Technical Publication

The Relative Effectiveness of Different Agents in Dealing with Coal Pulverizer Fire and Explosion Prevention

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Presented to
Coal Technology '84
Houston, Texas
November 14, 1984

RPI-0031

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ABSTRACT

Under an Electric Power Research Institue program, a series of laboratory experiments was conducted to compare agents used for extinguishing fire and for inerting equipment to prevent explosions. The tests included injecting agents at a slow rate for an extended period of time and also injecting a fixed quantity of agents as rapidly as possible.

INTRODUCTION

The trend toward utilizing coal as a primary fuel for power generation has increased in the past decades. Not only are new units being built to fire pulverized coal (P.C.), but more and more older units are being converted to burn P.C. This increased use of P.C. is linked to a corresponding increase in the number of problems related to the handling and preparation of the coal. Studies conducted by the Edison Electric Institute and the Electric Power Research Institute (EPRI) have identified some of the problems. One major problem is fire and explosion occurrences associated with pulverized coal which have resulted in personal injury, property damage and loss of revenue. In an effort to discover solutions, EPRI is sponsoring a research program to investigate P.C. fires and explosions. Under this EPRI program, Riley Stoker Corporation directed a series of experiments conducted at the research laboratories of Fenwal, Inc. The experiments involved testing various extinguishing agents on a standardized coal fire in a simulated coal pulverizer. The purpose of the experiments was to determine a relative effectiveness of various agents.

Presently many users of P.C. are injecting various agents into their equipment to extinguish fires or to inert the equipment atmosphere attempting to prevent possible explosions. The amount, type and success of agents used in actual plants has varied greatly, resulting in no standards to determine the relative effectiveness of the agents.

FIRE EXTINGUISHING

The fire related experiments consisted of a series of tests involving simulated, deep-seated pulverizer fires. The tests were conducted in a 12 cubic foot drum, shown schematically in Figure 1. The drum had a hole cut in one side over which sheet metal with various apertures could be placed. In these experiments, the aperture was either a 1-inch or 3-inch diameter hole. The 1-inch diameter aperture simulated new, tight-fitting dampers with an air leakage flow of 10% of full air flow rate.

In each test, a similar sub-bituminous coal mass was placed in a metal basket 10 inches in diameter by three inches deep, ignited, and allowed to come to full burn before being inserted in the simulated pulverizer. Various types and amounts of extinguishing agents then were applied to the deep-seated fire through nozzles mounted at the top of the pulverizer, as shown in Figure 1.

Two modes of agent application were used: dump and flow. In dump mode, a fixed volume of agent was released almost instantaneously into the pulverizer. In flow mode, the agent was released into the pulverizer at a fixed flow rate over a relatively long period of time.

Two thermocouples were mounted in the pulverizer, one in the center of the fire, the other three inches from the top of the pulverizer, directly above the fire location. The simulated pulverizer body remained at ambient air temperature throughout the tests. A fire was considered extinguished when the temperature at the upper thermocouple dropped to the arbitrary value of 125°. All agents were tested with the 1-inch diameter damper air flow. The most effective agents, those with the shortest treated-fire burn times, were tested with the 3-inch diameter damper airflow.

As stated above, the utility industry uses a fairly wide variety of fire extinguishing agents, as well as a number of combinations of those agents. In an effort to determine the most effective extinguishing agents for a pulverizer fire, tests of most agents available for industry use were performed at the Fenwal test facility. The agents tested were: water, steam, CO_2, N_2, foam, lime, Halon 1301, Hymix (50% mixture by weight of Halon 1301 and monobasic ammonium phosphate), laboratory flue gas (15% moisture, 15% CO_2, 4% O_2, 66% N_2), and wetted water (water plus 1% wetting agent to reduce surface tension for increased spray diffusion area).

