

Chapter 5

(from Firefighting and Blowout Control Abel Engineering, Houston Texas)

Firefighting Operations

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INTRODUCTION

Oil and gas well firefighting is unique in relation to other firefighting operations. Structural fires, forest fires, even petrochemical fires are distinguishable by the fact that, if the fire is contained, the fuel source will eventually be consumed and the fire will die out. But oil and gas well fires can burn for years unless they are extinguished and the flow is stopped. To safely and efficiently control a burning well requires a thorough understanding of the mechanics of petroleum fires, extensive knowledge of the tools available to accomplish the required tasks and experience in managing the unique risks associated with the job.

There are three main aspects of firefighting in well control operations:

- Preventing ignition of combustible mixtures.
- Containing the fire while capping the well.
- Extinguishing the fire so operations can safely proceed.

Note— Not all well fires are extinguished. In some cases, the well is ignited or left burning intentionally, for safety and environmental reasons.

MECHANICS OF THE CRUDE OIL FIRE

All substances burn only in vapor form. A solid or liquid must be converted into a vapor, or broken into fine particles and mixed with oxygen in the correct proportions, in order to burn.

A crude oil fire has several unique characteristics:

- Low gravity crudes may have either a high or low flash point, depending on the flash point of the light ends in the crude.
- High gravity crudes most often have low flash points.

- As vapor pressure increases, the flash point is lower. Vapor pressure is dependent on the amount of low-end hydrocarbons present in the mixture of crude oil.
- Low flash point crude, at a temperature above the fire point, will burn continuously when ignited by a spark or flame near the surface.

Note— It may be useful to review the definitions of terms used above in the Glossary of Terms found in the appendix.

It is important to understand that it is the vapor that burns. The ratio of the vapor (fuel) and air (oxygen) must be correct for combustion to continue. The flame is the result of combustion, and the only means to stop the burning and extinguish the flame is to alter the burning mixture of vapor and air. This is known as starving the fire. “All fires are extinguished by starving.”¹

FLAMMABLE VS. COMBUSTIBLE

Flammable materials are easily ignited because of their readiness to form a flammable vapor. Wood requires considerable energy to convert it to a vapor, so it is classified as combustible rather than flammable. Combustible materials can be controlled by cooling, while flammables cannot be extinguished by cooling alone. Some higher flash point oil fires can be extinguished by cooling. For example, diesel will cease burning if the surface temperature is reduced to 150°F. However, gasoline must be cooled to -45°F, which cannot be done with water. A water fog will not extinguish a gasoline fire by cooling. It will extinguish the flame, however, if the fog is concentrated enough to reduce the air percentage to less than 34% of the vapor-air mixture.

THE FIRE TRIANGLE

For many years, instructors have used a triangle to represent the basic components of a fire. Although this is a useful description, it does not emphasize the necessary fuel (vapor) and oxygen (air) mixture required for combustion in the presence of heat. In Figure 5.1, the traditional oil fire triangle is labeled A. Our modified version is labeled B. Firefighting, in general, deals with the fuel-vapor and oxygen-air components of the triangle, because combustion has already begun. Fire *prevention* deals primarily with the heat or ignition source.

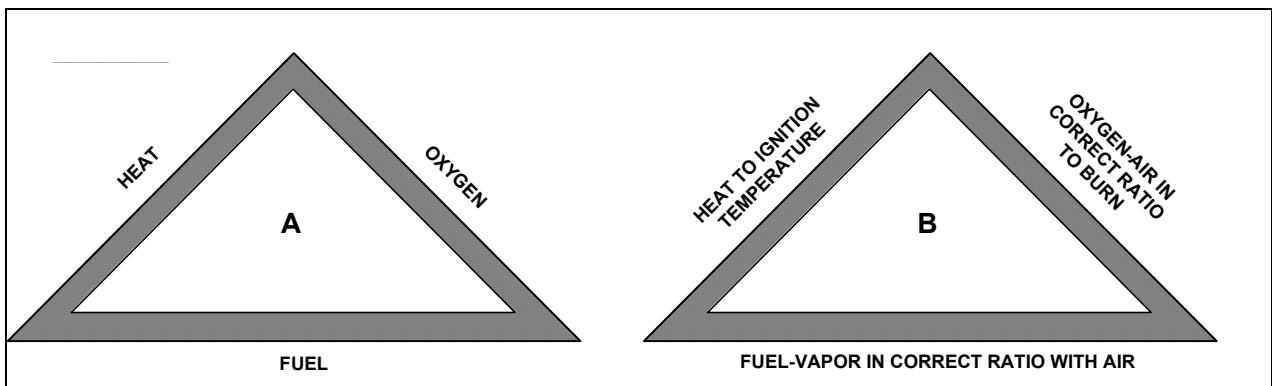


Figure 5.1 Fire Triangles

Tradition says that to extinguish a fire, one leg of the triangle must be eliminated. In well control situations, this is an over-simplification. Well fires are extinguished by altering the burning ratio of the vapor and air mixture for the specific crude or gas beyond its flammable range. This is

done by reducing the oxygen-air or the fuel-vapor components. If either is eliminated, or reduced, the fire is quickly extinguished because the flame is starved, either for lack of fuel or oxygen.

Most petroleum liquids are flammable when the range is from 1 to 7% vapor and from 99 to 93% air. Hydrocarbon gases are flammable in the range of 1.9 to 9.5% vapor mixed with 98.1 to 93% air. A hydrocarbon liquid (crude oil) fire will extinguish when the oxygen-air mixture is reduced to below 93%; the oxygen-air mixture must be reduced below 90.5% for gas. From the fuel side, to eliminate the burn, the liquid fuel-vapor percentage must be reduced below 1%, and for gases it must be reduced below 1.9%.

REDUCTION OF VAPOR/AIR VOLUMES

Vapor pressure governs the rate of burnoff. The higher the rate at which oxygen is brought into the mixture, the faster it will be burned off, but the more difficult it will be to shift the mixture to a non-flammable range. Again, high-vapor-pressure fires can only be reduced by cooling the mixture. The fire is finally extinguished by reducing the vapor-air mixture below 93% in volume of air. This can be done by introducing foam, or by filling the air with inert gas or an inert material, such as dry chemicals.

Explosives are sometimes used to extinguish a burning wild well flame. This method eliminates the available air and starves the fire. However, reignition is likely unless the heat sources are cooled prior to detonation, and afterwards maintained at a temperature below the ignition point.

PROPAGATION OF FLAME

A wild well's flame increases when vapors surrounding the fire are in the flammable range. When the concentration of vapor is too high, the flame will not spread because the mixture is too 'rich' to burn. Danger exists when material produced by the well accumulates. This is the case with gasoline or heavy gases, such as H₂S. The vapors may build up and combine with air to form a combustible mixture adjacent to the fire, presenting the danger of a real explosion.

IGNITION SOURCES

Fire ignition always originates at a source. Without being too general, a fire's ignition source is simply heat, applied in the correct conditions for combustion.

