THE EFFECT OF IGNITION SOURCE AND STRENGTH ON SPHERE INERTION RESULTS

Everett W. Heinonen
Center For Global Environmental Technologies (CGET)
New Mexico Engineering Research Institute (NMERI)
The University of New Mexico
Albuquerque, New Mexico, USA

INTRODUCTION

For the past two years, the New Mexico Engineering Research Institute (NMERI) has been conducting testing sponsored by the U.S. Environmental Protection Agency to determine the amount of halogenated agents required to inert common flammable fuels. Testing has been carried out in the NMERI inertion sphere (Reference 1) using a capacitive discharge DC spark formed between two steel electrodes inside the sphere as the source of ignition. A DC spark has been one of several sources used to determine flammability limits (the minimum and maximum concentrations of fuel that can be ignited in air with no inertant) and flammability curves, which determine the amount of inertant required to inert all fuel/air concentrations.

NMERI has conducted testing to determine flammability curves for both methane and propane using Halon 1301 as an inertant. NMERI curves were compared to those developed from other test organizations, particularly the Fenwal flammability curves of four ternary fuel-*-Halon 1301 systems (Reference 2). It was this Fenwal data upon which the NFPA 12A Halon 1301 inerting concentrations for propane and methane - 6.6% for propane and 7.7% for methane including 10% safety factors - were based (Reference 3). Significant differences existed between NMERI and Fenwal results for the peak Halon 1301 concentrations required to inert methane (Figure 1); Fenwal reported a 7% concentration while NMERI reported a concentration of 4.7549%. For propane, however, both organizations reported an inerting concentration in the range of 6%.

NMERI is in the process of designing a field-scale test facility to measure inerting concentrations on a larger scale. In order to provide input for a decision regarding the most appropriate ignition source for the field scale tests, an analysis of the test equipment and techniques used in the Fenwal and NMERI test series was undertaken to better understand the different results. Various factors such as ignition source, fuel/air/agent mixing within the test chamber, purity of fuel, test conditions, size and construction of the spheres, and method of cleaning the sphere between tests could affect test results; however, this paper concentrates only on the ignition source.