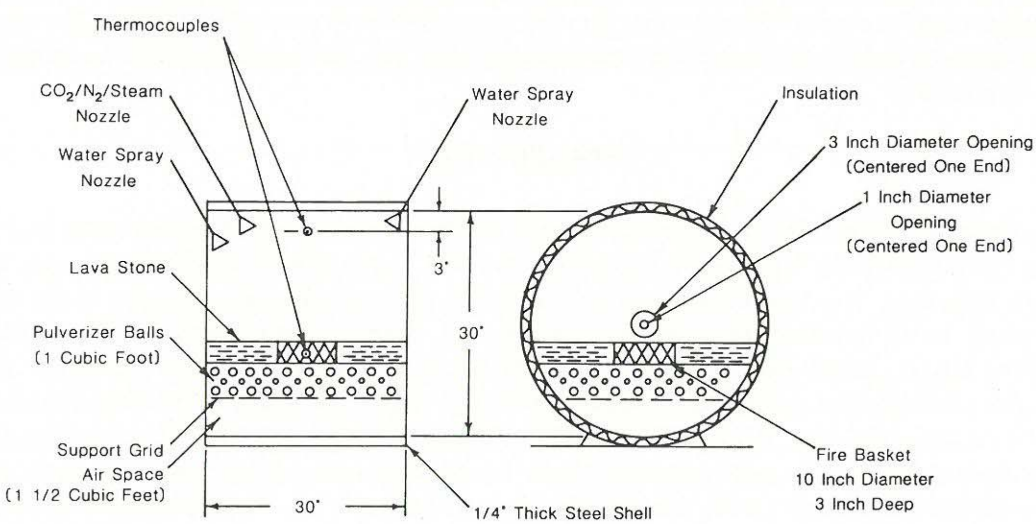

Figure 1 Simulated Deep-Seated Pulverizer Fire Test Drum

The results of the testing are presented graphically in Figures 2, 3 and 4. The use of three separate figures is a direct result of the difference in character of the liquid/solid agents and the gaseous agents. The weight of charge per typical application for any of the liquid/solid agents is about the same as for any other liquid/solid agent in comparison to the small weights of gaseous agents for the same typical application. Additionally, the gaseous agents tend to work on a volume basis by displacing oxygen/air needed for combustion rather than the surface-coating/combustion-blockage-layer basis of the liquid/solid agents. These factors tend to point to a weight basis for liquid/solid agents as in Figure 2 and an equivalent mill-volume basis for gaseous agents as in Figures 3 and 4. Liquid/solid agents most often would be applied in a burst or dump mode. The terms "burst" and "dump" indicate that the agent is released in a very short time period compared to the burn time, either treated or untreated.

Gaseous agents may be applied in either a dump mode analogous to the liquid/solid agents or a flow mode. In a flow mode, the agent is released much more slowly than in a dump mode. Additionally, the agent is released over a very long time, perhaps comparable to the treated burn time. This variability in application techniques for gaseous agents produces an effectiveness picture for both dump and flow modes as shown in Figures 3 and 4.

Figure 2 plots the approximate effectiveness of the liquid/solid fire extinguishing agents tested in this program. The fire size and intensity and air leakage conditions of the simulated mill were standardized and controlled fairly well to allow a direct comparison of results for the various agents. The effectiveness of an agent is computed as the percent decrease in burning time of the untreated, standardized fire. The burn duration of the untreated fire may be termed the free burning time. The effectiveness measure is plotted against the pounds of liquid/solid agent used in the dump mode to produce the reduction in free burning time. The majority of testing simulated new, tight dampers with air leakage of 10% of full mill air flow. Figure 2 also shows the results from tests made with three times this amount of air leakage representing the possible condition of aged dampers in a nominally closed position.

Figure 2 shows significant features, some of which will apply only to pulverizers with their contents at rest rather than in a running condition, and other features which are more universal. For example, for both foam and lime used in a non-running pulverizer with stationary contents, there exists an optimal or "perfect" amount of agent to apply to a fire of a particular size. Figure 2 shows that if less than this optimal amount is used in the non-running pulverizer, then the fire will burn longer. However, if more than the optimal amount is used, the fire does not go out any quicker. In this case, an amount of agent is wasted. This behavior is a direct result of the surface-coating/blockage-layer nature of these two "solid" agents. Maximum effectiveness is achieved once the minimum necessary layer is laid down on the fire in the non-running pulverizer. Any additional agent applied only makes the layer thicker without improving performance. This behavior would not be observed in an operating pulverizer with its contents in motion. The movement of the pulverizer contents would have the effect of spreading out the agent. Larger amounts of agent would have to be applied to compensate for the motion-induced dispersion of agent to regions uninvolved in the fire.