A short list of known ignition sources include:

- Welding.
- Hammering, scraping, sanding, and other friction-producing actions.
- Striking aluminum-painted iron or steel.
- Heated lines.
- Higher volume/velocity flow rates.
- Static electricity.

- Electric sparks.
- Lightning.
- Smoking, matches or other flame-producing devices.
- Spontaneous ignition.

Ignition is the release of energy required to trigger the initial combustion. This requires a combination of factors, including: type of material, temperature, energy released, volume and duration of heat.

Here is a simple example, where duration and the type of material influence ignition. The published ignition temperature for hydrogen is 1085°F versus 515°F for gasoline. However, hydrogen is much more susceptible to ignition, because less energy, less volume, and shorter application of heat is required to produce ignition. It requires only 0.00002 Joules to ignite hydrogen versus 0.001 Joules to ignite gasoline. The energy required to produce ignition varies by a factor of 500 between these two materials. This is because less heat volume is required, since the air spaces are smaller around hydrogen molecules than gasoline molecules. So, less heat is required to bridge these spaces and ignition is more easily triggered.

HEAT AND HEATED PARTICLES AS IGNITION SOURCES

A series of experiments was performed using a dish of gasoline and various ignition sources:

- A large heating coil held above the dish of gasoline. The size and amount of the heat cause quick ignition of the gasoline vapors (Gas liquid heated to 515°F).
- A thin heated wire (red hot) held above the dish did not ignite the gasoline vapor. If the liquid temperature was increased to over 1100°F and the surface area of the coil wire was increased, it caused ignition.
- Particles from a grinding wheel knocked into the dish did not cause ignition. The particles were too small and the temperature duration at their maximum is very short. The same experiment was performed using ethyl ether (ignition Temp = 356°F) with the same results.
- Conditions of the experiment above were altered by using a high-powered, air-driven emery wheel. Particle sizes and velocities were much larger. Ignition did not occur.
- Conditions of the experiment above were repeated with the base metal of normal carbon steel and spark-proof material held against the emery wheel until it was glowing red hot. This condition produced ignition when particles entered the vapor in large mass. (i.e. similar to the heated coil).
- Ethyl ether was poured onto concrete. Heated particles from a sledge hammer striking the concrete could not be knocked from the wetted area, and particles knocked from a dry area did not ignite the vapor.
- An electrical spark produced from separated electrodes produced ignition, while closed electrodes with current flowing *did not* produce ignition.

The conclusion of these experiments is that ignition from a spark produced by metal-to-metal contact, such as a strike from a shop hammer, is extremely unlikely. The “spark” is not a spark at all, but is rather a small, heated particle. The surfaces of these fragments are so small that the highest attainable temperature would not be enough to cause ignition. To ignite petroleum product vapor, a temperature well above those attainable from a single strike of a metal-to-metal blow is required.

The ignition process of a cigarette lighter (wheel on flint) has been incorrectly described as a metal-to-metal spark. This thinking has led to the use of so called spark-proof tools. The actual ignition process of a wheel-flint lighter is due to the heat that is generated by the wheel on the flint in the correct vapor-air mixture atmosphere, not “sparks” from the metal wheel. No doubt, there is justification for “spark-proof” tools, but it is not always easy to determine when that is actually the case. The heated-particle scenario is one of the most misunderstood phenomena in the fire-safety field.²

ELECTRIC SPARKS AS IGNITION SOURCES

An electric spark will, under normal conditions, ignite petroleum vapors³. An electric spark is generally very hot, but as in the case of heated surfaces, the proper volume of air is required to cause a fire.

The energy level of an electric spark is an important factor. For example, low inductance, as in a two-cell flashlight, is insufficient to create a spark that will cause ignition. But a spark from higher current circuits, such as an automobile starter coil, can cause ignition. It is the circuit characteristics and the switch that govern the spark's ability to cause ignition.

The filament in flashlights and some electrical bulbs may not be large enough to produce the necessary heated surface area to ignite a vapor. Yet, when broken, light bulb globes are sometimes an ignition source. This happens because the filament melts and electricity arcs between the separated ends. The combined energy release from the heated surface and the arc can cause ignition. Separately, neither would be an ignition source.

The electrical spark problem has been controlled by:

- Providing a massive housing around the potential spark, called an "explosion-proof" device.
- Isolation of the spark (ignition source) from the flammable mixture.
- Intrinsic circuit designs that are incapable of causing ignition.

IMPACT CAUSING SPARKS

There are three conditions under which energy can be applied by a blow (pick ax, shop hammer, etc.) and produce a spark⁴ :

- Striking steel with either a metal or a spark-resistant material where a steel particle is already partially loose. Here the particle breaks loose, oxidizes, and causes a spark.
- A "thermite reaction" is produced when metal strikes a metallic compound (usually an oxide). The compound is reduced chemically to produce an extremely high temperature spark.

- Impact of metal against rock has the possibility of creating a spark independent of the type of striking metal or material. In this case, the impact energy is converted to electrical energy when the rock crystals are broken under tensile stress. Sparking is encountered most readily with quartz, silica, and sandstone.

In the case of a blowout, there is reason to believe that a stream of gas or oil, flowing uncontrolled, could carry sand (silica) at velocities that, upon impact, could cause a spark. Metal objects propelled by the flow stream also could strike an oxide-based paint and create an ignition source. Therefore, it seems highly plausible that a prolific flow of gas carrying solid material could produce multiple ignition sources.

WATER AS AN IGNITION SOURCE

Water has never been directly responsible for a fire, but is often indirectly responsible. The expansion characteristics of water are 1600 times its liquid volume at 212°F and atmospheric pressure. Thus, water-oil mixtures at elevated temperatures can create a very dangerous situation. Water moving at high velocities has certain frictional characteristics which can cause the buildup of static electricity. This can lead to an explosion when the friction reaches its spark production peak. An example familiar to everyone is Lightning, which is the result of air moving water vapor at high velocities.

FIRE CONTAINMENT

If a well is flowing crude and on fire, the unburned portion of the oil may accumulate in or around the wellhead. Containment of this unburned oil is essential. This can be done by constructing a dike system similar to those found in tank farms around crude and gasoline storage vessels. Care must be taken to monitor and manage the hydrocarbon accumulation. In most cases, it is a good idea to remove it from the site as quickly as possible.

NATURAL GAS FIRES

To understand gas combustion, one should first study methane's characteristics. Methane makes up most of all natural gases. The results of mass spectrometric analysis of common natural gas is shown in Table 5.1.

Table 5.1 Composition Of Common Natural Gas

CONSTITUENT	VOLUME FRACTION (%)
Methane	90.7
Ethane	5.5
Propane	1.6
Butane	0.5
Pentane	0.5
Nitrogen	0.86
Helium	0.3
Napthenes	0.04

Numerous factors are involved in the hazards of methane combustion: volatility, vapor density, rate of mixing with air, flammability mixture range, minimum spontaneous ignition temperature, ignition energy requirements, burning rate, flame radiation, etc. There is no method to accurately assess the importance of each factor and each can be influenced by the surrounding environment. To get a good overview, it is useful to compare the characteristics of methane to other combustible fuels. These comparisons are shown in Table 5.2.

