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SAVANNAH RIVER LABORATORY

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SRL
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BENZENE/NITROUS OXIDE FLAMMABILITY IN THE PRECIPITATE HYDROLYSIS PROCESS (U)

SUMMARY

Hydroxylamine nitrate (HAN) is used in the DWPF precipitate hydrolysis process to prevent formation of excessive quantities of organic high boilers and tars. These materials result from reaction of organics with nitrite ion which is added to inhibit corrosion. The HAN/nitrite reaction produces a gas which is primarily nitrous oxide (N2O). N2O is an oxidant which can form flammable mixtures with benzene which is present due to hydrolysis of the tetraphenylborate slurry. Extensive computer modeling of the reaction and laboratory testing of flammable mixtures were used to establish the following inerting requirements to prevent flammable benzene/N2O mixtures:

C. T. Randall, 704-T
Authorized Derivative Classifier

Table 1
Minimum Oxidant for Combustion
(MOC) of Benzene by N2O at 1.5% H2O

Inertant	O2 (vol %) [1]	MOC (vol %)
Nitrogen [2]	0	21.3 [3]
	2.0	19.7 [4]
Carbon dioxide [5]	0	29.4 [3]
	2.0	28.0 [4]

[1] Present to simulate large air leak
[2] Includes H2O at 1.5% and CO2 at ≤ 0.7%
[3] Calculated from equivalent N2O; see discussion, pg. 8
[4] Includes O2
[5] Includes H2O at 1.5% and N2 associated with air leak (7.5%)

DISCUSSION

Background

Sodium nitrite will be added in the Waste Tank Farm to prevent corrosion of the carbon steel tanks containing washed precipitate slurry. Nitrite is also generated in the storage tank due to radiolysis of nitrate. At the proposed levels of nitrite (0.05 to 0.2 molar), the reactions in precipitate hydrolysis produce excessive amounts of high boiling and tar-like compounds which cause both fouling of the precipitate reactor and inadequate organic removal for melter processing. In an exhaustive search for a chemical compound which would pre-react the nitrite, the only viable candidate found was hydroxylamine nitrate (HAN). Small and large scale studies have shown that HAN reduces the nitrite sufficiently to produce acceptable levels of high boilers and tars.

The simplest representation of the nitrite ion reaction with formic acid and hydroxylamine is

(1) $NaNO_2 + HCOOH \; <-->> \; HNO_2 + NaCOOH$

(2) $NH_2OH \cdot HNO_3 + HNO_2 + NaCOOH \; --> \; N_2O + 2\ H_2O + NaNO_3 + HCOOH.$

The nitrous acid formed in step (1) reacts with the phenyl groups to form the high boilers and tars. Also of interest is the reaction of carbonate ion with formic acid forming CO_2 gas:

(3) $CO_3{=} + 2\ HCOOH \; --> \; CO_2 + 2\ COOH^- + H_2O$

Experiments in the Integrated Precipitate Hydrolysis System (IPHS), the 1/2000 scale Hastelloy unit, indicate the actual HAN/nitrite reaction gas composition (including the carbonate/formic reaction) is ~ 95% N2O, 2% CO2, 2% NO, and <0.1% NO2.

At the same time, tetraphenylborate is being hydrolyzed by formic acid and water producing benzene:

(4) $CsB(C_6H_5)4 + HCOOH + H_2O \rightarrow CsCOOH + (HO)B(C_6H_5) + 2\ C_6H_6$

The nitrous oxide (N2O) produced by the HAN/nitrite reaction is a very good oxidant and can form flammable mixtures with benzene.

The potential for flammable mixtures in the precipitate hydrolysis process (PHP) is not a new hazard. Operation of the PHP at a slight vacuum relative to the processing cell will produce some air in-leakage. To prevent formation of a flammable benzene/air mixture, the process was provided with a N2 purge to maintain the O2 concentration well below the minimum oxidant for combustion (MOC). However, the co-generation of benzene and N2O presented a new hazard; especially since the benzene/N2O reaction is significantly more energetic than the benzene/air reaction. Calculation of the theoretical adiabatic pressure increase, summarized below, indicates the benzene/N2O reaction is about 2.7 times more powerful than the benzene/air reaction.

Table 2
Theoretical Adiabatic Pressure Increase
for Benzene/Air and Benzene/N2O Mixtures

	Benzene/Air	Benzene/N2O
Stoichiometry		
Reactants	$C_6H_6 + 7.5O_2 + 28.2N_2$	$C_6H_6 + 15N_2O$
Products	$6CO_2 + 3H_2O + 28.2N_2$	$6CO_2 + 3H_2O + 15N_2$
n_b/n_i	1.01	1.50
ΔH (kcal/mol C_6H_6)	740	1051
Adiabatic ΔT (°C)	2780	5430
P_b/P_i	8.6	23.3

The calculations were done using standard industry methods for estimating the worst case peak pressure rise of a gas phase reaction. The term n_b/n_i is the ratio of the moles of gas after burning to the initial moles of gas and P_b/P_i is the comparable pressure ratio.

If the above mixtures were ignited at atmospheric pressure and 100°C, the maximum ending pressure for the benzene/air mixture is 112 psig while the maximum pressure for benzene/N2O is 328 psig. The additional energy arises principally from two sources: there is almost 50% more gas volume after combustion of benzene/N2O and the heat of reaction is about 40% higher. While much of the DWPF equipment would probably survive a benzene/air ignition with little

or no damage, a benzene/N2O ignition would likely cause significant damage.

As part of the effort to implement the HAN process, the Nitrite Reduction Task Team (NRTT; chaired by A. R. Greening of the Engineering Department) requested the Engineering Services Division (ESD) of the E. I. Du Pont Company's Engineering Department to

- determine the MOC's for various gas mixtures containing benzene, N2O, O2, H2O, NO, and NO2.
- evaluate N2, CO2, and Halon® as inertants to prevent ignition.

Flammability Modeling and Testing

During the past three years, the E. I. Du Pont Company has developed a new approach to determining the flammability characteristics of vapor mixtures. This approach has become especially useful in multicomponent mixtures which may vary in composition. The method combines microkinetic modeling (flame characterization) of the fast, gas phase flame reactions with traditional flammability testing. The modeling was done by P. G. Gelblum, ESD consultant, and the testing by J. E. Johnston of the Engineering Test Center. The model is based on the kinetics of the individual free radical reactions. Testing is used to "calibrate" the model, the model is then used to predict the flammability limits and MOC for a given fuel mixture, and finally testing is again used to verify the calculated points.

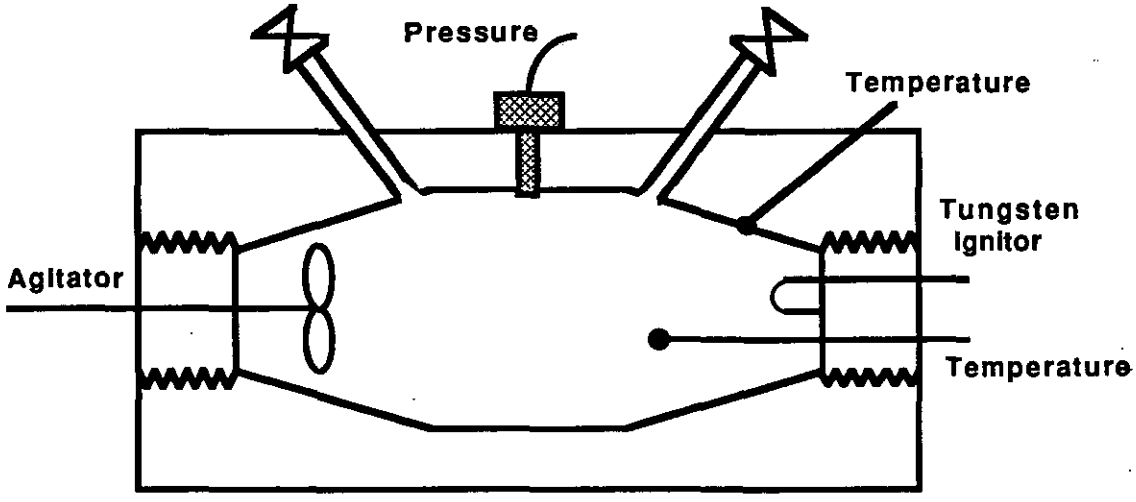
Testing

Testing was carried out at Du Pont's Carney's Point laboratory using the traditional bomb apparatus. The bomb consists of a 1750 cc pressure vessel with breech loading ports at each end (diagram on page 5). The vessel has external heating to allow testing at elevated temperatures. An agitator is used to ensure uniform mixing of the components. Gases and vapors are loaded through tubing connected to the top. The pressure is measured by a transducer and both the wall and vapor space temperatures are measured by thermocouples. A tungsten wire igniter is used to initiate burning of the mixture. (The standard igniter is nichrome which fuses at ~ 1350°C. Initial work with our mixtures was done with a nichrome igniter. However, test results were somewhat erratic and it was decided to use tungsten instead to ensure ignition. Tungsten fuses at 3410°C.)