Water and Hymix, on the other hand, exhibit a very desirable characteristic in these non-running pulverizer tests. As more agent is applied, the effectiveness goes up faster than the amount of agent applied. The initial amount applied aids rather than hinders the additional amounts in spreading into the involved regions. Although these tests show this effectiveness enhancement characteristic only for the non-running pulverizer case, this beneficial characteristic also should apply to a discharge into an operating pulverizer. The wetted water results show that the addition of a wetting agent to reduce surface tension and promote spray dispersion actually can be worse than using plain water. However these tests used only one wetting agent at a single concentration. Different wetting agents and different concentrations of any one agent can change both the spray and extinguishing effectiveness characteristics significantly. Therefore, based on these limited experiments, it is not possible to say that wetting agents for water are always detrimental to fire extinguishing effectiveness.

The few data points in Figure 2 for the higher airflow rate through the simulated pulverizer indicate the negative influence of higher pulverizer airflow/leakage on extinguishing effectiveness for even the liquid/solid

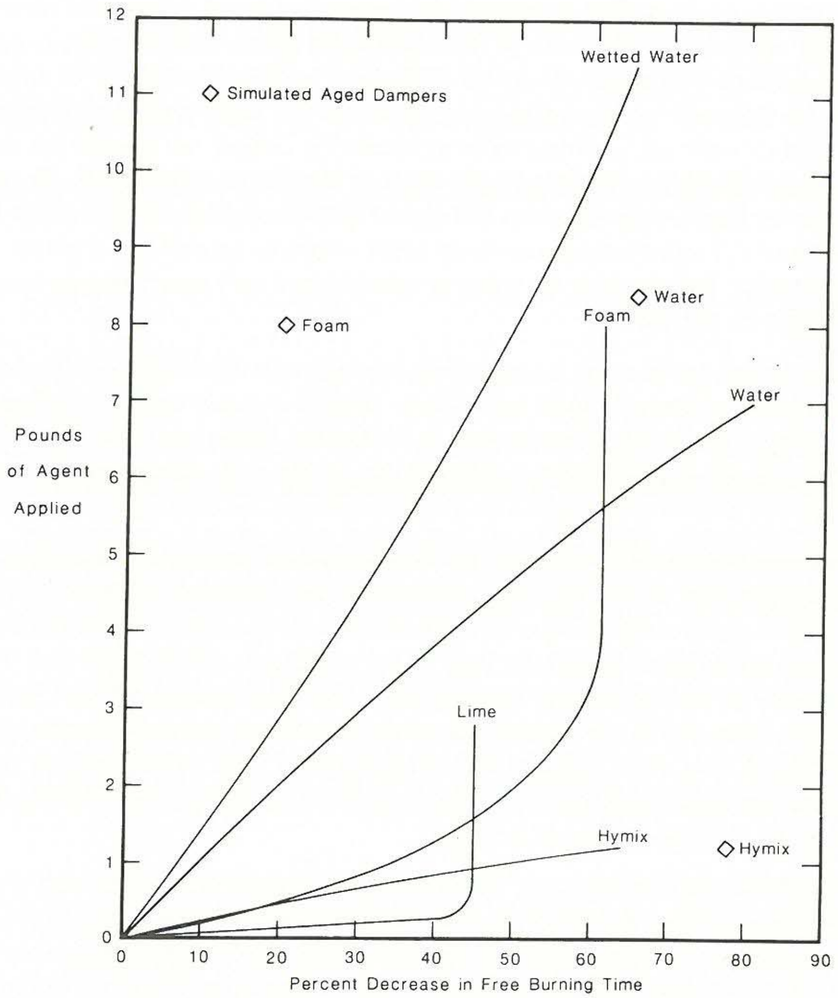

Figure 2 Non-Gaseous Extinguishing Effectiveness

agents. These results show that the more airtight a pulverizer can be made when a fire is detected in it, the faster, easier, and more economically the fire can be put out by the extinguishing system.