Table 5.2 Combustion Characteristics Of Various Fuels⁵

FUEL	A Spontaneous Ignition Temp. (°C)	B Hot Gas Ignition Temp. (°C)	C Laminar Burning Velocity (cm/sec)	D Minimum Ignition Energy (MJ)	E Flammable Range (%)	F Limiting Oxygen Index (%)
Methane	537	1,325	39	0.3	5.0-14.0	12.1
Propane	466	990	44	0.3	2.2-9.5	11.4
n-Butane	405	990	-	0.3	1.9-8.5	12.1
n-Hexane	248	-	-	0.3	1.2-7.5	11.9
i-Octane	418	-	-	0.3	1.1-6.0	-
n-Dodecane	204	-	-	-	-	-
JP-1	228	-	-	-	-	-
Benzene	562	1,020	48	-	1.4-7.0	11.2
Methyl alcohol	-	950	-	-	7.1-36.5	10.3
Diethyl Ether	-	960	48	0.2	1.7-23.2	-
Ethylene	-	900	74	0.08	3.1-28.6	10.0
Propylene	-	1,060	51	-	2.0-11.1	11.5
Hydrogen	-	750	170	0.02	4.0-75.0	5.0

(Note: This table is an adaptation of the table in the cited reference.)

Elements in Table 5.2:

- A - Minimum Spontaneous Ignition Temperature of Combustibles in Air
- B - Comparison Between Hot Gas Ignition and Limit Flame Temperatures
- C - Activation Energies in High Temperature Combustion: 4th Symposium
- D - Minimum Ignition Energy Concept and Its Application to Safety Engineering
- E - Limits of Flammability of Gases and Vapors
- F - Minimum concentration of oxygen to support flame propagation when stoichiometric fuel-air mixture is diluted with nitrogen

Twenty MMSCF/D of burning methane produces a very large quantity of heat energy:

$$\left(\frac{231.5 \text{ ft}^3}{\text{sec}}\right) \times \left(\frac{0.04475 \text{ lb}}{\text{ft}^3}\right) \times \left(\frac{248 \text{ Btu}}{\text{lb}}\right) = 2,569 \frac{\text{Btu}}{\text{sec}} \text{ or } 647 \frac{\text{kCal}}{\text{sec}}$$

As a result of the large amount of heat energy, the wild well fire can be very difficult to extinguish and is, of course, extremely dangerous to personnel, equipment and the environment.

It is important to know the properties of methane to understand its burning characteristics. These properties are listed in Table 5.3.

Table 5.3 Properties Of Methane⁶

Molecular Weight	16.04
Density of gas @ 32°F (0°C)	0.04475 lb/ft ³ (0.7168 g/l)
Density of gas @ -258.7°F (-161.5°C)	0.1094 lb/ft ³ (1.753 g/l)
Boiling Point	-258.7°F (-161.5°C)
Density of liquid @ -263.2°F (-164°C)	25.9 lb/ft ³ (415 g/l)
Heat of vaporization	248 Btu/lbm (138 cal/gram)
Heat of combustion, liquid	23,910 Btu/lbm (13.27 kcal/gram)
Heat of combustion, gaseous	21,240 Btu/lbm (11.8 kcal/gram)
Critical temperature	-116.5°F (-82.5°C)
Critical pressure	673 psi (4.64 MPa)

(Note: this table is an adaptation of the table in the cited reference.)

One favorable attribute of methane is its dispersion characteristics. Methane is lighter than air, allowing quick dispersion if quantities are limited. Obviously, this is a benefit when compared to heavier-than-air fuels that can remain undispersed as combustible layers along the ground. However, methane can accumulate in confined areas such as under roofs in an enclosed structure.

Experience indicates that methane fires are best extinguished by inert gas. The high spontaneous ignition temperature shows that reignition will not result from surfaces heated by the

fire, as would be the case in a low-flash-point crude oil fire. However, most blowing gas wells carry some quantities of low-flash-point oil condensate.

WATER DELIVERY SYSTEMS

A common aspect of most major blowouts is that a high-volume water delivery system must be in place for cooling, prevention of ignition and personnel protection. Over the years, this has been accomplished by using both existing and specially built equipment.

The modern designs of water delivery systems make assembly and operation quick and simple. Today, the standard firefighting pump in the well control industry is a $\pm 4,000$ gpm centrifugal pump, powered by a ± 500 hp diesel engine. These pumps are typically mounted on a skid with the suction manifold, fuel supply and a protective cage, combined in one unit for easy lifting from a single attachment point. A typical firefighting pump is shown in Figure 5.2.

The piping used for distribution is lightweight aluminum with an internal diameter of ± 4 in. The pipe has “quick unions” to facilitate fast rig-up. It is stored on specially built pipe racks to simplify transportation to the wellsite. The pipe racks and allied equipment are designed to allow loading onto commercial and military transport aircraft such as the Boeing 747 and the C-130 Hercules.