The procedure for "shooting" a mixture begins with cleaning of the vessel and installation of a new igniter. The vessel is evacuated and the gases and vapors are loaded by partial pressure beginning with the least volatile first. The mixture is agitated and allowed to stabilize at the test temperature. The igniter is then energized. The data collected are maximum pressure rise, rate of pressure rise, maximum vapor temperature, and the state of the igniter at ignition. (In the tabulated data, HW indicates the mixture ignited from a hot wire while F indicates fusion of the wire at 3410°C.) The criteria established by the NRTT to designate a

flammable event (that is, a "go") are a maximum pressure rise of more than 15 psi and rate of pressure rise more than 75 psi/sec. The ΔP limit was established based on DWPF equipment design pressures.

Flammability Test Apparatus



• 1750 cc • Traced & Insulated • Tungsten Ignitor • 100°C • 1 atm

P. G. Gelblum's and J. E. Johnson's reports on the modeling and testing results are included as Appendix I. (Additional information and discussion of methods can be found in a similar DPST on In-Tank Precipitation flammable mixtures.[1]) The reports contain details of the modeling calculations and a listing of the test results.

Errors

In Tables 0 through 5 of Johnston's report, data is presented which was determined using standard bomb loading techniques. Close scrutiny of the data revealed some inconsistencies which were attributed to loading errors of the low concentration components. The benzene concentrations at ~ 1.5% were particularly suspect. Therefore, a special loading technique was developed to meet our test requirements. With the new technique, the loading error for the individual components in the test mixture is estimated to be ± 0.1%. The data in Tables 6 and 7 were generated using the new techniques and are the data used to "calibrate" the model and establish the MOC's.

The errors in the MOC's are estimated by Gelblum to be 0.3 to 0.5% for mixtures containing 1.5% H2O. (See Appendix I for P. G. Gelblum's discussion of errors.) However, the estimates tend to be conservative for the following reasons:

- By the nature of the combined modeling/testing method, the model tends to find the very lowest possible value that will produce a "go".
- Even then, the predicted model value is used if it is lower than the test value.
- The use of a tungsten igniter very likely induced "go's" in mixtures which would have produced "no go's" with a nichrome igniter

Therefore, the errors are likely to be one-sided; that is, the true explosion test value of the MOC is more likely to be higher than the reported value than it is to be lower than the reported value.

RESULTS

Several conclusions were drawn from the extensive modeling and testing studies. These conclusions (discussed in more detail below) are:

- The actual gas mixture (~ 95% N2O, 2% NO, 0.1% NO2) has an MOC in N2 of > 22% and is, therefore, slightly less flammable than pure N2O (MOC = 21.3%). The use of N2O instead of the actual gas mixture is an acceptable, conservative substitute.
- Halon® will suppress the flammability of benzene/N2O but the required concentration (~ 17%) is impractically high. At lower concentrations (< 10%), Halon® actually accelerates the rate of combustion.
- Water vapor, nitrogen, and carbon dioxide are all satisfactory inertants for benzene/N2O. Their order of effectiveness is CO2 > H2O > N2.
- Water vapor, which is present in high concentrations at certain times, is a poor candidate for use as an inertant because it is easily condensed and its presence (and concentration) cannot be assured.
- As benzene oxidants, N2O and O2 are comparable based on their molecular oxygen content. Specifically, when the oxidant is primarily N2O ($0 \leq O2 \leq 5\%$), the mixture can be converted to equivalent N2O as follows:

$$\text{Eqvlnt } N2O = 100 * \frac{N2O + 2*O2}{100 + O2}$$

This weights the O2 for its oxygen content and then normalizes mixture to 100%.

- At the condition of the salt cell vent condenser (SCVC) exit (~1.5% H2O at 10°C), the MOC's for benzene/N2O with N2 or CO2 inerting are

Table 3
MOC's for N2 and CO2 at 1.5% H2O

Inertant	Oxidant concentrations O2 (vol %) [1]	N2O (vol %)	MOC - Eqvlnt N2O (vol %) [2]
Nitrogen [3]	2.0	17.7	21.3
Carbon dioxide [4]	2.0	26.0	29.4

[1] Present to simulate large air leak
[2] Calculated values
[3] Includes H2O at 1.5% and CO2 at ≤ 0.7%
[4] Includes H2O at 1.5% and N2 associated with air leak (7.5%)

Data

In the following discussions, test data from Johnston's report are frequently referenced. To facilitate analysis and presentation, this data was loaded into a database program. Appendix II contains several tables (Tables 1 through 8) which are subsets of the complete database. The complete data set is contained in Table 9 of Appendix II.

The following runs are missing from Johnston's data:

Run #	Reason
A121 - A141	Bad strain gage
A149 & A152	Unknown reasons

The following runs from Johnston's data were deleted from the database program for N2/CO2 MOC analysis:

Run #	Reason
A001 - A005	No inert add, N2O/benzene UEL
A008 - A021	Halon® tests
A027 - A030	Halon® tests
A083 - A085	Halon® tests
A088	Halon® test
A092 - A094	Halon® tests
A108 - A112	Halon® tests
A096 & A097	Bomb pressure drifting at ignition
A156	Contained Hg and nitrosobenzene
C001	Nichrome igniter; would have been a "go" with tungsten
C038	Long mixing time; repeat (C041) was a "go"

A note on run numbers: Johnston's report contains data collected using three different loading "regimes"; that is, three different loading techniques. Each time Johnston started a new regime or changed the primary inerting agent, he would start numbering the runs over again. When his data was loaded into a single database, the run numbers were given an alpha prefix while retaining the same numeric value. In the database, run numbers "Annn" correspond to the data in Johnston's tables 1a through 5e, run numbers "Bnnn" are the data from Johnston's tables 6a and 6b (CO2 data), and runs "Cnnn" are from Johnston's tables 7a through 7d (N2 data).

Actual gas mixture vs. N2O

Table 1 of Appendix II shows the benzene/gas mix MOC with N2 inerting is somewhere between 22% and 27%. Testing to that point had indicated the MOC for N2O/benzene/N2 would be about 20%. Therefore, it was judged that N2O alone would be satisfactory to simulate the oxidant produced by the HAN/nitrite reaction. Subsequent testing and modeling confirmed the N2O MOC to be 21.3%.

Halon®

Literature on Halon® indicated that in some cases, modest concentrations of Halon® 1301 (~ 5% for benzene in air) could be used as a suppressant to prevent ignition. Testing of Halon®/ benzene/N2O mixtures (Table 5 in Johnston's report, Appendix I) indicate

- about 17% Halon® 1301 was required to suppress ignition, and
- at < 10%, Halon® seemed to accelerate the reaction rate.

Modeling by Gelblum confirmed that Halon® forms free radicals which increased the reaction rates resulting in some high dP/dt's. This also accounts for why so much Halon® is required to suppress ignition.

Equivalence of N2O and O2 as oxidants

In the DWPF, small amounts of air will leak continuously into the salt cell which is maintained at a slight negative pressure. During the HAN/nitrite reaction step, dilution by N2O and additional inert reduces the O2 concentration at the SCVC to about 0.2 to 0.4 %.[2] However, if there was a large or sudden leak, the O2 concentration could be much higher. Therefore, much of the testing was done with 2% oxygen to simulate a very large leak. In addition, while testing benzene/N2O/N2 at 1.5% H2O, several different levels of O2 were included (0-5%). These data are in Table 3 of Appendix II. The following are approximate flammable minimum oxidant concentrations from that table:

Table 4
MOC for N2 Inerting at 1.5% H2O

O2 (vol %)	N2O (vol %)	Ttl Oxdnt (vol %)
0	21	21
1.0	20	21
2.0	18	20
3.0	16	19
5.0	12.5	17.5

In terms of the MOC, it is obvious from these values that O2 is a more "potent" oxidant than N2O. It would appear to be about twice as potent on a molar basis which its quite reasonable since one mole of O2 has twice as much oxygen as one mole of N2O. Additionally, the MOC for benzene/O2/N2 is 11.0% which is almost exactly one half of the MOC for benzene/N2O/N2 (21.3%). Thus it seems reasonable to convert O2 to equivalent N2O when N2O is the primary oxidant by weighting the O2 by a factor of two and then normalizing the mixture back to 100%:

$$\text{Eqvlnt N2O} = 100 * \frac{\text{N2O} + 2*\text{O2}}{100 + \text{O2}}$$

Table 4, Appendix II, contains the same data as Table 3 except that it is sorted by equivalent N2O. It is clear from Table 4, Appendix II, that the MOC for benzene/N2O/O2/N2 at 1.5% H2O is ~ 21.5% equivalent N2O for O2 concentrations ranging from 0 to 5%.

Inerting effectiveness

The table below summarizes the data analysis contained in Tables 2 through 8 of Appendix II:

Table 5
Effectiveness of H2O, N2, and CO2
as Inerts in Benzene/N2O Mixtures

Inert	Table	H2O (vol %)	O2 (vol %)	Eqvlnt N2O (vol %)
N2	2	0	0	21.0
	3,4	1.5	0-5	21.7
	5	12.0	0	23.4 < MOC < 28.5
	6	20-22	2.0	22.5 < MOC < 23.2
CO2[1]	7	1.5	2.0	29.3
	8	22	2.0	27.5

[1] Includes 7.5% N2 from simulated air leakage

It can be deduced from this summary that water vapor is somewhat more effective than N2 for inerting since the MOC in the benzene/N2O/N2/H2O increases with increasing water. However, the opposite

is the case for benzene/N2O/CO2/H2O. Therefore, the relative effectiveness for inerting is CO2 > H2O > N2. This is the order which is expected because the molar heat capacity of CO2 > H2O > N2. (The primary way an inert prevents ignition is to absorb the heat of reaction thus preventing the mixture from reaching a temperature which is self-sustaining.)

