that $n = \frac{1}{2}$ for the sodium bicarbonate-base dry chemical and $n = 1$ for potassium bicarbonate-base dry chemical, for vertical jet fires. Also, as previously discussed, $R \sim R_o/2$ for limiting fires.

By assuming that $2R = R_o$, and with R, V, and n known, substitution in Equation 6 will give an approximation of $2b/a$. This approximate value for $2b/a$ will always be greater than the true value if data from extinguishments are used. If data from a failure to extinguish a fire having the same gas flow rate are available, another approximation of $2b/a$ can be obtained

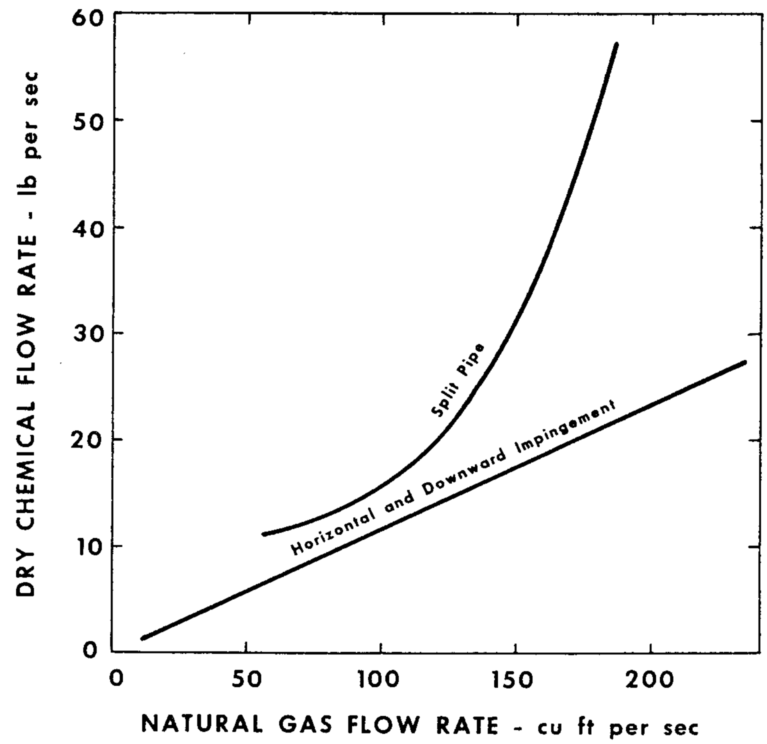


Figure 10. Recommended minimum dry chemical flow rates for extinguishment of horizontally and downwardly impinged, and split pipe, natural gas fires with short preburn times.

which will be lower than the true value. Averaging the two will give a closer approximation of the true value if there is only a slight difference in the two rates of dry chemical flow.

By using the approximate value for $2b/a$ and using $R_o = 2.5$ lb/sec, new values for V were calculated as a check on the extrapolated values. The calculations using the 1963 data gave 25 cu ft/sec for sodium bicarbonate-base, and 188 cu ft/sec for potassium bicarbonate-base dry chemicals. Comparison with the asterisked values in Table 2 shows the correlation to be good.

It was stated earlier in this paper that the dry chemical application rates are critical. It is logical to assume that this is true of all, or most, cases where extinguishment of combustible gases is the problem. Accordingly, it should be emphasized that the choice of hand and wheeled extinguishers for use on combustible gas fires should not be made on the basis of the Class B ratings, which are based on tests with gasoline fires. Extinguishers with high ratings may have lower dry chemical flow rates than other extinguishers with lower ratings. Therefore, extinguishers for use on combustible gas fires should be chosen on the basis of having nozzles producing concentrated high velocity streams of dry chemical at the highest flow rates compatible with the requirements of a nationally recognized testing laboratory.

The foregoing discussion of extinguishers for combustible gas pressure fires does not apply to extinguishers for fires in pools of liquefied com-

TABLE 2. *Maximum Extinguishable Fires of Natural Gas under Pressure*

Type of fire	*Dry chemical optimum flow rate, R_o (lb/sec)*	*Fire size (cu ft/sec)*	
		Sodium base dry chemical	*Potassium base dry chemical*
Vertical jet	2.5	22*	180*
	5	44†	360
	10	88†	730
	20	250	1,400
Horizontal impinge, short preburn	2.5	22	170†
	5	44	270†
	10	88	420
	20	180	670
Horizontal impinge, long preburn	2.5	7	49†
	5	14	70†
	10	28	110†
	20	57	170†
Downward impinge, short preburn	2.5	18	130†
	5	40	200†
	10	83	330†
	20	170	510†
Downward impinge, long preburn	2.5	5†	39†
	5	12†	60†
	10	15†	99†
	20	51†	150†
Split pipe, short preburn	2.5	3†	21†
	5	12†	60†
	10	49	200†
	20	120	360†
Split pipe, long preburn	2.5	1†	6†
	5	4†	18†
	10	15†	60†
	20	36†	110†

* Values extrapolated by calculations using empirical equations. See page 189.
† Estimates and extrapolations.

bustible gases. Tests made about 10 years ago by the writer at the Ansul Fire Test Station with fires in liquid propane and vinyl chloride in steel test pans indicated that such fires are similar to gasoline fires as far as extinguishment is concerned. The anomalous results reported in Reference 5, which showed sodium and potassium bicarbonate-base dry chemicals to be essentially equal in extinguishing effectiveness when used on fires in pools of liquefied natural gas, were probably due to lack of recognition of significant variables. For the extinguishment of fires in liquefied combustible gases, it is probable that Class B ratings indicate relative extinguishing effectiveness, although this opinion is not supported by test data. There are none.