Figure 5.2 Barge Supported Firefighting Spread

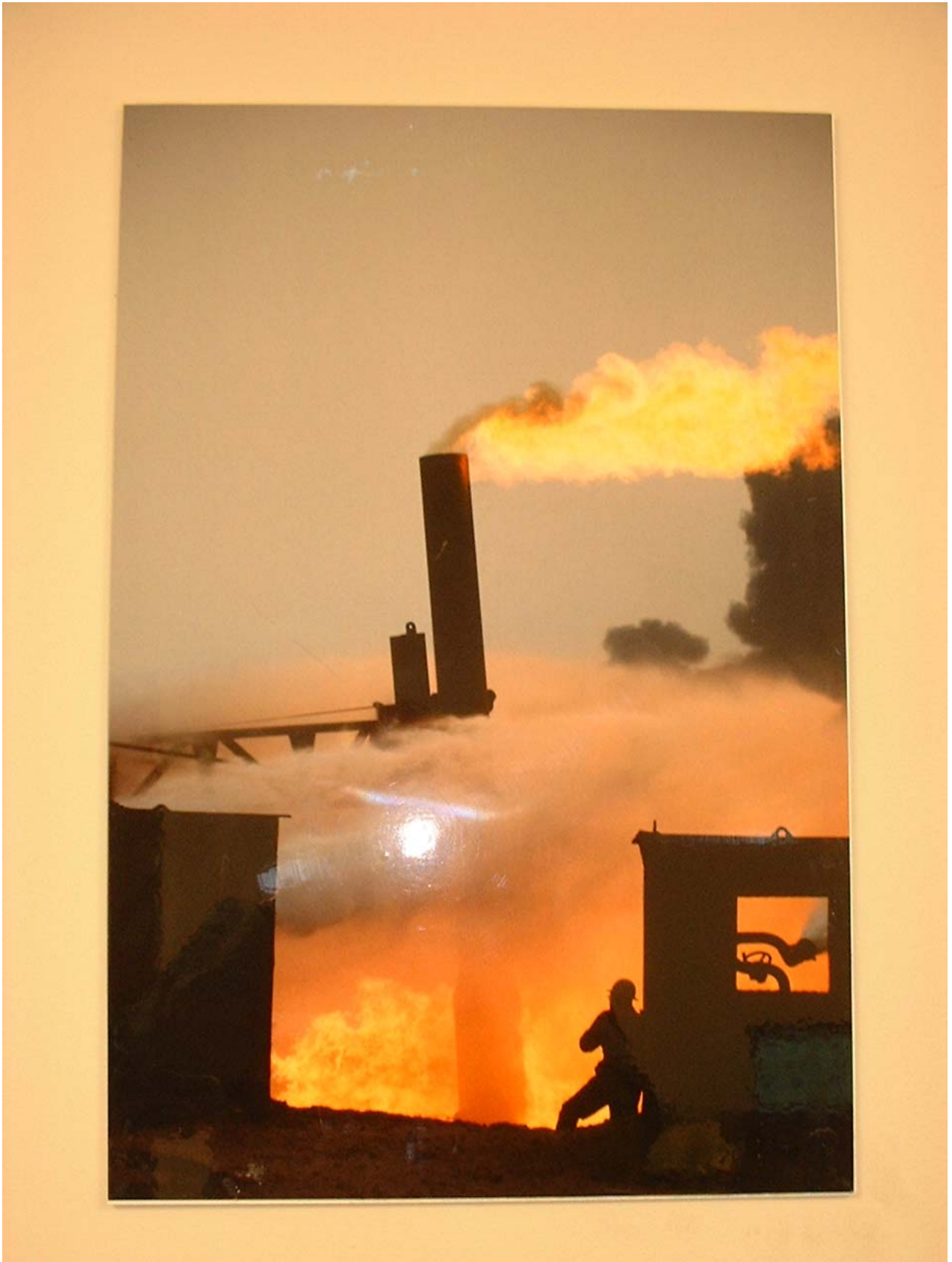


Figure 5.3 Working With Protective Water Spray



Figure 5.4 Crane Barge Firefighting Support



Figure 5.5 Marine Manifold On Offshore Location

One part of the water delivery system, the water supply, often requires an innovative solution based on the circumstances of the wellsite. If a large body of water is not readily available, some method of supplying and storing the necessary volume is required. This is often accomplished by excavating a large earthen pit. The water is then transported from an adjacent site at some reasonable distance by truck, or supplied with high-volume water wells.

The devices used to direct the water stream are called fire monitors. They are typically fitted with an adjustable nozzle which shapes the water flow from a concentrated stream to a fog. The fog setting provides a “wall of water,” for cooling and personnel protection. The dispersed droplets absorb a substantial amount of heat as they evaporate. Well control personnel have been able to undertake work surprisingly close to large fires under the protection of this water curtain.

COMBUSTIBLE ATMOSPHERES

Often, the well control team must work in combustible atmospheres. The potential of ignition (or reignition) of the well flow is arguably one of the most dangerous aspects of well control work, and every possible precaution must be taken.

Some ignition sources can be controlled, while others must simply be avoided. For example, it is not difficult to restrict activities such as welding, grinding and smoking on location. All electrical and heat-generating equipment near the combustible area can be shut down, as can diesel engines (which can ignite natural gas clouds when the gas is allowed to enter the air intake). Other potential ignition sources are not as easily controlled. Obviously, no work should be undertaken in combustible atmospheres in the presence of lightning. Strong winds can also create considerable static electricity, especially in areas of sand or loose soil.

All equipment such as cables, elevators, kelly hoses and possibly the tubing or drillpipe itself should be secured, to avoid impact with other metal objects. A high volume water stream or streams should be applied to the combustible flow in order to prevent dangerous vapor-air ratios from forming. This also aids in gas dissipation. Any work around the combustible area should be done using spark-proof tools. A standard item in all well control tool boxes is the brass hammer, which prevents sparks from being produced while connections are broken or tightened.

Gas escaping from a blowing well can even form combustible mixtures far away from the wellhead. For this reason, the proper equipment must be onsite to monitor gas concentrations. Numerous commercially available monitoring devices are available to measure gas concentrations and provide indications of the Lower Explosive Level (LEL). Gases released into the atmosphere travel in the mean wind direction. They also spread out in both the horizontal and vertical directions from the centerline of the point of release. The rate of spread in each direction is a complex function of micrometeorological conditions, the characteristics of the gases, and local geographical features. Figure 5.6 illustrates the behavior of a gas plume as it is emitted into the air under the action of a steady wind.

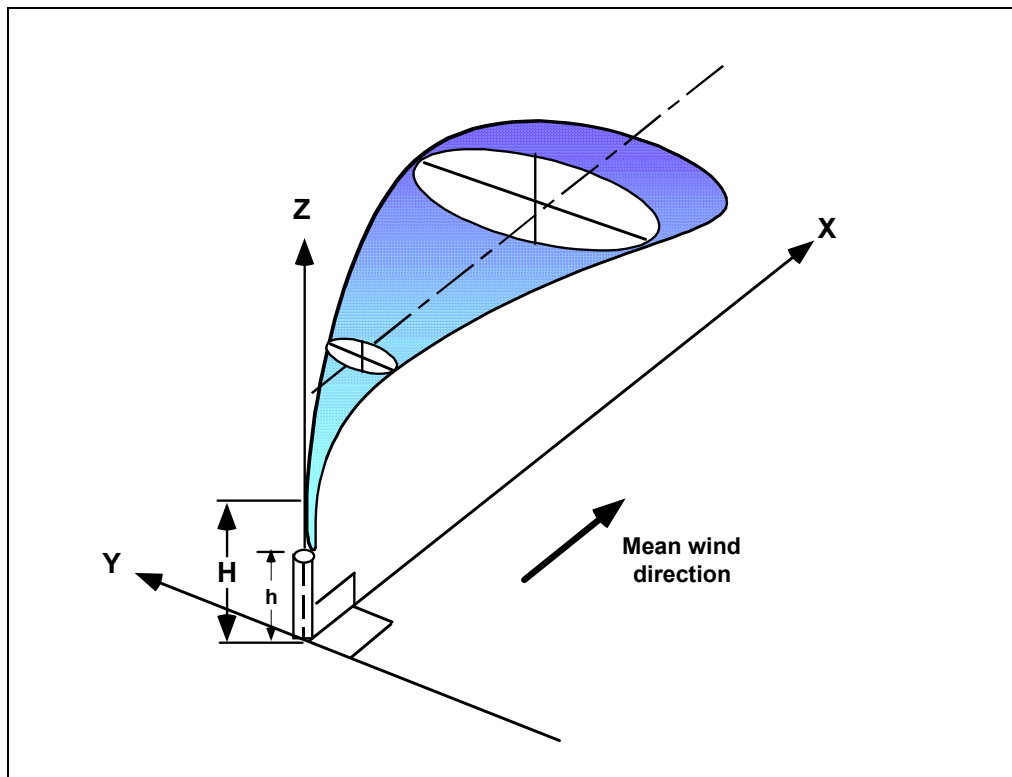


Figure 5.6 Spreading Of Gas Plume (from Turner, 1970)