Water vapor as an inertant

While water is a fairly effective inertant and is frequently present in concentrations exceeding 20%, in practice it should not be used (credited) as an inert when evaluating the flammability of a given mixture. This is because water is easily condensed and its presence is difficult to prove or assure. In addition, the SCVC exit temperature will run about 10°C and essentially all water present in the SCVC inlet will be condensed. For these reasons, the mixture flammability should be evaluated based on the relative concentrations of the oxidant (N2O and O2) and the non-condensible inerts (N2 and CO2). By ignoring the water and fuel concentrations and by inerting based only on non-condensibles, the actual oxidant concentration will be less leading to a wider margin of safety.

MOC vs. Total Inerts

In Gelblum's report (Appendix I), the results of the modeling and testing are stated in terms of Total Inerts instead of MOC:

Table 6
Total Inerts to Prevent Ignition of Benzene/N2O Mixture

	H2O (vol %)	Total Inerts (vol %)	O2 (vol %)
N2	1.5	78.8 ± 0.3 [1]	2.0
	22.0	77.5 ± 1.0 [1]	2.0
CO2	1.5	70.5 ± 0.5 [2]	2.0
	22.0	73.0 ± 0.3 [2]	2.0

[1] Includes N2, H2O, and traces of CO2 at the level of 0.7%
[2] Includes CO2, H2O and 7.5% N2 as associated with the 2% O2 that enters as air

The concentration of benzene at all of the above mixtures was ~ 1.5%. Therefore, the MOC for N2 inert at 1.5% water is

100% - 1.5% Benz - 78.8% Inerts = 19.7% Oxidant (including 2% O2).

When converted to equivalent N2O, the MOC is 21.3%. These are the MOC's reported for N2 with 1.5% water in Table 1 of this report (page 2). Similarly, the values for CO2 are 28.0% and 29.4%, respectively.

Quality Assurance

Gelblum's records and files are located in the ESD Working File of the Engineering Department, ID # 37635 and 37636. These records are to be turned over to the Savannah River site when the E. I. du Pont contract expires on April 1, 1989. Johnston's data files are also to be turned over to the site along with all other information related to tests done for Savannah River at the Engineering Test Center's Explosion Hazards Laboratory at Carney's Point, New Jersey.

References

1. Jacobs, R. A., "Flammability of Vapor Mixtures from In-Tank Precipitation", DPST-88-573, October 28, 1988.

2. Greening, A. R., et al, "Nitrite Reduction by Hydroxylamine Nitrate - Precipitate Hydrolysis Design Basis", DPST-87-293, July 31, 1987.

DPST-89-348

APPENDIX I

Reports by

P. G. Gelblum
Engineering Services Division
E. I. du Pont de Nemours & Co.

and

J. E. Johnston
Engineering Test Center
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R. A. Jacobs-SRL-SRP (704T)
A. R. Greening-AED-L43N09
J. M. Wesley-ESD-L2318
R. F. McCartney-ESD-L1364
IC 13 - RE

August 13, 1987

TO: J. E. JOHNSTON - ESD - ETC

FROM: P. G. GELBLUM - ESD - L1372

PROJECT S-1780 - SAVANNAH RIVER PLANT - 200S AREA
DEFENSE WASTE PROCESSING FACILITY
EXPLOSION HAZARDS STUDIES

LOWER EXPLOSION LIMIT STUDIES FOR MIXTURES OF C_6H_6, N_2O AND 2% O_2 WHEN INERTED BY WET N_2 OR CO_2, AT 1.5 OR 22% H_2O, AND 1 ATMOSPHERE PRESSURE

Ref: 1) The nitrite reduction task force group meeting at Louviers January 14, 1987
2) Same, but May 12, 1987
3) Same, but June 9, 1987

Explosion tests that were run since May 12, 1987, at ETC's Explosion Hazards Laboratory and corresponding flammability model calculations, have indicated that the Lower Explosion Limits, LELs, for mixtures consisting of benzene, C_6H_6, and nitrous oxide, N_2O, that are inerted by either nitrogen, N_2, or by carbon dioxide, CO_2, are strongly effected by the presence of oxygen, O_2, to increase it, and to a lesser degree, but in a reducing direction by the presence of water.

The highest concentration of O_2 constitutes the worst situation and sets the higher LEL, therefore, in the defined range of 0 to 2% O_2, the latter concentration of 2% oxygen is the only one to be summerized here, reference 2 and 3.

For systems inerted primarily by N_2 and containing H_2O in the range of from 1.5% to 22%, by volume, the LELs were found to improve/decrease with the increased concentration of H_2O as follows:

H_2O vol. %	Total Inerts[1] vol. %	O_2 vol. %
1.5	78.8 +/-0.3	2.0
22.0	77.5 +/-1.0	2.0

(1) Includes N_2, H_2O and traces of CO_2, at the level of 0.7%.

For the case that CO_2 was the primary inerting medium the LEL became worse/increase when the concentration of H_2O increases from 1.5 to 22.0% as follows:

H_2O vol. %	Total Inerts[2] vol. %	O_2 vol. %
1.5	70.5 +/-0.5	2.0
22.0	73.0 +/-0.3	2.0

(2) Includes CO_2, H_2O and 7.5% N_2, as associated with the 2% O_2 that enters as AIR.

LEL is defined here as an explosion event that generated an increase in pressure of less than 15 psi and a pressure increase rate, dP/dt, of less then 75 psi/sec, all generated in a 1.75 liter well mixed double cone-type vessel (Nixon reactor) at 1 atmosphere pressure and 100°C wall temperature, reference 1.

From the above CO_2 inerting results in a lower LEL relative to that of N_2: or 70.5% of primarily CO_2 inerts relative to 78.8% of primarily N_2 inerts at 1.5% H_2O, but 73.0% of primarily CO_2 inerts relative to 77.5% primarily N2 inerts at 22% H_2O. In terms of process gas (C_6H_6+N_2O[+ 2% O_2]) the lower level of CO_2 inerting translates into +39% and +17% increases in flow rates, respectively at 1.5 and at 22% H_2O.

The tabulated results indicate that H_2O causes the inerting effects of N_2 and of CO_2 to converge as the level of wetness increases: a difference of 8.3%, compared to 4.5%, both at absolute values, at 1.5 and 22% H_2O, respectively. The reason for the above decreasing value is related to the fact that the molar specific heat of H_2O has a value between that of CO_2 and of N_2.

It is important to note that due to the "addition" of oxygen to the net process gas of C_6H_6 and N_2O, such a mixture ignites more rapidly, than without it. However, the more rapid ignition implies a lower ignition temperature, which by definition, generates a weaker explosion. In the specific case of the mixture of C_6H_6 and of N_2O, the net result of adding any amount of O_2 does increase the LEL of such system.

Overall, the "addition" of both oxygen and of H_2O to the process gas, consisting of C_6H_6 and of N_2O, decreases the inherent large difference between the inerting effects of CO_2 and of N_2: close to a factor of 2 in the case of 1.5% H_2O and close to a factor of 3 in the case of 22% H_2O, both at 2% O_2.