The gaseous extinguishing agents applied in a dump mode do not work as well as the liquid/solid agents applied in a dump mode. This is shown in Figure 3 which plots the approximate effectiveness of the gaseous agents tested in a dump mode in this program. The amount of gaseous agent is plotted as a percentage of the simulated non-running pulverizer volume. Thus, the 100% amount indicates that the injected gas would displace the air inside the pulverizer exactly. This figure highlights the following points:

1. Nitrogen in dump mode even at 100% volume is ineffective as an extinguishing agent.
2. Steam, CO_2, and flue gas are essentially equivalent in performance in dump mode and are somewhat better than nitrogen. However, even applied in 100% volume amounts, they do not approach the performance of the liquid/solid agents.
3. Halon 1301 begins to approach the performance of liquid/solid agents. The upswing of the curve indicates that as long as the pulverizer can be made fairly airtight at the time of application, a critical minimum discharge of Halon 1301 will produce essentially maximum extinguishing effectiveness. In these tests, the critical minimum amount of Halon 1301 was equivalent to approximately ⅓ of the pulverizer volume. However, even with a realistically airtight pulverizer, the Halon 1301 does not produce the almost instantaneous fire quenching shown in its traditional applications.

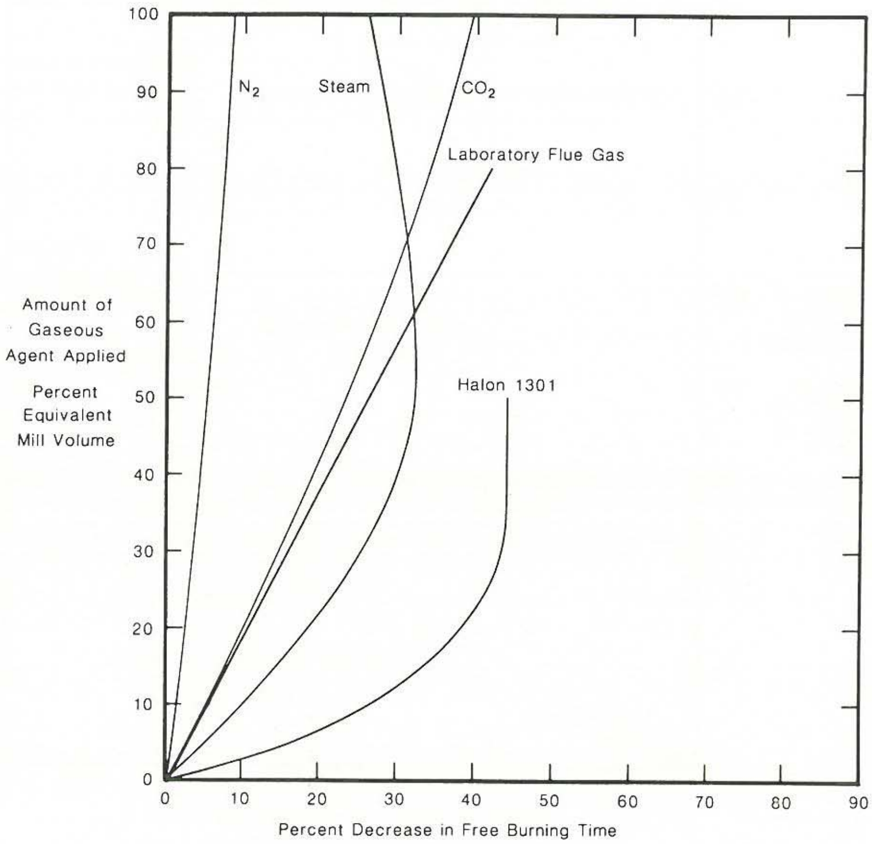

Figure 3 Gaseous Dump Flows Extinguishing Effectiveness

Based on these limited results, it appears that dump mode application of a gaseous agent (including even Halon 1301) in a running pulverizer would be ineffective. This conclusion is governed by the considerably higher airflow of a running pulverizer coupled with the low effectiveness values in Figure 3.