It has been shown that the spread of gas concentration can be approximated by a Gaussian or normal distribution (Turner⁸, 1970). The equation that models the normal dispersion of a gaseous cloud from an elevated source is given below in a form that predicts the steady-state concentration at a point (x, y, z):

$$SSC = \left[\frac{E}{2\pi V \sigma_y \sigma_z} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \right] \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) \right] \quad \text{Equation 5.1}$$

Where:

SSC = steady-state concentration at point (x, y, z), $\mu\text{g}/\text{m}^3$

E = emissions rate, $\mu\text{g}/\text{s}$

σ_y, σ_z = horizontal and vertical spread parameters, m

V = average wind speed at height H, m/s

y = horizontal distance from plume centerline, m

z = vertical distance from ground level, m

H = effective height ($H = h + \Delta h$)

where h = physical height of point of discharge and Δh = plume rise, m

Most current texts on air pollution can be used to review the development of Equation 5.1, and the assumptions implicit in its use. Some general relationships indicated are:

- Downwind concentration is directly proportional to emission rate E .
- The downwind ground-level concentration is generally inversely proportional to wind speed. (H also depends on wind speed in a complicated fashion which prevents a strict inverse proportionality).
- Since σ_y and σ_z both increase as the downwind distance x increases, the plume center-line concentration continuously declines with increasing x .
- Ground-level concentrations increase to a maximum value then decrease as one moves away from the emission point.
- The dispersion parameters σ_y and σ_z rise with increasing atmospheric turbulence (see following discussion). Therefore, unstable conditions generally decrease downwind concentrations.
- The maximum ground-level concentration calculated by the Gaussian dispersion equation decreases as effective height increases. The distance from the emission point at which the maximum concentration occurs also increases (See Figure 5.7).

The Gaussian dispersion equation is the basis for almost all of the computer programs developed by the U.S. Environmental Protection Agency for atmospheric dispersion modeling. For this reason, a brief discussion of atmospheric stability and an example of the use of the Gaussian equation are presented below. A complete discussion of micro meteorology is beyond the scope of this text.

The atmosphere is said to be unstable when there is good vertical mixing. This occurs when there is strong isolation and consequent heating of the layers of air near ground level (Williams⁹, 1973). The warm air rises and is replaced by cooler air, which in turn is heated and rises. This process is valuable for decreasing gas concentrations.

A stable atmosphere results when the surface of the earth is cooler than the air above it. Under these conditions, the layers of air next to the earth are cooled and no vertical mixing occurs. In a stable atmosphere, ground-level gas concentrations tend to be maximized.

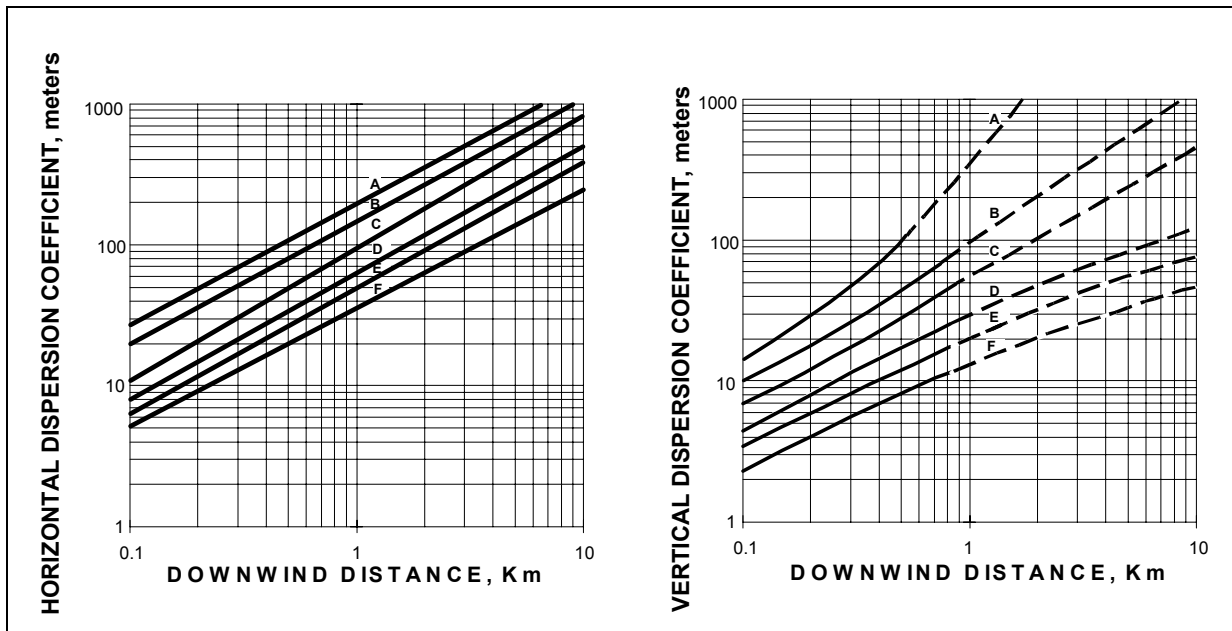


Figure 5.7 Dispersion Parameters (adapted from Reference 7)

Atmospheric stability has been empirically classified into six distinct categories arbitrarily labeled A through F, with A being the most unstable. Charts showing the values of the dispersion parameters⁷ σ_y and σ_z as a function of distance from the emission point are shown in Figure 5.7. Using these charts to obtain the dispersion parameters, the Gaussian equation (Eqn. 5.1) can be used to predict the gas concentration anywhere downwind of the source given a specified emission rate, effective height and wind velocity.

Figure 5.8 illustrates the prediction of ground-level ($z = 0$), downwind ($y = 0$) gas concentration as given by the Gaussian equation for three wind speeds. Note that the output of the Gaussian equation is in units of $\mu\text{g}/\text{m}^3$. This can be converted to units of Parts Per Million (PPM) with the following equation, from Turner⁸:

$$\left(\frac{\mu\text{g}}{\text{m}^3} \right) \times \frac{24.5}{MW} = \text{PPM}$$

Equation 5.2

where:

MW = Molecular weight of gas ($\text{CH}_4 = 16$, $\text{H}_2\text{S} = 34.17$)

PPM can be subsequently converted to percentage by dividing by 10,000. An example for the use of this calculation approach is shown in Example 5.1.