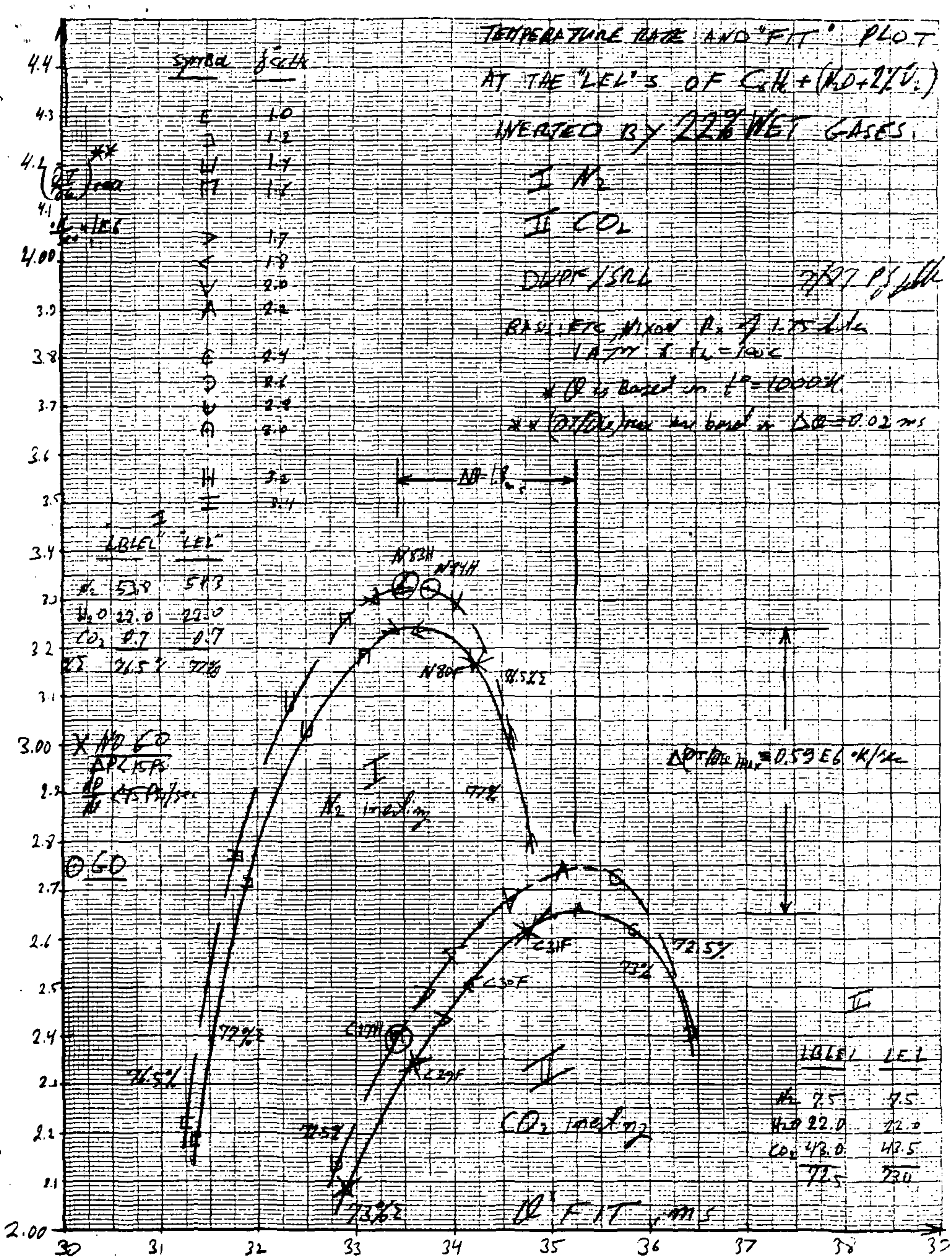
In the above tabulation, the level of accuracy attached to the total concentration value of inerts required to define an LEL, represents half of the difference in concentration between: 1) the Temperature Rate and FIT plot at a fixed level of total concentration of inerts where no single explosion test point had a pressure rise higher than 15 psi and a dP/dt higher than 75 psi/sec.; and 2) between a plot that did have at least one such event. Though the objective was to achieve overall accuracy levels of 0.3% of total inerts, it seemed to be important to do so only for the design case of N_2 inerting, of 2% O_2 and 1.5% H_2O. In all other cases, the closest test data available were used to calculate a level of accuracy, however, the targeted overall level of accuracy can be attained with only a few more tests, as required.

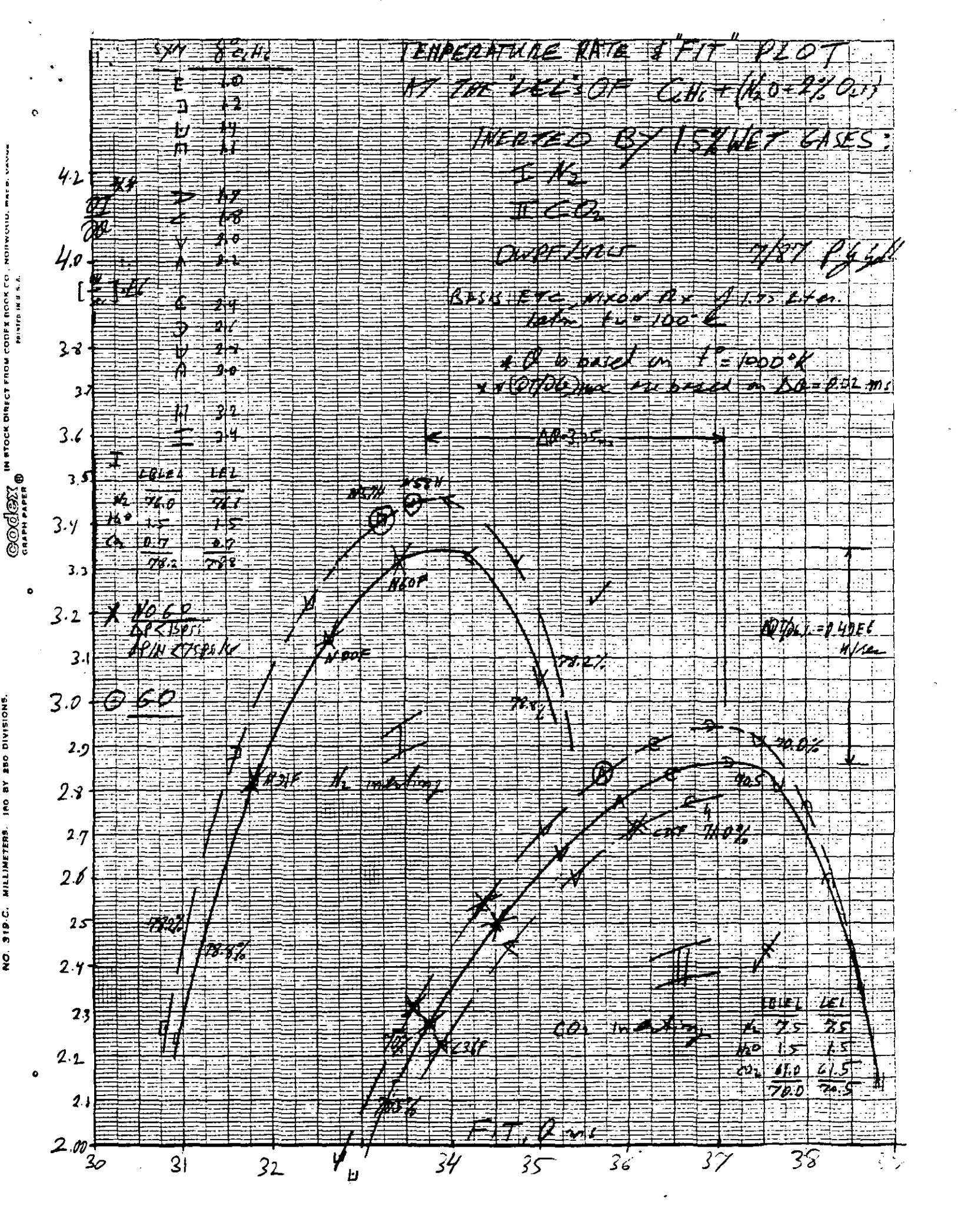
The explosion test programs were performed by the ETC Explosion Hazards Laboratory and coordinated by the ESD flame characterization model, FCM. The ESD FCM was run in an adiabatic mode, for a control volume, at ideal thermodynamic conditions. The resulting Temperature Rate and FIT plots at the LELs of the respective total N_2 and total CO_2 inerting levels of C_6H_6 and N_2O + 2% O_2 at 1.5%, and separately at 22% H_2O, by volume, concentrations are presented in Figures 1 and 2. Each of the Temperature Rate and FIT plots cover the range of C_6H_6 in the inerted process gas that increases from about 1.0% to 4.0%, by volume, with the increase in Flame Induction Time. The peak in the TR&FIT plot defines the concentration of C_6H_6 with the highest probability to become explosive at the given test conditions. Points to the left of this peak, lower FIT values, could become explosive, even if the peak does not but points right of the peak, higher FIT values, would not. Therefore, by lining up tests that were "not" explosive and fall on a TR&FIT plot at a higher concentration level of inerts than the RT&FIT plot where the last explosive test did occur, and by setting those tests up at fuel concentrations that "surround" the concentration of the last explosive events from the peak of the plot to the far left of it, a confirmation of the "validity" of such LEL, in terms of total inert concentration, has been established.

The LEL term used here is defined in terms of a total concentration of inerts, of a very specific composition, and not in the conventional terms of the concentration of the fuel, here C_6H_6. It is equally ambiguous to define such LELs in terms of a maximum oxygen concentration, MOC, because in the present case we deal with a mixture of a bonded oxygen, N_2O, and a free one, O_2 or air.

It thus is established that the close interaction of explosive tests with predictive calculations by a flammability model proved to have provided a technology for the systematic and accurate definition of Lower Explosive Limits, that so far did not exist.

PGG:hwb
PGG5.26





CC: J. E. Koonce-PET-SRP 704S

March 31, 1989

R. A. JACOBS
PETROCHEMICALS
SAVANNAH RIVER PLANT 704T

PETROCHEMICALS - SAVANNAH RIVER
ENVIRONMENTAL TESTING - EXPLOSION HAZARDS
DEFENSE WASTE FLAMMABILITY

INTRODUCTION

Chemical handling of irradiated waste was expected to generate enough nitrous oxide to form flammable mixtures with the benzene formed in the process. Existing data obtained by the Explosion Hazards Lab for Beaumont on similar mixtures needed to be repeated at lower lower temperatures and pressures for the proposed changes.

Any explosion in the Precipitate Reactor (PR) would result in a particularly hazardous event because of the presence of highly radioactive cesium being processed. Design of the PR system was complete and the facilities under construction when the use of Hydroxyl Amine Nitrate (HAN) was introduced. Resolution of the impact of HAN addition was requested by the HAN Task Force. There was also the probability that the ignition of N2O-Benzene would be sensitized by the presence of oxygen that will be present at low levels in the PR.

As a result of a series of meetings and communications before and during the course of the testing, a variety of potentially flammable combinations were identified.