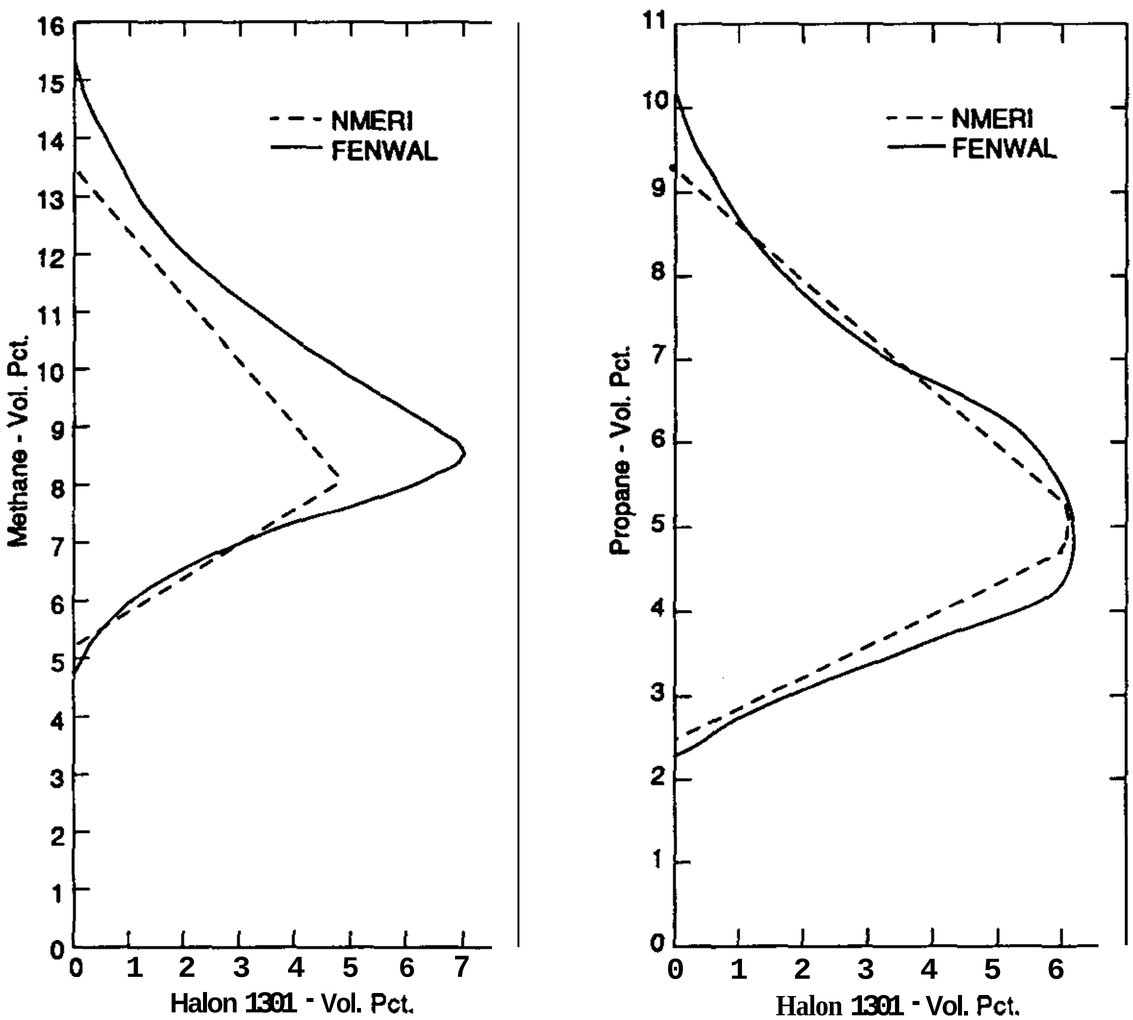


Figure 1. Flammability Curves, NMERI vs. Fenwal for Methane and Propane

PREVIOUS TESTING

Results from previous Halon 1301/methane inertion testing (Table 1) indicated that the concentrations of Halon 1301 required to inert a methane/air environment were greatest using higher ignition energies. While the inertion criteria differed (zero visual flame versus 25% tube flame length propagation versus 1 psig pressure rise), certain trends can be seen. The 1972 Du Pont mason jar and explosive burette tests, which used a 27 joule/second AC spark ignition source and a visual flammability criterion, resulted in inertion concentrations of 4.3% and 4.2%, respectively (Reference 4). These values correspond more closely to NMERI results than those of Fenwal. However, the Du Pont mason jar and intermediate-scale tests which used 176 joule kitchen matches for ignition resulted in inerting concentrations of 9%; explosion burette tests with the same ignition source resulted in an inerting concentration of 6.75%. Other Du Pont tests using the mason jar and explosion burette and a 1300 joule/sec AC spark resulted in maximum inerting concentrations of 40% and 10%, respectively (Reference 4).

While the results of these early tests may be questioned due to lack of uniformity of test procedures and analysis, trends nonetheless indicate that lower concentrations of Halon 1301 are required to inert mixtures ignited by lower energy sparks than those ignited by higher energy sparks or non-spark ignition sources. Bureau of Mines results presented in Table 1 include those of Hertzberg, et. al. (Reference 5), which measured an inerting concentration of approximately 5% for a spark of less than 1 joule and a concentration of approximately 9% for a 35 joule match (Figure 2), and Zlochower and Hertzberg (Reference 6) which indicate a concentration in excess of 17% (potentially not the maximum because of limited data availability) using a 1000 joule pyrotechnic ignition source. Note that NMERI stoichiometric results are superimposed on Figure 2.

Unfortunately, comparable data using propane as a fuel are not available. Except for the Fenwal and NMERI data, only the 1971 Du Pont mason jar tests included propane; the inerting concentration was 9% for the 176 joule kitchen match ignition source.

TABLE 1. METHANE/HALON 1301 INERTION RESULTS.