Also useful in this calculation is Equation 5.3 (after Craft and Hawkins¹⁰) which is a means to convert the specific density of the gas into mass units:

$$\rho_g = \frac{28.97 SG^* P}{z^* R^* T}$$

Equation 5.3

where:

- ρ_g = Density of the gas, lb/ft³
 SG = Specific gravity of gas (air = 1)
 P = Pressure, psia
 z = Gas compressibility factor, dimensionless
 R = Universal gas constant,
 T = Temperature, °R

EXAMPLE 5.1

Given:

30 mmscf/d of methane gas (CH₄, SG = 0.6 at 14.7 psi and 60°F [519.67°R])
 effective stack height, H, of 25 m
 Atmospheric Stability Class = B

Determine:

- Determine the downwind (y = 0) gas concentrations (%) at ground level (z = 0) at a distance of 500 m from the well with wind velocities of 3 m/s, 6 m/s and 9 m/s.
- A plot of downwind gas concentrations at varying distances of 0 to 1200 meters and wind velocities of 3 m/s, 6 m/s and 9 m/s.

Solution (a):

Convert volume flow rate, Q (mmscf/d), to emission rate, E (μg/s):

$$\rho_g = \frac{28.97 SG * P}{z * R * T} \Rightarrow \frac{28.97 * 0.6 * 14.7}{1.0 * 10.73 * 519.67} = 0.0458 \frac{lb}{ft^3}$$

$$E = \frac{30 \times 10^6 \text{ ft}^3}{\text{day}} * \frac{0.0458 \text{ lb}}{\text{ft}^3} * \frac{1 \text{ day}}{86,400 \text{ sec}} * \frac{453.59 \text{ g}}{\text{lb}} * \frac{10^6 \mu\text{g}}{\text{g}} \Rightarrow E = 7.2 \times 10^9 \frac{\mu\text{g}}{\text{s}}$$

$\sigma_y = 80$ and $\sigma_z = 46$ m (Figure 5.7). Using Equation 5.1 for a 3 m/s wind velocity:

$$SSC_{3 \text{ m/s}} = \left[\frac{7.2 \times 10^9}{2\pi(3)(80)(46)} (1) \right] \left[\exp\left(-\frac{(-25)^2}{2(46)^2}\right) + \exp\left(-\frac{(25)^2}{2(46)^2}\right) \right] \Rightarrow 179,092 \frac{\mu\text{g}}{\text{m}^3}$$

For the 6 m/s and 9 m/s cases:

$$SSC_{6 \text{ m/s}} = 89,546 \frac{\mu\text{g}}{\text{m}^3} \quad \text{and} \quad SSC_{9 \text{ m/s}} = 59,697 \frac{\mu\text{g}}{\text{m}^3}$$

Convert units using Equation 5.2:

$$\frac{179,092 \frac{\mu\text{g}}{\text{m}^3}}{16.04} * 24.5 = 273,551 \text{ PPM or } 27.4\%$$

$$\frac{89,546 \frac{\mu\text{g}}{\text{m}^3}}{16.04} * 24.5 = 136,775 \text{ PPM or } 13.7\%$$

$$\frac{59,697 \frac{\mu\text{g}}{\text{m}^3}}{16.04} * 24.5 = 91,183 \text{ PPM or } 9.1\%$$

Solution (b):

b) Figure 5.8 shows the result of this calculation over a range of values. Note that the distance at which the gas concentrations are within the explosive range varies considerably with wind speed. This calculation illustrates that wind direction and speed have direct and dramatic impact on gas dispersion.

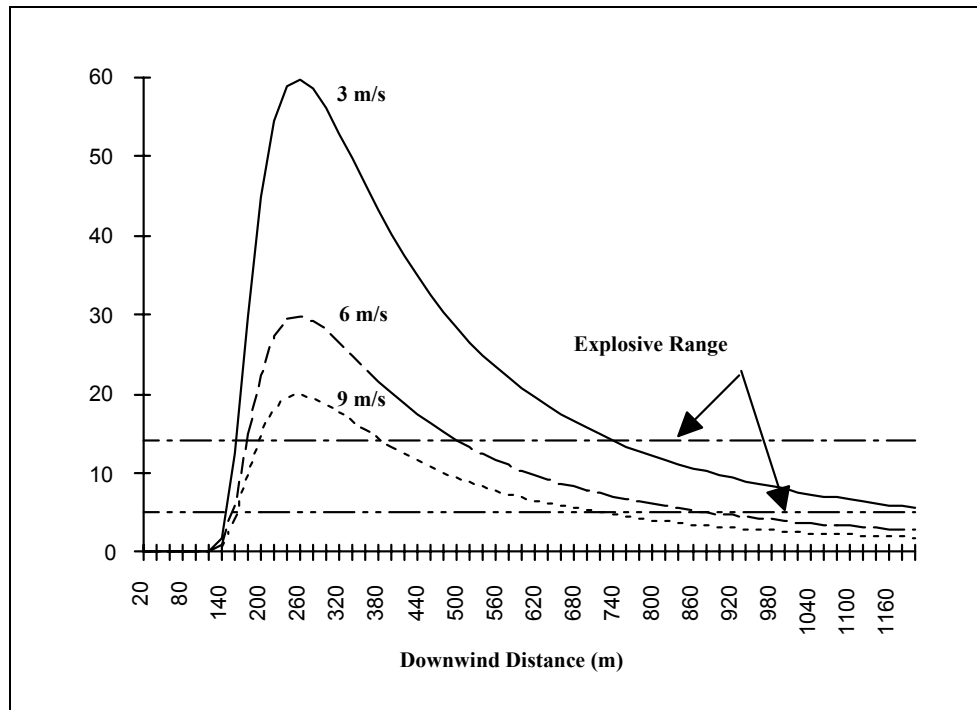


Figure 5.8 Gas Dissipation At Various Wind Speeds

EXTINGUISHING WELL FIRES

The preceding sections of this chapter described the mechanics of fires, water delivery systems and explosive limits. In the process of controlling a blowout, it is often necessary or advantageous to extinguish the well fire. This section offers a discussion of means that have proven to be effective for extinguishing gas and oil fires.

Well fires are distinctly different from refinery-type oil fires (tanks of oil, pits, tankers, etc.). This is mainly because the source of fuel continuously renews itself.

This this type of dynamic fire can be extinguished by various means:

- Pure water (fresh or sea water).
- Dry chemicals (potassium bicarbonate, sodium bicarbonate, etc.).
- Explosives.
- Combinations of explosives, water and/or chemicals.

WATER AND CHEMICALS FOR FIRE SUPPRESSION

Many oil and gas fires can be extinguished by applying water only. For water to be effective, the flow must be well defined and confined to a single vertical stream. Combustion occurs when the correct proportion of air and fuel are present. In a single vertical stream, this happens some distance above the exit point. Depending on the volume of flow, the burning interface can be a considerable distance above the exit.