At the request of R. A. Jacobs (Petrochemicals-Savannah River), a set of tests adequate for identification of the minimum oxygen concentration required for flammability or a complete flammability envelope was determined.

Because of the large number of variables and high moisture levels involved, the ESD Flame Characterization Model (FMC) was ultimately employed to guide the selection of vapor compositions that were close to the edge of the flammable range. The model makes use of numerical analysis of reaction networks using the CHEMNIN computer code developed at Sandia National Laboratories. This approach was made after meetings with Savannah River personnel and was used on all compositions except for those containing Halon.

The following systems were studied:

Data Table No.	System	
	LOADING REGIME: Excess water and benzene (liquids) N2O added to 1-atm.	
0:	BENZENE-N2O-H2O: WATER-BENZENE-SATURATED N2O	Versus temperature
	LOADING REGIME: Water added by volumetric liquid injection Water levels may be fractionally low due to unheated agitator Mixtures made up to 30 PSIA, mixed, & vented to 1-atm. Benzene guided by stoichiometry	
1a:	BENZENE-N2O	Binary
1b:	BENZENE-N2O-N2	
1c:	BENZENE-N2O-NITROGEN-MERCURY-NITROSOBENZENE	1-point check
2a:	BENZENE-N2O-N2-H2O	
2b:	BENZENE-N2O-N2-H2O-MERCURY-NITROSOBENZENE	2-point check
3a:	BENZENE-N2O-CO2-H2O	
4a:	BENZENE-N2O-NO2-NO	
4b:	BENZENE-N2O-NO2-NO-N2	
4c:	BENZENE-N2O-NO2-NO-N2-H2O	
5a:	BENZENE-N2O-HALON	
5b:	BENZENE-N2O-N2-HALON-H2O	
5c:	BENZENE-N2O-NO2-NO-HALON	
5d:	BENZENE-N2O-NO2-NO-HALON-H2O	
5e:	BENZENE-N2O-NO2-NO-N2-HALON-H2O	
	LOADING REGIME: Water added by partial pressure under vacuum Agitator heated Water loading precision improved 2X by increasing make-up pressure to 50 PSIG Benzene level guided by use of kinetic flame model (P. G. Gelblum, who also judged that nitrogen oxides were adequately represented by N2O alone) Additional oxidant added at request of SRP (oxygen)	
6a:	BENZENE-N2O-O2-N2-H2O-CO2: H2O = 1.5%, N2 = 7.5%	
6b:	BENZENE-N2O-O2-N2-H2O-CO2: H2O = 22%, N2 = 7.5%	
7a:	BENZENE-N2O-N2 (Supercedes Table 1b)	
7b:	BENZENE-N2O-N2-H2O (Supercedes Table 2a)	
7c:	BENZENE-N2O-O2-N2-H2O	
7d:	BENZENE-N2O-O2-H2O	

RESULTS AND CONCLUSIONS

HOT WIRE IGNITION: Tests of vapor mixtures involving various combinations of benzene, N2O, NO2, NO, O2, N2, CO2, Halon 1301, and water prepared by partial pressures, in many cases close to the dew point of water. The flammable range turned out to be extremely narrow at its tip, requiring the use of unprecedented precision (0.1%) in vapor compositions.

Halon 1301 was found paradoxically to increase the flammability of benzene in N2O at low concentrations.

Mercury was found to produce only a marginal, if any, increase.

PROCEDURE

HOT WIRE IGNITION TESTS: Flammability was studied using in a horizontal 1750 cc Nixon Reactor which is a 316 stainless steel heavy wall vessel specially designed for explosion hazards determinations. It was equipped with a strain gauge pressure transducer mounted centrally in the side wall, magnetically driven agitator, two 1/16" diameter stainless steel sheathed thermocouple (one touching the bottom inside wall, and another in the vapor space), external electrical heating, and a 10 mil 2.5" tungsten hot wire ignitor mounted on one of the end walls. The pressure transducer and thermocouple were connected to appropriate signal recording instrumentation. Except as noted, all components were measured into the test vessel by partial pressure. The loading precision in the runs on Tables 6 & 7 was plus or minus 0.1 vol.%. Except as noted, benzene and water vapors were added from heated stainless steel cylinders by way of heated transfer lines and valves.

The sequence of loading and operation of the test vessel was as follows:

1. Stabilize test vessel temperature with agitator running.
2. Evacuate test vessel.
3. Add vapors to required positive partial pressures, beginning with the component having the lowest vapor pressure (water).
4. Continue agitation for 10 minutes.
5. Turn off agitator and activate hot wire with increasing current until a deflagration occurs or until the tungsten hot wire fuses (3410 deg. C. hot spot).
6. Vent, open, and clean test vessel.
   Replace the ignitor if it was fused and re-seal vessel.

The data for benzene-NOx obtained previously for Beaumont indicated that the heat obtained from fusion of a 20 gauge nichrome hot wire igniter (at 1350 deg. C) was not sufficient to ignite some mixtures of benzene-NOx-N2. (This is the ignitor normally employed for flammability studies at our laboratory.) It was ultimately agreed at meetings between ESD and Savannah River personnel that the tungsten ignitor would be employed.

In the case of some near-limit mixtures, a deflagration would result only as the ignitor was fused.

ACKNOWLEDGEMENTS

Test work was performed by L. C. Nixon, E. B. Moore, and J. M. Chase at the Engineering Test Center's Explosion Hazards Laboratory at Carneys Point, New Jersey. Kinetic modeling was provided by ESD's P. G. Gelblum.

ENGINEERING SERVICE DIVISION
Engineering Test Center

James E. Johnston

J. E. Johnston

TABLE O
N2O SATURATED WITH BENZENE & WATER
FLAMMABILITY VS. TEMPERATURE
FLAMMABILITY OF SRP'S DWPF PRECIPITATE HYDROLYSIS PROCESS VAPORS
1750 cc Vessel - Agitator - 2.5" 10 mil Tungsten Hot Wire Ignitor
5 cc each of liquid benzene and liquid water into evacuated vessel
N2O added to P=1 atm.

RUN	TEMP. DEG. C.	Pmax PSIG	Delta T Deg. C.	(dP/dt)max psi/sec	Time to Pmax,msec
1	22	267	160	65113	9.8
2	23	316	163	78260	9.3
3	39	0.8	4	-	-
4	29	est 368	190	-	-
5	34	256	177	29412	39
6	38	2	-	-	-

TABLE 1: DRY N2O SYSTEMS
FLAMMABILITY OF SRP'S DWPF PRECIPITATE HYDROLYSIS PROCESS VAPORS
1750 cc Vessel - Agitator - 2.5" 10 mil Tungsten Hot Wire Ignitor
T = 100 Deg. C., P = 1 Atm.
ESD/ETC, EXPLOSION HAZARDS LAB JEJ/LCN/JMC 8-30-88

RUN	BENZ-ENE	N2O	NO2	NO	N2	H2O	N2+H2O	MISC	HW or F*	delta Pmax PSIG	dP/dt max psi/sec	delta Tvapor deg.C
1a:	BENZENE-N2O											
1	25.0	75.0					0.0		F	286	7353	>397
2	35.0	65.0					0.0		F	1		1
3	30.0	70.0					0.0		F	1		2
4	25.0	75.0					0.0		F	3		19
5	20.0	80.0					0.0		F	>87		235
40	20.0	80.0					0.0		F			2
41	10.0	90.0					0.0		F	65	1282	273
42	10.0	90.0					0.0		F	61	1020	238
43	5.0	95.0					0.0		F	38	512	177
44	15.0	85.0					0.0		F			3
1b:	BENZENE-N2O-N2											
6	5.0	57.5			37.5		37.5		HW	188	21340	144
7	5.0	45.0			50.0		50.0		HW	est.180		157
57	3.1	46.9			50.0		50.0		HW	33	467	192
58	2.8	42.2			55.0		55.0		HW	33		163
59	2.8	42.0			55.0		55.0		HW	21	1020	124
60	2.8	42.0			55.0		55.0		HW	27	279	161
61	1.9	28.1			70.0		70.0		F			2
62	2.2	32.8			65.0		65.0		F	12	98	98
66	2.3	27.9			70.0		70.0		F			2
67	1.6	28.4			70.0		70.0		F			2
69	1.5	33.5			65.0		65.0		HW	24	175	142
70	1.2	18.8			80.0		80.0		HW			2
71	1.2	28.8			70.0		70.0		HW	30	93	82
72	0.3	29.7			70.0		70.0		F	0		2
73	0.8	19.2			80.0		80.0		F	0.1		4
74	0.8	29.3			70.0		70.0		F	0.4		7
75	1.0	24.0			75.0		75.0		F	0.2		5
86	1.5	18.6			80.0		80.0		F	0	0	0
87	1.4	23.6			75.0		75.0		F			
89	1.5	28.5			70.0		70.0		HW	17	96	127
90	1.5	23.5			75.0		75.0		F			
91	1.3	23.8			75.0		75.0		F			3
95	2.2	32.8			65.0		65.0		F			3
97	1.4	33.6	DRIFTING		65.0		65.0		F	1		1
105	1.2	33.8			65.0		65.0		HW	34	74	109
106	1.3	33.7			65.0		65.0		HW	38	100	109
107	1.4	33.6			65.0		65.0		HW	64	457	110
114	1.8	23.2			75.0		75.0		HW	57	360	101
142	5.0	45.0			50.0		50.0		HW	156	17123	141
155	5.0	45.0			50.0		50.0		HW	168	9328	171
1c:	BENZENE-N2O-NITROGEN-MERCURY-NITROSOBENZENE											
156	5.0	45.0	0.14**		50.0		50.0	Hg***	HW	176	20833	154