Reference	Apparatus Type and Volume	Spark Type	Spark Energy	Inertion Criterion	Inertion Conc., %
Du Pont (1971)	Mason jar (0.965 l)	Kitchen match	176 J	Visual zero flame	9.0
Du Pont Intermediate scale (1971)	55 gal. drum (233 l)	Kitchen match	176 J[a]	Visual zero flame propagation	9.0
Du Pont (1972)	Mason jar (0.965 l)	Kitchen match	176 J[a]	Visual zero flame propagation	9.0
		AC spark	27 J/sec		4.3
		AC spark	1300 J/sec	"	40.0
	Explosion Burette (10.2 cm diameter X 121.9 cm) (9.91 l)	Kitchen match	176 J[a]	Visual zero flame propagation	6.75
		AC spark	27 J/sec		4.25
		AC spark	1300 J/Sec		10.0
Fenwal (1976)	Explosion Sphere (5.6 l)	DC spark w/graphite rod	~ 11 J[b]	1 psig pressure rise	7.0
Bureau of Mines (1979)	Flammability Chamber (8 l)	DC Spark	< 1 J[a]	1 psig pressure rise	~ 5.0
		Match	35 J[a]	1 psig pressure rise	~ 9.0
(1991)	Flammability Chamber (20 l)	Pyrotechnic Igniter	1000 J[a]	Unknown	> 17.0
NMERI (1992)	Explosion Sphere (7.9 l)	DC spark	70 J[b]	1 psig pressure rise	4.75-4.9

[a]Effective energy
[b]Stored energy

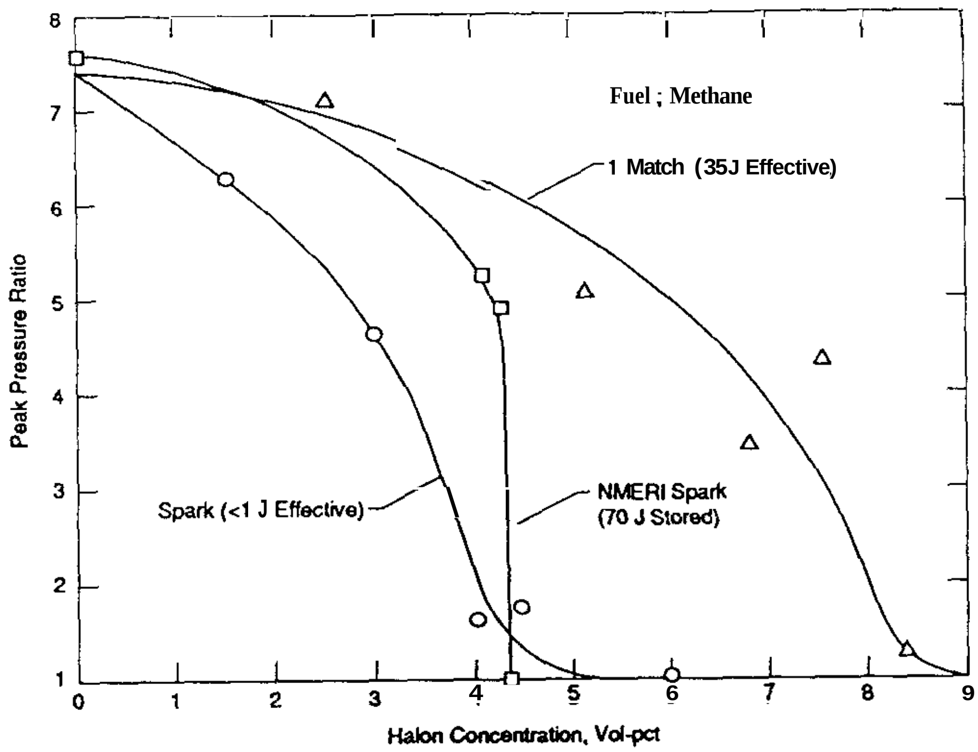


Figure **2.** Effect of Ignition Strength on Stoichiometric Methane-air Explosions (Ref 5).

ANALYSIS

Several authors have attempted to explain the effect of **spark** energy on inertion testing. In Reference 5, Hertzberg et al. indicated that the conventional Halon 1301 inerting value of between **4%** and 5% is obtained only with a weak ignition source, and is not a true inertion level but rather the concentration required to prevent ignition by **a spark** source; the **maximum** inertion concentration with a strong ignition source **appears** *to* be in the **8%** range. Bartknecht (Reference 7) indicates that the widest range of flammability limits does not occur until an ignition energy of 10,000 joules is reached, but he does not describe how this value is determined.