Flow mode application of gaseous extinguishing agents is more effective than dump mode application and should be the preferred method for these agents. In the testing in a simulated non-running pulverizer in this project, the performance of the gaseous agents in flow mode matched the performance of the liquid/solid agents tested. Figure 4 plots the approximate effectiveness of the gaseous agents tested in flow mode against the amount of agent expressed as a percentage of the simulated pulverizer volume. This figure shows that continuous addition of gaseous agents resulted in improved performance when compared to Figure 3. The results for nitrogen in flow mode are substantially better than for nitrogen in dump mode. To some extent, the improvements are the result of the larger equivalent pulverizer volumes possible in flow mode application.

Nonetheless, the performance of the gaseous agents using 200% pulverizer volume rivals that of the liquid/solid agents shown in Figure 2. These tests are not definitive in answering the questions of how much to flow, how fast to flow, or how long to flow the agent for any particular fire occurrence. However, they tend to indicate that in a non-running, fairly airtight pulverizer, nitrogen and flue gas would give essentially equivalent, adequate performance of a level better than that of CO_2. Additionally, as shown in Figure 4, these tests indicate that in a non-running pulverizer a fixed amount of gaseous agent produces better performance when released at a slightly faster rate over a slightly shorter time. Flow mode application of gaseous agents is more suitable than dump mode application in an operating pulverizer or, in general, pulverizers with high air leakage rates. Flow mode application of gaseous agents could give performance comparable to the liquid/solid agents for these conditions.

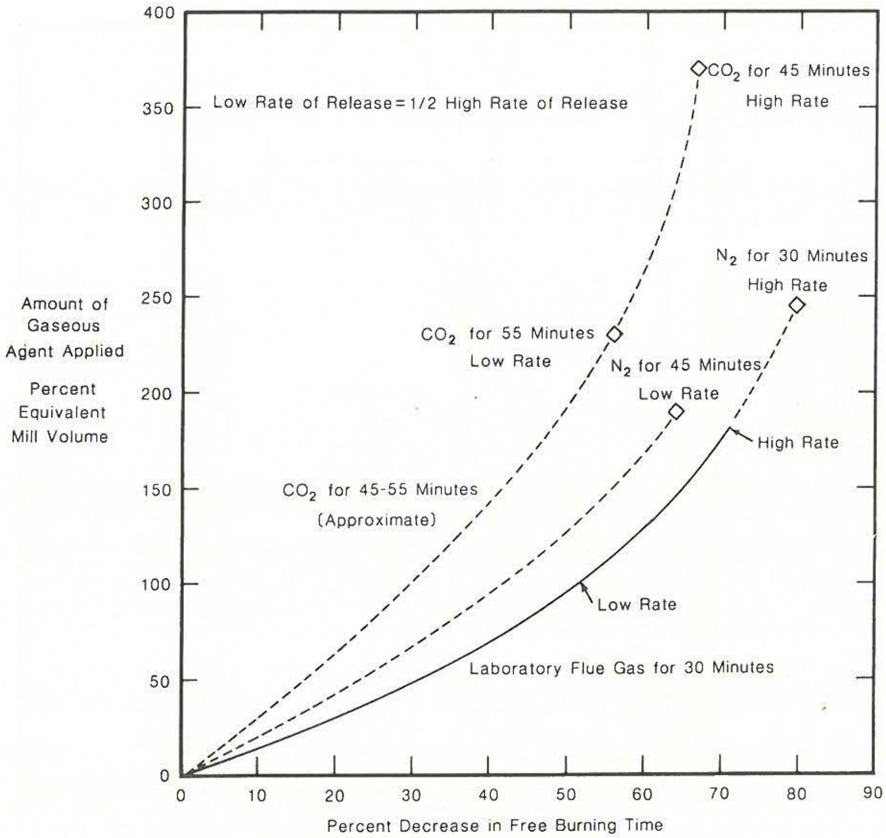

Figure 4 Gaseous Flow Extinguishing Effectiveness

The results shown in Figures 2, 3 and 4 and discussed above are not sufficient for the design of an extinguishing system for a real pulverizer. In particular, before a series of extinguishing system design guidelines could be formulated, more testing is needed in the following areas:

1. A quantification of the influence of a much wider range of pulverizer airflow/leakage rates or agent performance.
2. A quantification of the influence of a much wider range of fire size and intensity (in relation to pulverizer size) on agent performance.
3. A quantification of the effect of fire location inside the mill on agent performance.
4. An understanding of the influence of the amount of motion of a burning coal mass on agent performance.

These areas will require a sizeable experimental program. The results of the testing in this project have identified the most promising liquid/solid agents (water, Hymix, foam, and possibly lime) and gaseous agents in flow mode (nitrogen, flue gas, and possibly CO_2). This identification should minimize the testing and maximize the useful information. The results of such a test program should be performance curves for the various agents. With adequate performance curves, practical and effective extinguishing systems could be designed to balance safety, performance and economy.

EXPLOSION INERTING AND SUPPRESSION

In addition to the extinguishing tests, Fenwal conducted a few explosion suppression tests for an isolated or cut-off mill condition. Suppression, it should be noted, is distinct from inerting. Suppression is the release of an agent into an area in which an explosion may occur in order to prevent the buildup of destructive pressure

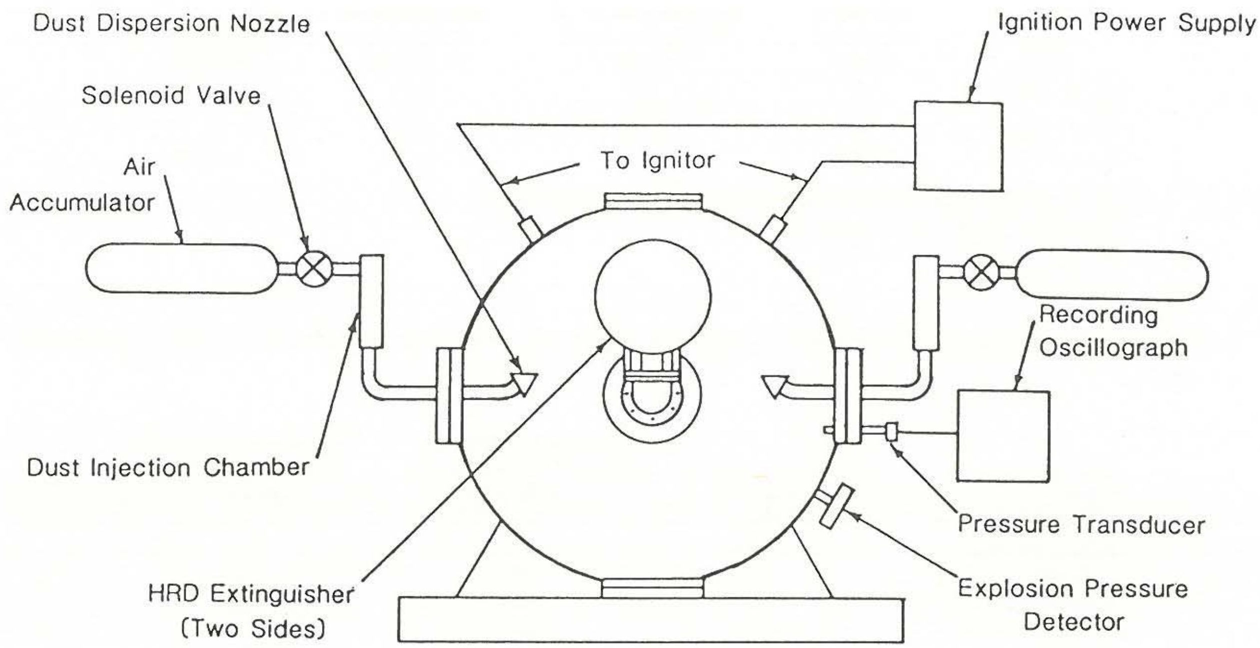

Figure 5 67 Cubic Foot Vessel in Mill Explosion Suppression Tests

waves. Inerting is the release of agent into an area in which an explosion has begun in order to produce a non-explosive condition. The explosion suppression tests were conducted in the 67 cubic foot vessel as shown in Figure 5 and included an explosion pressure detector and two commercially made High-Rate-Discharge (HRD) extinguishers. The explosion pressure detector was set to trip at 0.5 psig in order to detect explosions or explosive buildup as quickly as possible while minimizing spurious noise factors. The detector signal initiated discharge of extinguishing/suppression agent from the HRD extinguishers. Pressurized agent was discharged through explosively opened 3-inch burst disc valves on the extinguishers, 3-inch 90 degree elbows, and out into the vessel through spreaders located at opposed stations on the vessel's equator.