Water is effective when it can be concentrated at the burning interface. If there is lateral flow, the fire will be difficult, if not impossible, to extinguish with water alone. The lateral flow must be removed and the flow made vertical for water to be effective. For example, in the Kuwait oil fires, the reason for the blowout was wellhead damage from purposely set demolition charges. This left the wellheads damaged in extraordinary ways. Often, there was both lateral and vertical flow from a damaged wellhead component. In most cases, if the lateral flow was eliminated by cutting off the wellhead, leaving only one vertical flow, the fire could be extinguished with a relatively small amount of water. One should be cautioned not to look to the Kuwait fire for guidance for all oil well fire fighting operations. All well fires have unique characteristics.

Generally, it is safe to say that the fire can be contained and extinguished with much less effort if the flow can be made to exit the well in a single vertical stream. More about debris removal is offered in Chapter 6, Capping Operations. That chapter offers methods for cutting off damaged wellheads and equipment.

In some cases, water proves to be totally inadequate in extinguishing the fire and other means have been necessary. Chemicals, such as those used for industrial fires, can be effectively applied in oil and gas well fires. Usually a combination of chemicals and water can be used together in extinguishing the fire. The water serves two purposes: cooling, and conveying chemical to the fire.

This text is not intended to be an all encompassing reference on firefighting chemicals, so details are not offered here on types of chemicals that can be used in well fires. Since these events occur worldwide, it has been the practice of the authors to use locally available products to aid in the firefighting operations. Therefore, details on specific chemicals are avoided, and no endorsement of any single product or vendor is implied. Fire suppressant chemicals have been mentioned because they often have a useful purpose in well fire suppression.

EXPLOSIVES FOR FIRE SUPPRESSION

Explosives are perhaps the most dramatic method employed to extinguish well fires. C4, gunpowder and dynamite have been used successfully. The method is simple in theory, but requires precise operational techniques for its application. As in a pure water method, explosives have the best chance of success if the flow is concentrated in a single stream. However, as with many well firefighting techniques, the use of explosives has not been analyzed on a scientific basis. Consequently, there are no formulas to determine the size of the charge or shot and its precise deployment method. It is more art than science, so "rules of thumb" are used rather than calculations.

Shots for extinguishing an oil fire have ranged from 100 to 500 lbs of high grade dynamite. The amount used also depends upon the grade of explosives available. The intensity of the fire, weather conditions, available water support and the type of effluent will all be factored into the procedure. The explosive is conveyed to the fire by a 60 to 70 foot boom, so that the operators will be a safe distance from the explosive while it is being deployed.

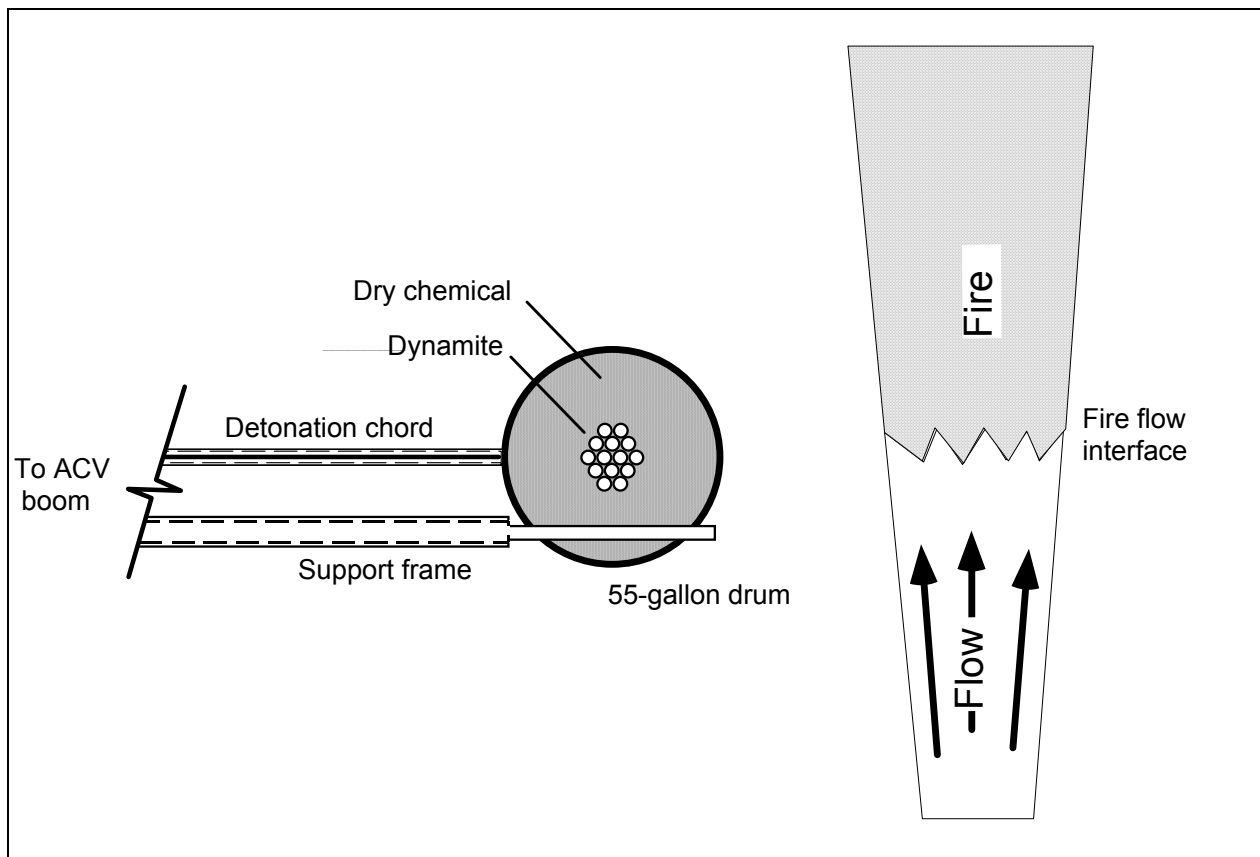


Figure 5.9 Explosive Shot for Fire Extinguishing

Figure 5.9 shows a schematic of a typical shot drum and its loading for extinguishing a fire. The explosive is placed near the interface of the flow and lower section of the fire. Care is taken to keep the shot cool so that pre-ignition does not occur. Personnel are removed to a safe distance and the shot is detonated by means of the detonation cord. The explosion has the effect of snuffing out the fire as if it were a candle and was blown out by a strong gust of wind. The scientific explanation of the physics of this technique are not known. But it is safe to say that the explosion creates an inert interface at the point where combustion occurs and temporarily interrupts the flow, thereby starving the fire by eliminating the fuel source. The fire is extinguished as a result.

Caution!— It is not the objective of the authors to offer precise and exacting detail in this text, but rather, to offer a general description of proven, viable methods to deal with a serious problem. Exact details are left out of this discussion on explosives, because of the volatile nature of explosives and the adverse environment where they are used. The authors strongly recommend that only experts attempt this technique.