Figure **3** is a comparison of NMERI, Fenwal, and Bureau of Mines data for **Halon** 1301 inertion **of** methane. It indicates that, since both the flammability region and maximum inerting concentration for the Fenwal tests were greater than those for **NMERI,** the possibility exists that more energy was available in the Fenwal testing than the **NMERI.**

Bartknecht (Reference 7) states, "the higher the energy transferred from the ignition source to the surrounding gas mixture, the wider the range of concentrations permitting autonomous flame propagation. Especially the upper explosion limit will be moved toward higher gas concentrations." Note that, in Figure 3, the upper flammability limit is between 13% and 14% for NMERI tests, 15% for Fenwal tests (which is also the generally accepted value for methane), and 17.5% using the Bureau of Mines higher energy source. This indicates that the NMERI ignition source contained the least energy of the three.

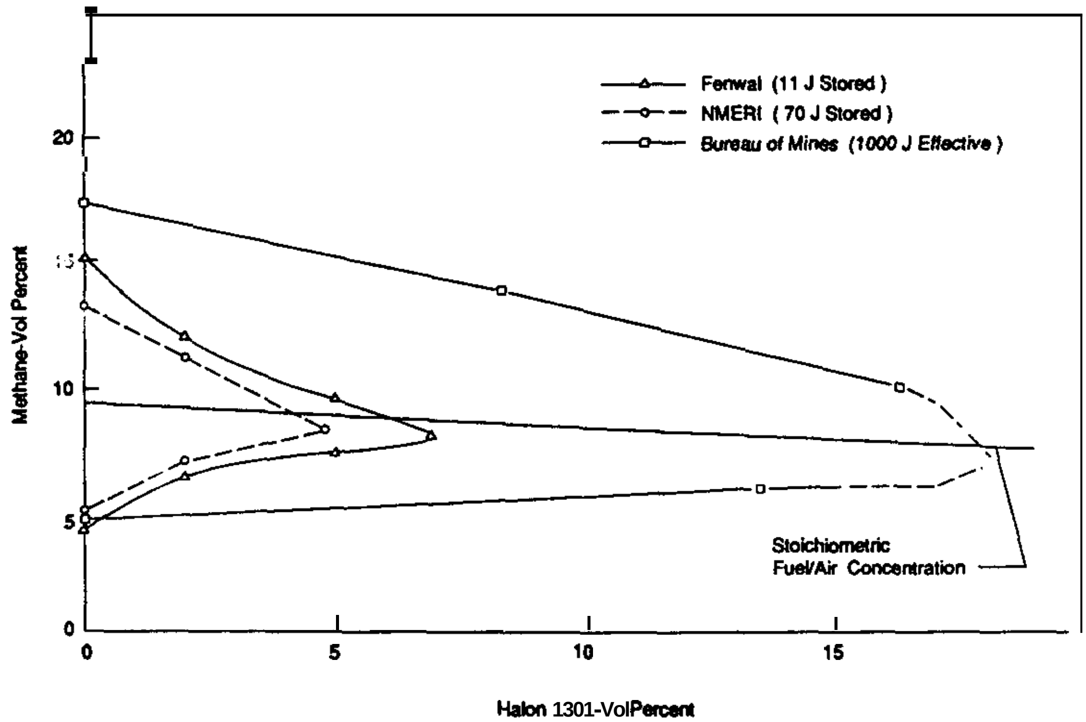


Figure 3. Methane/Halon 1301 Inertion Concentrations, NMERI-Fenwal-Bureau of Mines.

Nearly all inertion results, including those generated by NMERI, are based on the premise that the energy available in the DC spark is the energy stored in the capacitors which is then directly transformed into an effective spark energy. Hertzberg, Conti, and Cashdollar (Reference 8) of the Pittsburgh Research Center calculated the effective energy contained in a spark at various stored energy levels, charging voltages, and chamber volumes (Figure 4). By measuring the pressure rise due to the spark in very small chambers, they calculated that the effective spark energy may only be a fraction of the stored energy. The data set in Figure 4 most representative of the NMERI sphere is the lower curve, because the capacitors were charged to 165 volts. Although data are not reported above 15 joules stored electrical energy, the curve of effective versus stored energy begins to approach horizontal at that value, indicating that beyond 10 joules stored energy, the effective spark energy remains at about 1 joule. This is the region (5 to 15 joules stored energy) where Rangasamy (Reference 9), Silva Filho (Reference 10), and Duarte (Reference 11), in their Masters theses at Worcester Polytechnic Institute, reported that Halon 1301 inertion concentration using propane as a fuel became insensitive to higher levels of ignition energy (Figure 5). This suggests the possibility that the reported inertion concentration may have been a result of a limitation of the spark ignition system, rather than the inerting capability of Halon 1301.