Halon 1011 (chlorobromomethane), in an amount to give a concentration of 30 cc/ft^3 when discharged, was the only agent tested in this limited series experiment. A large selection of potential suppression agents was not tested because the earlier explosion testing had shown that high pressure explosive phenomena could not be produced in this limited geometry configuration. The intent of this series of suppression tests was quite limited. The goal was to demonstrate whether or not chemical extinguishing agents could function as suppressors of the initial stages of mill deflagration leading to explosions. For all tests, initial conditions before fuel ignition were atmospheric pressure and ambient temperature.

In a first test, a mixture of CO and coal dust was ignited with the suppression devices armed. The CO charge was 29.5% by volume, producing a stoichiometric CO/air mixture while the coal dust concentration was 0.40 oz/ft^3 of Oklahoma sub-bituminous. Although the HRD extinguishers discharged properly, the explosion pressure reached 100 psig indicating that the attempt was unsuccessful. The rapid pressure rise was the reason the suppression attempt failed. The high rates of pressure rise in environments with significant CO concentrations indicate that the burning zone is expanding too quickly for the discharge of extinguishing agent to combat. Only two choices exist to control this problem: either faster sensing and discharge extinguisher/suppression systems must be built, or CO levels must be monitored very carefully to prevent CO buildup in regions where ignition may occur. These results are given in Table I which indicates that current HRD extinguisher technology may be a reasonable candidate for explosion suppression systems when used in an enviroment low in CO concentration. Although not conclusive, the results in Table I point to the importance of CO in raising flame speeds and rates of burn-zone expansion beyond the response-time limitations of current suppression technology.

VESSEL FUEL	MAXIMUM PRESSURE (PSIG)	MAXIMUM RATE OF PRESSURE RATE (PSI/SEC)	SUPPRESSION ATTEMPTED (30 CC/FT^3)	SUPPRESSION RESULT
CO & COAL*	99	745	NO	—
CO	101	3400	NO	—
CO & COAL	80	2000	NO	—
CO & COAL	100	—	YES	FAILED

29.5% CO by volume, stoichiometric CO/air mixture, unless noted
Coal Type - Oklahoma Bituminous
Coal Concentration - 0.40 oz/ft^3
*1.0% CO by volume

Test Results for Explosion Suppression on Carbon Monoxide and Coal Dust Mixtures using Halon 1011

COAL TYPE	CONCENTRATION (OZ/FT^3)	MAXIMUM PRESSURE WITHOUT SUPPRESSION (PSIG)	MAXIMUM PRESSURE WITH SUPPRESSION (PSIG)**
Penna. Bit. (coarse)	0.90	*	*
Penna. Bit. (fine)	0.70	*	*
Okla. Bit. (coarse)	0.40	108	1.25
Wyoming Bit. (coarse)	0.50	106	1.5
N. Dakota Lignite (coarse)	0.70	108	1.75

* Dust did not ignite
Optimum Explosion Concentration from Appendix D used for each coal
** 30 cc/ft^3 concentration after discharge