*HW = hot wire; ** Nitrosobenzene, weighed in; calc. as vapor
F = fused at 3410 deg. C. ***Hg = liquid mercury present

TABLE 2: WET N2O-N2 SYSTEMS
FLAMMABILITY OF SRP'S DWPF PRECIPITATE HYDROLYSIS PROCESS VAPORS
1750 cc Vessel - Agitator - 2.5" 10 mil Tungsten Hot Wire Ignitor
Water by volumetric liquid injection - All other gases by partial pressure
T = 100 Deg. C., P = 1 Atm.
ESD/ETC, EXPLOSION HAZARDS LAB JEJ/LCN/JMC 8-30-88

RUN	BENZ-ENE	N2O	NO2	NO	N2	H2O	N2+ H2O	MISC	HW or F*	delta Pmax PSIG	dP/dt max psi/sec	delta Tvapor deg.C
2a: BENZENE-N2O-N2-H2O												
45	1.2	17.6			51.1	30.1	81.2		F			2
46	1.6	24.7			43.6	30.1	73.7		F			4
47	2.6	38.8			28.5	30.1	58.6		F	32	461	153
48	2.1	31.7			36.0	30.1	66.1		F			2
49	2.8	42.2			35.0	20.0	55.0		HW	35	4332	175
50	2.2	32.8			45.0	20.0	65.0		HW	15	185	110
51	1.6	23.4			55.0	20.0	75.0		F			2
52	1.9	28.1			50.0	20.0	70.0		F			2
53	2.4	35.3			32.2	30.1	62.3		HW	27	294	141
54	1.6	23.4			65.0	10.0	75.0		F			2
55	1.9	28.1			60.0	10.0	70.0		F			2
56	2.2	32.8			55.0	10.0	65.0		HW	14	147	107
80	1.1	26.9			60.0	12.0	72.0		HW	18	137	133
81	0.9	22.1			65.0	12.0	77.0		HW	16	84	99
82	0.7	17.3			70.0	12.0	82.0		F	0		3
96	1.2	28.8	DRIFTING		58.0	12.0	70.0		F	1		2
98	1.4	33.6			53.0	12.0	65.0		HW	>25	>309	89
99	1.2	23.8			63.0	12.0	75.0		F	1		3
100	1.8	44.6			45.7	7.9	53.6		HW	>50	2406	148
101	1.4	33.6			45.0	20.0	65.0		HW	>25	1059	122
102	1.2	28.8			50.0	20.0	70.0		HW	56	340	92
103	1.2	28.8			58.0	12.0	70.0		HW	2		3
104	1.2	23.8			55.0	20.0	75.0		HW	4	7	9
113	1.8	23.2			63.0	12.0	75.0		HW	42	187	91
115	1.8	23.2			55.0	20.0	75.0		HW	3	1	8
116	1.5	28.5			58.0	12.0	70.0		HW	64	781	125
117	1.5	28.5			50.0	20.0	70.0		HW	63	204	113
118	1.4	28.6			50.0	20.0	70.0		HW	66	561	110
119	1.4	28.6			50.0	20.0	70.0		HW	46	139	86
120	2.4	35.6			50.0	12.0	62.0		HW	15	50	158
147	1.2	18.8			68.0	12.0	80.0		F	1	0.3	2
148	1.4	18.6			68.0	12.0	80.0		HW	est.40	100	87
150	1.4	18.6			68.0	12.0	80.0		F	1		
151	1.4	18.6			68.0	12.0	80.0		F	1		
153	1.4	28.5			58.1	12.0	70.1		F			
154	1.5	28.5			58.0	12.0	70.0		F			
2b: BENZENE-N2O-N2-H2O-MERCURY-NITROSOBENZENE												
149	1.36	18.5	0.14**		68.0	12.0	80.0	Hg***	F	1		
152	1.36	28.5	0.14**		58.0	12.0	70.0	Hg***	F	1		6

*HW = hot wire; F = fused at 3410 deg. C.

** Nitrosobenzene, weighed in; calc. as vapor

***Hg = liquid mercury present

TABLE 3: WET N2O-CO2 SYSTEM
FLAMMABILITY OF SRP'S DWPF PRECIPITATE HYDROLYSIS PROCESS VAPORS
1750 cc Vessel - Agitator - 2.5" 10 mil Tungsten Hot Wire Ignitor
Water by volumetric liquid injection - All other gases by partial pressure
T = 100 Deg. C., P = 1 Atm.
ESD/ETC, EXPLOSION HAZARDS LAB JEJ/LCN/JMC 8-30-88

RUN	BENZ-ENE	N2O	NO2	NO	N2	H2O	N2+H2O	MISC	HW or F*	delta Pmax PSIG	dP/dt max psi/sec	delta Tvapor deg.C
3a: BENZENE-N2O-CO2-H2O								CO2				
143	1.8	23.2				12.0	12.0	63.0	F	1		4
144	2.0	23.0				12.0	12.0	63.0	F			2
145	2.3	27.7				12.0	12.0	58.0	HW	3	3	8
146	2.5	27.5				12.0	12.0	58.0	HW	5	6	17

*HW = hot wire; F = fused at 3410 deg. C.

TABLE 4: MIXED NOx SYSTEMS
FLAMMABILITY OF SRP'S DWPF PRECIPITATE HYDROLYSIS PROCESS VAPORS
1750 cc Vessel - Agitator - 2.5" 10 mil Tungsten Hot Wire Ignitor
Water by volumetric liquid injection - All other gases by partial pressure
T = 100 Deg. C., P = 1 Atm.
ESD/ETC, EXPLOSION HAZARDS LAB JEJ/LCN/JMC 8-30-88

RUN	BENZ-ENE	N2O	NO2	NO	N2	H2O	N2+H2O	MISC	HW or F*	delta Pmax PSIG	dP/dt max psi/sec	delta Tvapor deg.C
4a: BENZENE-N2O-NO2-NO												
22	9.0	43.3	43.3	4.6			0.0		HW	173	9111	240
23	7.6	65.8	21.9	4.6			0.0		HW	143	8333	216
24	10.3	21.3	64.0	4.5			0.0		HW	153	8929	236
25	6.2	89.1	0.0	4.7			0.0		HW	79	7692	195
26	11.5	0.0	84.1	4.4			0.0		HW	160	8636	335
4b: BENZENE-N2O-NO2-NO-N2												
31	4.5	21.6	21.6	2.3	50.0		50.0		HW	103	12500	196
32	4.0	19.5	19.5	2.0	55.0		55.0		HW	78	750	221
33	1.8	8.7	8.7	0.9	80.0		80.0		HW	0	0	8
34	2.7	13.0	13.0	1.4	70.0		70.0		F	46	1471	129
35	2.2	10.8	10.8	1.1	75.0		75.0		HW	61	4167	183
36	1.8	8.7	8.6	0.9	80.0		80.0		HW	58	1567	218
37	0.5	2.2	2.1	0.2	95.0		95.0		F			2
38	0.9	4.3	4.3	0.5	90.0		90.0		F			5
39	1.3	6.5	6.5	0.7	85.0		85.0		F			5
63	1.2	17.8	0.2	0.7	80.0		80.0		F			2
64	1.9	26.7	0.3	1.1	70.0		70.0		F			1
65	2.5	35.6	0.4	1.5	60.0		60.0		HW	15	240	110
68	2.7	38.3	0.4	1.6	57.0		57.0		HW	24	431	141
4c: BENZENE-N2O-NO2-NO-N2-H2O												
76	1.6	34.6	0.4	1.5	50.0	12.0	62.0		HW	24	176	157
77	1.3	30.1	0.3	1.3	55.0	12.0	67.0		HW	20	147	147
78	0.9	21.0	0.2	0.9	65.0	12.0	77.0		F	0.2		5
79	1.1	25.5	0.3	1.1	60.0	12.0	72.0		HW	18	128	133

*HW = hot wire; F = fused at 3410 deg. C.