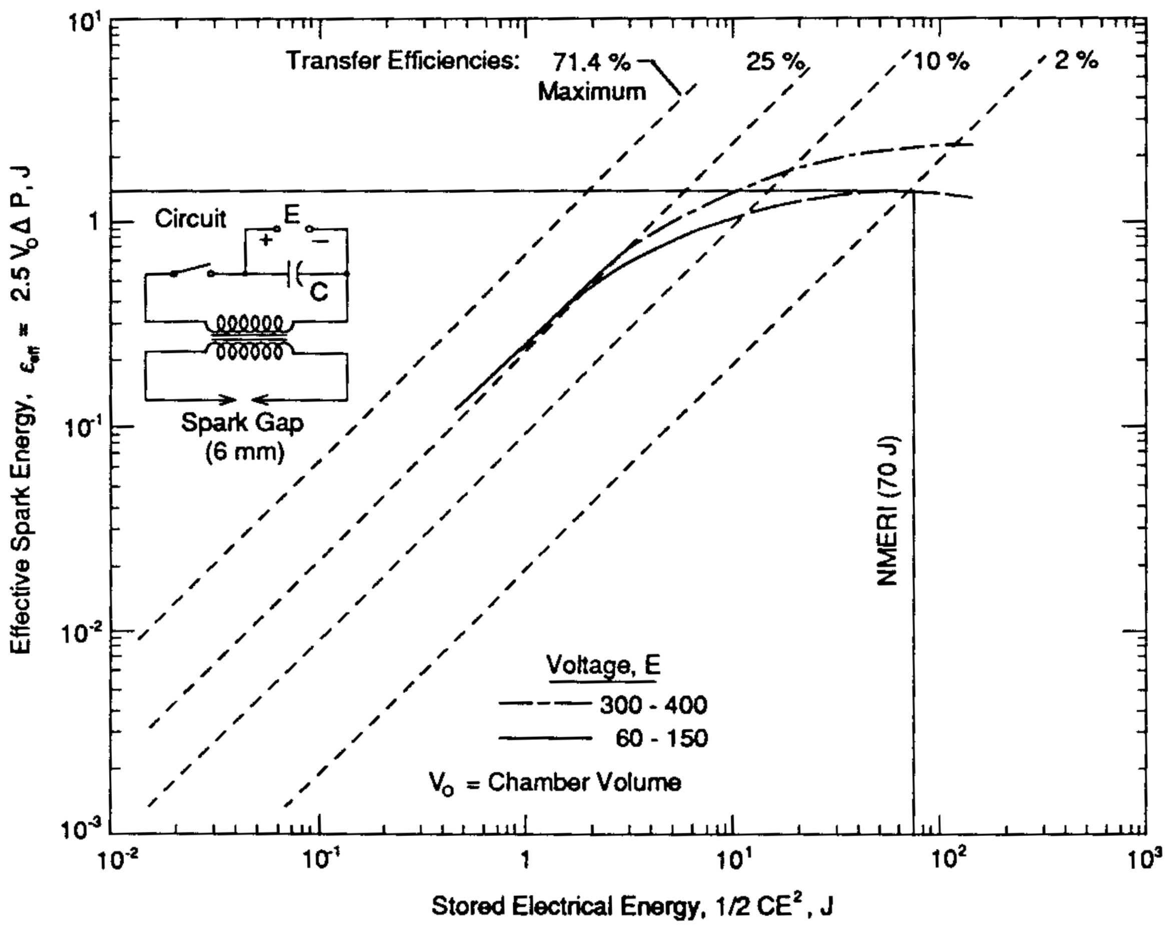


Figure 4. Effective Spark Energies as a Function of Stored Electrical Energy (Ref 8).