Coarse Grind: 70% through 200 mesh
Fine Grind: 90% through 325 mesh

Test Results for Explosion Suppression on Five Coal Dusts using Halon 1011

Table I

The final series of explosion-related experiments conducted at Fenwal dealt with steam inerting to prevent an explosion in an otherwise explosive environment. The limited goal of these experiments was to determine the minimum quantity of steam needed to prevent an explosion in an isolated or cut-off pulverizer filled with a reactive coal dust cloud heated to a typical working temperature of 250°F. The tests were conducted in the 67 cubic vessel shown in Figure 5. Coal dust was injected into the vessel by partial pressure. A nitrocellulose ignitor triggered 0.3 seconds after the steam was introduced into the vessel provided an energetic ignition source to set off explosions.

The results of this series of limited steam inerting tests are given in Table II. Repeated tests at 18% steam by volume failed to produce an explosion, whereas lesser amounts of steam failed to inert the vessel. Therefore, it was concluded that a minimum steam volume of 18% provided a non-explosive environment in the simulated isolated pulverizer. However, under-inerting with steam appears to lead to a more explosive condition in the pulverizer. Table II shows that as the volume of steam in the pulverizer was increased from 0% to 17%, the maximum pressure in an explosion increased by 11 psi, from 57 to 68 psig. One hypothesis is that small amounts of steam participate in gasification reactions with the coal to produce highly combustible and explosive gaseous species. The pulverizer volume used in this experiment was very small compared to that of pulverizers used in a utility plant. Thus, the possibility exists that using too little inerting steam could result in a major explosion in a large pulverizer rather than preventing what could have been a much smaller explosion if no steam inerting had been used at all. It is important to note that the 18% minimum value obtained in these tests is related specifically to the simulated isolated pulverizer used in this experiment. Further testing is necessary to determine whether or not this is a universal value.

% Steam	Steam Pressure (cm Hg)	Explosion	Maximum Pressure (psig)
5	38	Yes	57
10	76	Yes	57
12	91	Yes	58
13	9	No	—
13	9	Yes	65
14	106	Yes	68
15	114	No	—
15	114	Yes	67
16	122	No	—
16	122	Yes	68
18	137	No	—
18	137	No	—

Coal Type – Oklahoma Bituminous
Coal Concentration – 0.40 oz/ft^3

Table II Steam Inerting Test Results

CONCLUSIONS

The only extinguishing agent that was guaranteed effective under laboratory conditions was water. Water is inexpensive but deluging or flooding must be used to be sure of successful extinguishing.

All the gaseous materials were found to be relatively ineffective. The use of steam as an extinguishing agent did create a precarious situation. Using steam with a fire present developed a more reactive gas and, if a detonation developed, the carbon monoxide and methane produced magnified resultant forces. In addition, steam proved to be one of the worst extinguishing agents; the more steam is applied, the less effective it becomes.

Other extinguishing agents showed promise of alleviating the disadvantages of water. However, further research with large scale testing is required prior to recommendations for actual plant installation.

The testing of steam inerting showed that under controlled laboratory conditions, no guaranteed safe level of steam inerting could be determined. Explosive forces developed in an atmosphere with as much as 16% steam by volume. It is doubtful that steam inerting even in excess of 16% by volume can be proven safe. Whether detected or not, a fire, if present, may change the pulverizer atmosphere to allow a detonation to develop.

Total inerting is not possible with a dynamic pulverizer system; the inertant only reduces the oxygen available for an explosive reaction. It is difficult to determine whether the inertant is effective. In many instances the oxygen content is in the explosive range when coupled with other gases. Many inertants prevent fire detection although they do not extinguish fires.

If a plant determines that an inerting system is necessary, additional instrumentation and controls are required. Extensive training is required to assure full understanding of the system by operational and maintenance personnel. Inerting is no guarantee of elimination of explosions but, with extreme care, the frequency of explosions can be reduced.

The above information is from laboratory testing and is not derived for any specific plant or utility. Suggestions are not intended to solve a specific concern. Care must be taken when enacting any modification. Because of the complicated relationship of the variables coupled to the creation of fires and explosions, initiating modifications without a thorough analysis may produce results that are directly opposite from those desired.