TABLE 5: N2O-HALON SYSTEMS
FLAMMABILITY OF SRP'S DWPF PRECIPITATE HYDROLYSIS PROCESS VAPORS
1750 cc Vessel - Agitator - 2.5" 10 mil Tungsten Hot Wire Ignitor
Water by volumetric liquid injection - All other gases by partial pressure
T = 100 Deg. C., P = 1 Atm.
ESD/ETC, EXPLOSION HAZARDS LAB JEJ/LCN/JMC 8-30-88

RUN	BENZ-ENE	N2O	NO2	NO	N2	H2O	N2+H2O	MISC	HW or F*	delta Pmax PSIG	dP/dt max psi/sec	delta Tvapor deg.C
5a: BENZENE-N2O-HALON												
								HALON				
8	9.8	89.4					0.0	0.8	HW	297	61437	142
9	6.3	89.8					0.0	5.0	HW	304	62258	271
10	6.3	73.2					0.0	20.5	F	0		2
11	6.3	81.3					0.0	12.4	F	0		3
12	5.6	85.4					0.0	9.0	HW	174		186
13	5.7	83.3					0.0	11.0	HW	186	13636	211
14	5.8	82.4					0.0	11.8	HW	190	23077	203
15	6.5	80.8					0.0	12.7	HW	178	20930	286
16	5.1	78.7					0.0	16.2	HW	147	14516	220
17	5.1	75.8					0.0	18.6	F	0		5
18	5.0	77.6					0.0	17.4	F	0		8
19	10.2	71.2					0.0	18.6	F	0		4
20	5.1	78.0					0.0	16.9	F	0		4
21	6.3	76.1					0.0	17.6	F	0		3
5b: BENZENE-N2O-N2-HALON-H2O												
								HALON				
108	3.4	50.6			25.0	12.0	37.0	9.0	HW	25	500	160
109	3.1	46.9			25.0	12.0	37.0	13.0	HW	116	6849	154
110	2.9	43.1			25.0	12.0	37.0	17.0	HW	76	1493	102
111	2.6	39.4			25.0	12.0	37.0	21.0	F	-	-	4
112	2.8	41.3			25.0	12.0	37.0	19.0	HW	84	1000	125
5c: BENZENE-N2O-NO2-NO-HALON												
								HALON				
27	7.2	34.6	34.6	3.6			0.0	20.0	F	0		7
28	7.6	36.8	36.8	3.9			0.0	15.0	F	0		15
29	8.1	38.9	38.9	4.1			0.0	10.0	HW	139	7353	194
30	7.6	36.8	36.8	3.9			0.0	15.0	F	0		18
5d: BENZENE-N2O-NO2-NO-HALON-H2O												
								HALON				
83	3.0	67.4	0.7	2.8		12.0	12.0	14.0	HW	37	513	243
84	2.9	65.6	0.7	2.8		12.0	12.0	16.0	HW	365	294	241
85	4.3	60.5	0.6	2.6		12.0	12.0	20.0	HW	19	192	168
5e: BENZENE-N2O-NO2-NO-N2-HALON-H2O												
								HALON				
88	1.8	24.9	0.3	1.1	50.0	12.0	62.0	10.0	F			3
92	2.2	31.2	0.3	1.3	50.0	12.0	62.0	3.0	HW	10	64	106
93	2.2	30.3	0.3	1.3	50.0	12.0	62.0	4.0	HW	9	54	104
94	2.0	27.6	0.3	1.2	50.0	12.0	62.0	7.0	F			2

*HW = hot wire; F = fused at 3410 deg. C.

TABLE 6: WET N2O/O2-CO2 SYSTEM
FLAMMABILITY OF SRP'S DWPF PRECIPITATE HYDROLYSIS PROCESS VAPORS
1750 cc Vessel - Agitator - 2.5" 10 mil Tungsten Hot Wire Ignitor
All components by partial pressure
T = 100 Deg. C., P = 1 Atm.
ESD/ETC, EXPLOSION HAZARDS LAB JEJ/LCN/EBM 8-30-88

RUN	BENZ	N2O	O2	N2O+ O2	N2	H2O	CO2	N2+ H2O+ CO2	HW or F	delta Pmax PSIG	dP/dt max psi/sec	delta Tvapor deg.C
6a: BENZENE-N2O-O2-N2-H2O-CO2: H2O = 1.5%												
1	3.0	29.0	2.0	31.0	7.5	1.5	57.0	66.0	HW	49	224	114
2	2.8	27.2	2.0	29.2	7.5	1.5	59.0	68.0	HW	54	483	103
3	2.8	25.2	2.0	27.2	7.5	1.5	61.0	70.0	F	2		7
4	2.8	26.2	2.0	28.2	7.5	1.5	60.0	69.0	F	11	12	61
5	2.7	25.8	2.0	27.8	7.5	1.5	60.5	69.5	F	2.4		11
6	2.6	25.8	2.0	27.8	7.5	1.5	60.6	69.6	F	11	12	61
7	2.6	26.4	2.0	28.4	7.5	1.5	60.0	69.0	HW	33	50	135
8	2.8	25.7	2.0	27.7	7.5	1.5	60.5	69.5	F	1.2		3
9	2.5	25.6	2.1	27.7	7.8	1.5	60.5	69.8	F	3		12
10	2.5	26.0	2.0	28.0	7.5	1.5	60.5	69.5	HW	33	53	146
11	2.5	25.5	2.0	27.5	7.5	1.5	61.0	70.0	F	2		8
32	1.6	26.4	2.0	28.4	7.5	1.5	61.0	70.0	F	1.6		7
33	2.2	25.8	2.0	27.8	7.5	1.5	61.0	70.0	HW	27	31	109
34	2.2	23.8	2.0	25.8	7.5	1.5	63.0	72.0	F	1.5		5
35	2.2	24.8	2.0	26.8	7.5	1.5	62.0	71.0	F	4		20
36	1.6	25.4	2.0	27.4	7.5	1.5	62.0	71.0	F	1.1		4
37	1.4	25.6	2.0	27.6	7.5	1.5	62.0	71.0	F	2		9
38	1.8	25.7	2.0	27.7	7.5	1.5	61.5	70.5	F	3.2		19
39	1.6	25.9	2.0	27.9	7.5	1.5	61.5	70.5	F	2.9		13
40	1.8	26.2	2.0	28.2	7.5	1.5	61.0	70.0	F	5.5		30
41	1.6	26.4	2.0	28.4	7.5	1.5	61.0	70.0	F	3.6		24
6b: BENZENE-N2O-O2-N2-H2O-CO2: H2O = 22%												
12	2.8	27.2	2.0	29.2	7.5	22.0	38.5	68.0	F	3		13
13	2.8	29.2	2.0	31.2	7.5	22.0	36.5	66.0	HW	51	225	106
14	2.0	28.0	2.0	30.0	7.5	22.0	38.5	68.0	HW	39	137	105
15	2.7	26.3	2.0	28.3	7.5	22.0	39.5	69.0	HW	33	50	100
16	2.2	26.8	2.0	28.8	7.5	22.0	39.5	69.0	HW	45	180	105
17	2.4	25.6	2.0	27.6	7.5	22.0	40.5	70.0	HW	38	100	114
18	2.3	24.7	2.0	26.7	7.5	22.0	41.5	71.0	F	4.5		23
19	2.1	24.9	2.0	26.9	7.5	22.0	41.5	71.0	HW	36	89	124
20	2.1	24.9	2.0	26.9	7.5	22.0	41.5	71.0	HW	36	89	121
21	2.2	23.8	2.0	25.8	7.5	22.0	42.5	72.0	F	3.4		18
22	2.0	24.0	2.0	26.0	7.5	22.0	42.5	72.0	F	2		8
23	2.3	25.2	2.0	27.2	7.5	22.0	41.0	70.5	F	2		8
24	1.8	24.2	2.0	26.2	7.5	22.0	42.5	72.0	F	13		72
25	1.8	23.7	2.0	25.7	7.5	22.0	43.0	72.5	F	2.5		10
26	1.6	24.4	2.0	26.4	7.5	22.0	42.5	72.0	HW	27	37	110
27	1.6	23.9	2.0	25.9	7.5	22.0	43.0	72.5	HW	30	43	111
28	1.6	22.9	2.0	24.9	7.5	22.0	44.0	73.5	F	2		8
29	1.6	23.4	2.0	25.4	7.5	22.0	43.5	73.0	F	2.7		13
30	1.4	23.6	2.0	25.6	7.5	22.0	43.5	73.0	F	2.4		10
31	2.0	23.0	2.0	25.0	7.5	22.0	43.5	73.0	F	1.5		7

*HW = hot wire; F = fused at 3410 deg. C.

TABLE 7: MISC. SYSTEMS
FLAMMABILITY OF SRP'S DWPF PRECIPITATE HYDROLYSIS PROCESS VAPORS
1750 cc Vessel - Agitator - 2.5" 10 mil Tungsten Hot Wire Ignitor
All components by partial pressure
T = 100 Deg. C., P = 1 Atm.
ESD/ETC, EXPLOSION HAZARDS LAB JEJ/LCN/EBM 3-31-89