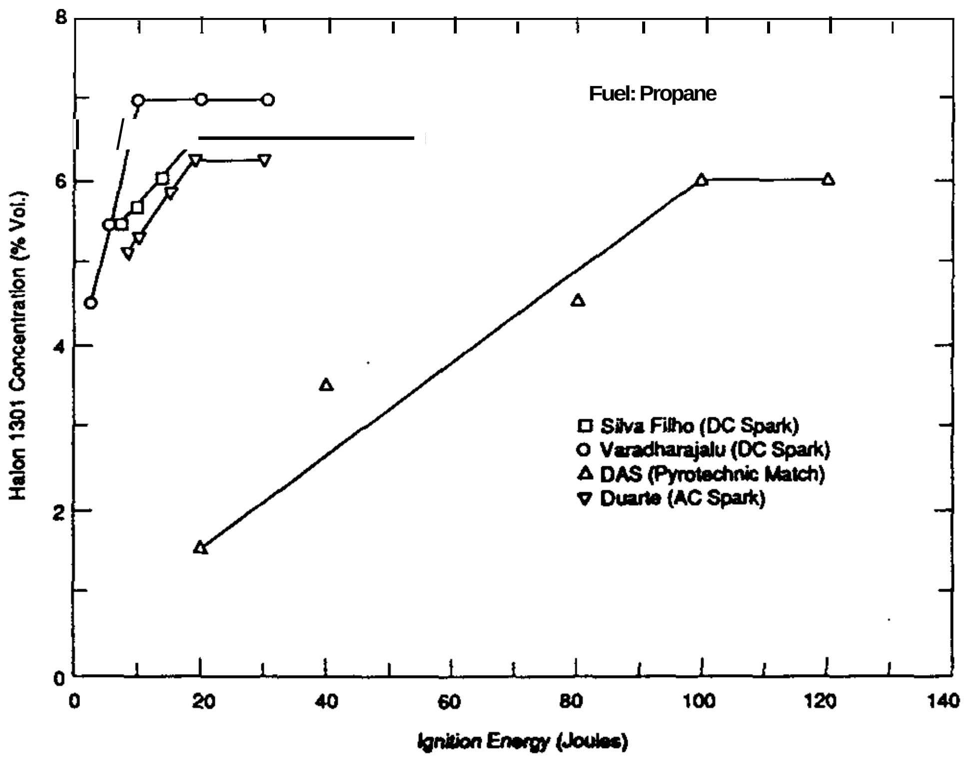
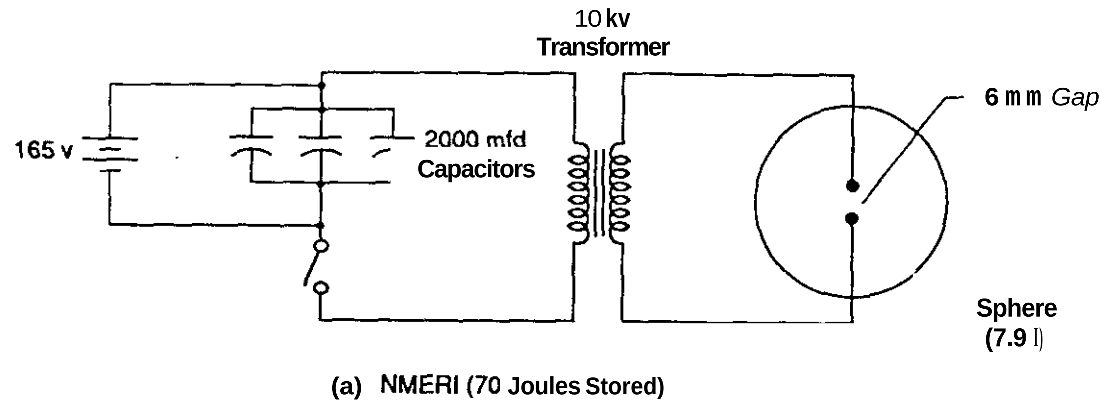


Figure 5. **Halon** 1301 Inerting Concentration vs. Ignition Energy, Propane (Ref 11).