ONSHORE FIREFIGHTING SPREAD

Onshore firefighting operations should be designed for changing situations. In all firefighting operations, the paramount focus must be protection of the intervention team, then equipment and the well. With that in mind, escape routes must be planned and careful consideration given to the prevention of hazards such as accumulation of oil or condensate which, under certain conditions, could ignite. Figure 5.10 shows a typical site preparation for a desert type land operation (typical to the Kuwait campaign in 1991).

OFFSHORE FIREFIGHTING CONSIDERATIONS

Offshore firefighting operations deal with the same issues as those on land, in terms of personnel protection, cooling and prevention of ignition. Obviously, the water source is not a major concern, however, the method of applying the water in the necessary volumes can be. In many areas, marine vessels with substantial fire fighting capabilities (10,000 to 20,000 gpm) are in very limited supply. It is often necessary to equip the primary support vessel with an adequate water delivery system. This entails mounting standard firepumps on the deck of the vessel, along with a discharge manifold system. The discharge manifold should be pre-fabricated to reduce the time involved with this phase of the project.

If a crane barge is used as the primary support vessel, it may be possible to find one with onboard “jet” pumps which are typically used in pipe laying operations. These pumps are normally capable of delivering 5,000 to 6,000 gpm at ± 300 psi. In some instances, the pumps mounted on the support vessel can be connected to the water system onboard a platform or drilling rig. This technique has proven very beneficial to the success of the project. The availability of remote connections to the onboard firefighting water system should be an important consideration for both existing and planned platforms.

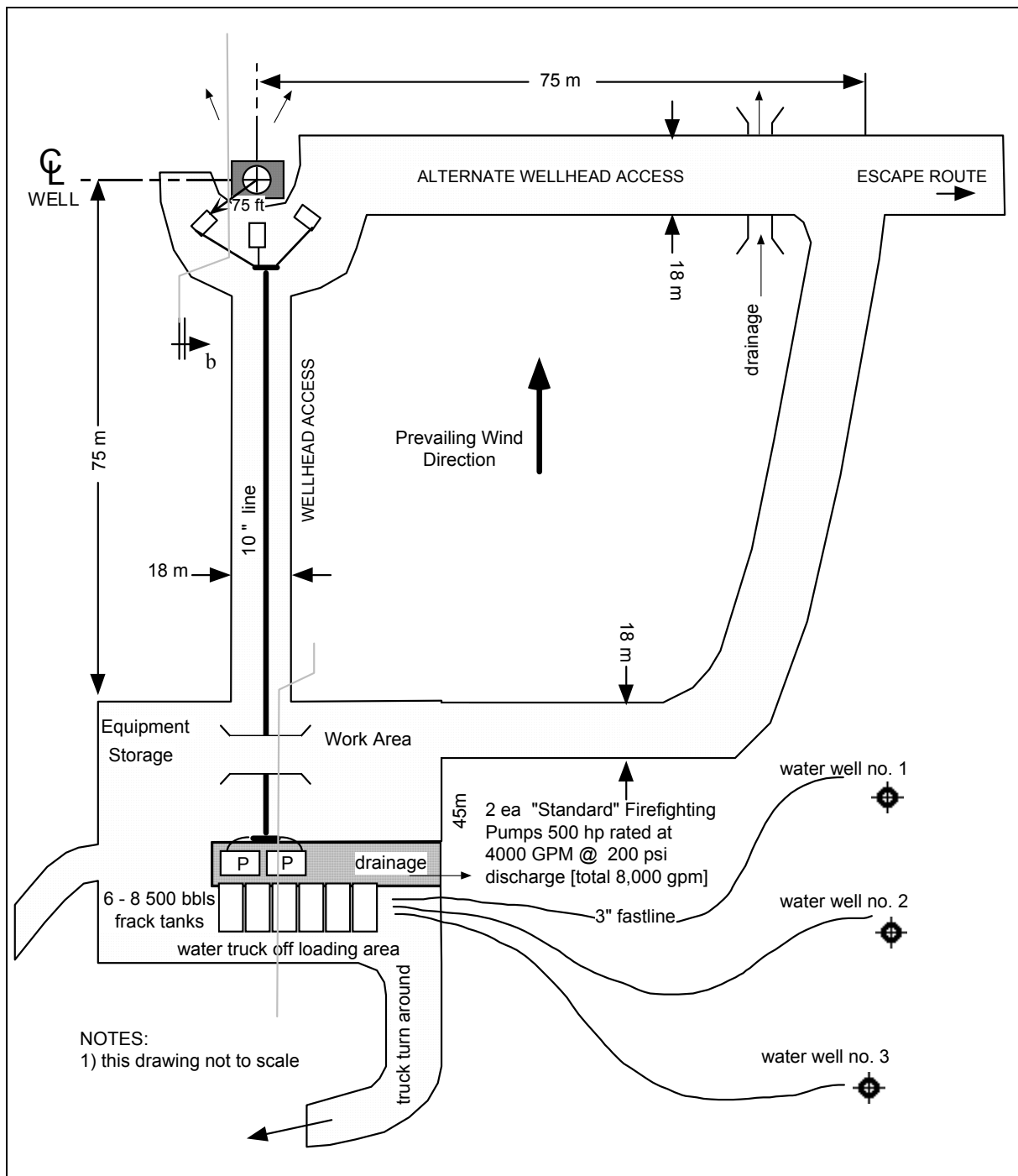


Figure 5.10 Typical Fire Fighting Spread for a Land Fire

In most situations, firefighting water monitors will be placed on the structure once adequate room is available. This is done to provide the precise control of water streams necessary to safely undertake work around the blowing well.

Offshore blowouts sometimes require extended periods of time in order to acquire and mobilize the necessary equipment. In the interim, it is critical that water be applied either to cool the structure or prevent ignition of the flow. Operators should plan for this contingency by maintaining a current list of available marine vessels with firefighting capabilities in their area.

It should be noted that large, high volume water cannons are capable of causing significant structural damage if a concentrated stream is applied. For cooling purposes, the water stream

should be adjusted so that a curtain of water, as opposed to a concentrated stream, is applied to the target. If a jack-up drilling rig is involved, severe damage may result from flooding, which could seriously impair control efforts. If time permits, abandonment procedures should include securing water-tight doors and opening the ballast tank dump valves.

CONCLUSION

Oilwell firefighting often involves factors not found in other firefighting operations. The most apparent difference is that oil and gas well firefighting involves not only containing and extinguishing the fire, but certain control operations so work may proceed without injury to personnel or damage to equipment.

Safe operation in oil and gas well firefighting demands a thorough knowledge of the mechanics of both oil and gas fires and ignition. Specialized tools and equipment are designed to be used with well fires. Well control personnel must be intimately acquainted both with the proper methods of providing a safe working environment, and the equipment used to accomplish the tasks required.

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