CONCLUSIONS

Analyses of data provided by the aforementioned testing programs have led to the following conclusions:

- Potassium bicarbonate-base dry chemical is superior to sodium bicarbonate-base dry chemical as an extinguishing agent for fires in natural gas.
- The degree of superiority of potassium bicarbonate-base dry chemical varies with the type of pressure fire. Based upon comparative dry chemical flow rates for identical fire sizes, it has a minimum superiority of 2 to 1 for vertical jet fires and 7 to 1 for impingement fires. Based upon comparative fire sizes for identical dry chemical flow rates, it has a minimum superiority of 6 to 1 for vertical jet fires and 3 to 1 for impingement fires.
- The rate of dry chemical application is critical.
- Concentrated, high velocity dry chemical streams are superior to "soft" or fan streams for the extinguishment of natural gas pressure fires.
- Fires in impinging jets are much more difficult to extinguish than fires in non-impinging jets, especially after burning long enough to heat to redness the metal or earth upon which they impinge.

RECOMMENDATIONS

In the light of the results of the tests and the conclusions drawn from them, the following recommendations are made for fighting natural gas pressure fires:

- Use potassium bicarbonate-base dry chemical that closely approximates United States military specifications,[10] especially with regard to surface area.
- Use listed fire extinguishing equipment that produces high velocity concentrated streams of dry chemical at the highest flow rates compatible with the requirements of a nationally recognized testing laboratory.
- Use mobile equipment with hose lines equipped with nozzles that produce concentrated streams of dry chemical at the highest manageable flow rates (approximately 10 lb/sec) and with sufficient dry chemical

capacity to permit continuous application for a minimum time of 25 sec if water is also carried for cooling purposes. If water is not carried, dry chemical capacity should be sufficient for a 60-sec continuous application, but the dry chemical should be applied intermittently after initial extinguishment.

• For fighting large fires, special reflective protective clothing should be worn by the fire fighters.

NOMENCLATURE

A = area of vertical jet flame, sq ft
D = diameter of vertical jet flame, ft
h = height of vertical jet flame, ft
Q = quantity of dry chemical required to extinguish fire, lbs
R = dry chemidal flow rate, lb/sec
R_o = optimum dry chemical flow rate, lb/sec
T = dry chemical flow time, sec
V = natural gas flow rate, cu ft/sec
a, b, m, and n = constants that vary with the type of dry chemical and the type of fire.

REFERENCES

[1] "Natural Gas Fire Tests," Technical Bulletin No. 32, 1953, The Ansul Co., Marinette, Wisconsin.
[2] Guise, A. B., "Control of Natural Gas Fires," *Pipe Line Industry*, Feb. 1958, pp. 54–56.
[3] Letter of May 5, 1967 from Roger R. Cholin, Safety First Products, Elmsford, New York.
[4] Neill, R. R., "The Hydrocarbon Flame Extinguishing Efficiencies of Sodium and Potassium Bicarbonate Powders," Report 5183, 1958, U.S. Naval Research Laboratory.
[5] Burgess, D., and Zabetakis, M., "Fire and Explosion Hazards Associated with Liquefied Natural Gas," Report No. RI 6099, 1962, Bureau of Mines, U.S. Department of the Interior.
[6] Rawlins, E. L., and Shellhardt, N. A., "Back-Pressure Data on Natural Gas Wells and Their Application to Production Practices," Monograph No. 7, 1935, Bureau of Mines, U.S. Department of the Interior, pp. 128–129.
[7] Sylvia, R. P., "New York's 13-Alarm Night of Flame," *Fire Engineering*, Vol. 120, No. 4, April 1967, pp. 44–47.
[8] Guise, A. B., and Lindlof, J. A., "A Dry Chemical Extinguishing System," NFPA *Quarterly*, Vol. 49, No. 1, July 1955, pp. 52–60.
[9] Johnson, N. L., and Leone, F. C., "Statistics and Experimental Design," Vol. 1, Wiley, New York, 1964, p. 382 *et seq*.
[10] "Military Specification, Fire Extinguishing Agent, Potassium Dry Chemical," MIL-F-22287A(Wep), 23 Nov. 1962, and Amendment 1, 1 Nov. 1963.

ACKNOWLEDGMENTS: The author appreciates the cooperation of The Ansul Company in making available the test data of the 1951 and 1965 tests with permission to use photographs, and of the Safety First Products Corporation in making available the test data of the 1963 tests.