Figure ***6*** is a schematic of the Fenwal and NMERI ignition methods. Differences between the two methods include the graphite rod located between the electrodes in the Fenwal **tests**, the higher charging voltage for Fenwal ***(290*** volts vs. 165 for NMERI), and the absence of **a** transformer in the Fenwal circuit. The Fenwal ignition method could potentially produce a spark with more effective energy than the NMERI method for several **reasons.** First, losses through the transformer were eliminated. Second, although the electric circuit is different than the Bureau of Mines circuit shown in Figure **4,** higher charging voltages tend to produce greater effective energies. Finally, because of the corona discharge method **used** by Fenwal, less energy was expended to initiate the **spark** channel between the electrodes, and more energy was available for ignition of the flammable mixture.

If the curves in Figure 2 are analyzed, it appears that results from the Bureau of **Mines tests** using a 1 joule effective energy ignition source **are** similar to those from the NMERI source using 70 joules **stored** energy. The bottom curve in Figure **4** confirms this value, indicating an effective energy of slightly over 1 joule for an effective energy of 70 joules. Because the flammability limits are greater for the Fenwal tests than the NMERI test, and the inerting concentration higher, Figure 3 indicates that the Fenwal source contained greater effective energy than the NMERI source.



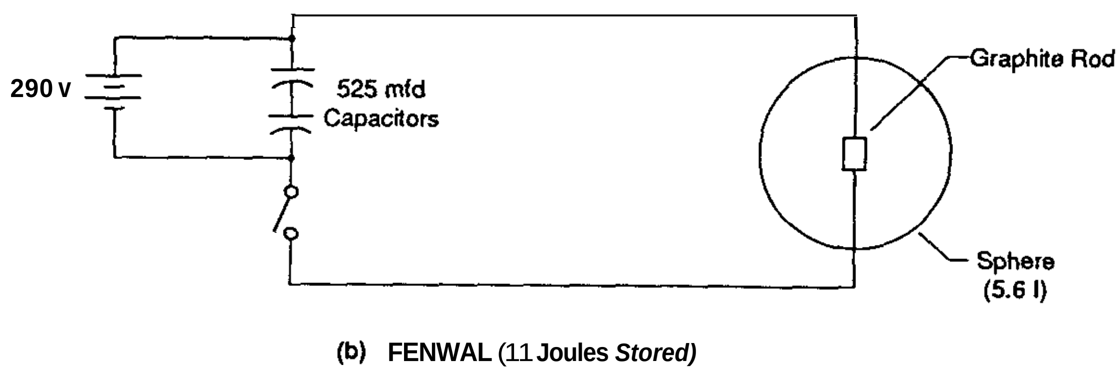


Figure 6. NMERI and Fenwal Ignition System Schematic

While the previous analysis provides one explanation of the difference between NMERI and Fenwal methane results, other factors could affect the difference between propane and methane results. Methane, being lighter than propane, may require additional mixing to achieve a homogeneous mixture. The overall mechanism of igniting methane and propane might be different. Blanc, et al. (Reference 12) reported that propane requires slightly less energy to ignite than methane (0.25 vs. 0.29 millijoules), but a difference of this magnitude may not be considered significant. However, it has also been reported that the presence of halons can inhibit the spark due to their electron affinity and high electron capture probability (Reference 5), which "causes them to interfere directly with the electron avalanche processes in the spark discharge." In some as-yet unknown way, this interference may affect the inertion of methane more than propane. A final variable is the separation of the spark gap. When NMERI tests were run at spark gaps greater or less than the standard *6* mm separation, lower inertion concentrations were required.

CONCLUSION

This paper has presented one potential explanation, based on the effective energy available for ignition of a flammable mixture, for the differences between NMERI and Fenwal methane inertion results. It has hypothesized that the effective energy available in the **NMERI** source is far less than the 70 joules stored energy, most likely in the 1 joule range. This analysis has pointed out that equipment and techniques must be similar if inertion results are to be compared between test organizations. Although the design of the ignition source for the field-scale test facility has not been finalized, it appears that, based on previous test results, a 100 joule or greater electric or pyrotechnic match would provide the most reliable ignition source.

RECOMMENDATIONS

A standard methodology for inertion testing should be developed. Research involving different ignition sources, fuels, and factors such mixing, cleaning between tests, and chamber size should be conducted to provide data for the standardized method. Additionally, the effective energy of the ignition source used for any inertion testing should be determined.

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