RUN	BENZ	N2O	O2	N2	H2O	CO2	N2+ H2O+ CO2	HW or F	delta Pmax PSIG	dP/dt max psi/sec	delta Tvapor deg.C
7a:	BENZENE-N2O-N2 (Supercedes Table 1b)										
4	1.6	23.4		75			75.0	HW	47	289	107
5	1.7	23.3		75			75.0	HW	50	190	105
7	3.2	23.3		74			73.5	F	1.5		
8	1.3	18.7		80			80.0	F	1		6
9	1.8	23.2		75			75.0	HW	48	186	110
10	1.6	18.4		80			80.0	HW	1		5
11	1.4	18.6		80			80.0	F	1.3		8
12	1.5	18.5		80			80.0	F	1.4		6
13	1.6	23.4		75			75.0	HW	43	192	103
14	1.9	23.1		75			75.0	HW	50	222	105
15	1.4	18.6		80			80.0	F	0.7		3
35	1.5	21.0		77.5			77.5	HW	7	11	37
39	1.5	19.7		78.8			78.8	F	1.2		5
40	1.6	19.6		78.8			78.8	F	1.3		5
42	1.7	19.5		78.8			78.8	F	1.5		5
7b:	BENZENE-N2O-N2-H2O (Supercedes Table 2a)										
1	1.3	28.7		58	12		70.0	F*	0.5		3
2	1.5	28.5		58	12		70.0	HW	60	588	106
3	1.7	28.3		58	12		70.0	HW	64	746	112
6	1.3	28.7		58	12		70.0	HW	63	556	123
16	1.6	23.4		63	12		75.0	F	2		7
17	1.8	23.2		63	12		75.0	F	1.8		7
18	1.7	23.3		63	12		75.0	F	2		10
19	1.9	23.1		63	12		75.0	F	2		9
20	1.4	18.6		68	12		80.0	F	2		4
21	1.3	18.7		68	12		80.0	F	1.4		5
22	1.5	18.5		68	12		80.0	F	1.2		4
23	1.6	18.4		68	12		80.0	F	1.4		4
36	1.5	21.0		76.0	1.5		77.5	F	1.3		4
43	1.5	19.7		77.3	1.5		78.8	F	1.4		5
44	1.6	19.6		77.3	1.5		78.8	F	1.4		5
45	1.7	19.5		77.3	1.5		78.8	F	1.7		6
89	1.6	22.0		74.9	1.5		76.4	HW	31	52	84
7c:	BENZENE-N2O-O2-N2-H2O										
24	1.6	17.4	1.0	78.5	1.5		80.0	F	1.2		4
25	1.7	22.3	1.0	73.5	1.5		75.0	HW	61	549	92
26	1.4	16.6	2.0	78.5	1.5		80.0	F	1.2		3
27	1.5	19.0	2.0	76.0	1.5		77.5	F	32	68	126
28	1.5	17.7	2.0	77.3	1.5		78.8	F	2.4		11
29	1.5	20.5	0.5	76.0	1.5		77.5	F	2		10
30	1.5	19.0	2.0	75.3	1.5	0.7	77.5	HW	42	170	104
31	1.5	19.0	2.0	75.3	1.5	0.7	77.5	HW	38	124	107
32	1.5	19.5	2.0	74.8	1.5	0.7	77.0	HW	40	135	96
33	1.5	18.0	2.0	76.3	1.5	0.7	78.5	HW	6		32
34	1.5	17.0	2.0	77.3	1.5	0.7	79.5	F	2.2		13

TABLE 7: MISC. SYSTEMS (continued)

7c: BENZENE-N2O-O2-N2-H2O (Continued)

37	1.5	20.0	1.0	76.0	1.5		77.5	HW	37	74	122
38	1.5	19.5	1.5	76.0	1.5	See41		F	2.5	LngMix	4
41	1.5	19.5	1.5	76.0	1.5		77.5	HW	34	88	111
46	1.5	18.7	1.0	77.3	1.5		78.8	F	1.7		8
47	1.6	18.6	1.0	77.3	1.5		78.8	F	1.6		6
48	1.7	18.5	1.0	77.3	1.5		78.8	F	1.7		7
49	1.5	18.5	1.5	77.0	1.5		78.5	F	2.4		11
50	1.8	18.6	1.5	76.6	1.5		78.1	F	2.2		11
51	1.6	18.1	2.0	76.8	1.5		78.3	HW	23	26	76
52	1.6	18.7	1.5	76.7	1.5		78.2	HW	29	52	86
53	1.8	18.0	2.0	76.7	1.5		78.2	F	1.8		7
54	1.6	19.2	1.0	76.6	1.6		78.2	F	1.7		9
55	1.7	19.1	1.0	76.7	1.5		78.2	F	2.0		12
56	1.7	18.6	1.5	76.7	1.5		78.2	F	3.9		16
85	1.5	16.4	3.0	77.6	1.5		79.1	HW	54	281	85
86	1.5	12.8	5.0	79.2	1.5		80.7	HW	22		77
87	1.5	15.9	3.0	78.1	1.5		79.6	F	3.5		17
88	1.5	12.3	5.0	79.7	1.5		81.2	F	2.8		16
57	1.6	18.2	2.0	76.0	1.5	0.7	78.2	HW	29	47	95
58	1.7	18.1	2.0	76.0	1.5	0.7	78.2	HW	32	53	102
59	1.6	17.6	2.0	76.6	1.5	0.7	78.8	F	3		15
60	1.7	17.5	2.0	76.6	1.5	0.7	78.8	F	3		16
61	1.6	20.4	0.5	75.8	1.5	0.18	77.5	F	2.5		12
62	1.7	20.3	0.5	75.8	1.5	0.18	77.5	F	2.3		14
63	1.6	18.1	2.0	74.6	3	0.7	78.3	F	4.4		22
64	1.6	18.1	2.0	65.6	12	0.7	78.3	F	1.5		5
65	1.6	20.1	2.0	55.6	20	0.7	76.3	F	0.6		2
66	1.5	19.5	2.0	74.8	1.5	0.7	77.0	F*	36	103	103
67	1.5	18.8	2.0	75.5	1.5	0.7	77.7	F*	39	136	104
70	1.9	21.1	2.0	52.3	22	0.7	75.0	F	1.0		3
71	1.7	21.3	2.0	52.3	22	0.7	75.0	F	1.5		8
72	1.9	20.1	2.0	53.3	22	0.7	76.0	F	1.3		5
73	1.7	23.6	2.0	50.0	22	0.7	72.7	HW	35	106	89
74	2.2	21.8	2.0	51.3	22	0.7	74.0	HW	48	303	81
75	2.1	21.4	2.0	51.8	22	0.7	74.5	HW	52	282	95
76	2.0	21.0	2.0	52.3	22	0.7	75.0	HW	33	97	93
77	2.0	20.5	2.0	52.8	22	0.7	75.5	HW	47	213	88
78	2.0	20.3	2.0	53.0	22	0.7	75.7	HW	47	200	86
79	1.9	21.1	2.0	52.3	22	0.7	75.0	HW	48	246	82
80	2.0	19.0	2.0	54.3	22	0.7	77.0	F	3		17
81	2.0	20.0	2.0	53.3	22	0.7	76.0	HW	37	106	95
82	1.9	20.1	2.0	53.3	22	0.7	76.0	HW	40	120	93
83	1.8	19.7	2.0	53.8	22	0.7	76.5	HW	31	62	82
84	1.9	19.6	2.0	53.8	22	0.7	76.5	HW	38	117	94
90	1.4	17.8	2.0	76.6	1.5	0.7	78.8	F	2.5		10
91	1.2	18.0	2.0	76.6	1.5	0.7	78.8	F	1.4		5
92	1.6	16.4	2.0	57.3	22	0.7	80.0	F	1.7		9
93	1.2	16.8	2.0	57.3	22	0.7	80.0	F	1.0		4
94	1.6	17.9	2.0	55.8	22	0.7	78.5	F	1.8		5
95	1.2	18.3	2.0	55.8	22	0.7	78.5	F	1.0		4

7d: BENZENE-N2O-O2-H2O

68	1.6	75.7	2.0		20	0.7	20.7	HW	94	1833	133
69	1.6	75.7	2.0		20	0.7	20.7	HW	125	3255	153

*Nichrome; see Run 6

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APPENDIX II

Database* Analysis of Flammability Testing Data

Units in all following tables are:

Values	Units
Composition	vol %
Pressure	psig
dP/dt	psi/sec
Temperature	°C

*** Microsoft® File**

Table 1 - Benzene/Actual gas mix/N2/H2O

Run #	Benz	N2O	O2	NO2	NO	Ttl Oxdnt	Eqvlnt N2O	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
A063	1.2	17.8		0.2	0.7	18.7	18.9	80.0			F	0.0		2	
A078	0.9	21.0		0.2	0.9	22.1	22.3	65.0		12.0	F	0.2		5	
A079	1.1	25.5		0.3	1.1	26.9	27.1	60.0		12.0	HW	18.0	128	133	
A064	1.9	26.7		0.3	1.1	28.1	28.3	70.0			F	0.0		1	
A077	1.3	30.1		0.3	1.3	31.7	31.9	55.0		12.0	HW	20.0	147	147	
A076	1.6	34.6		0.4	1.5	36.5	36.8	50.0		12.0	HW	24.0	176	157	
A065	2.5	35.6		0.4	1.5	37.5	37.7	60.0			HW	15.0	240	110	
A068	2.7	38.3		0.4	1.6	40.3	40.5	57.0			HW	24.0	431	141	

Run #	Benz	N2O	O2	NO2	NO	Ttl Oxdnt	Eqvlnt N2O	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
C015	1.4	18.6				18.6	18.6	80.0			F	0.7		3	
C010	1.6	18.4				18.4	18.4	80.0			HW	1.0		5	
C008	1.3	18.7				18.7	18.7	80.0			F	1.0		6	
C039	1.5	19.7				19.7	19.7	78.8			F	1.2		5	
C011	1.4	18.6				18.6	18.6	80.0			F	1.3		8	
C040	1.6	19.6				19.6	19.6	78.8			F	1.3		5	
C012	1.5	18.5				18.5	18.5	80.0			F	1.4		6	
C042	1.7	19.5				19.5	19.5	78.8			F	1.5		5	
C007	3.2	23.3				23.3	23.3	74.0			F	1.5			Above UFL
C035	1.5	21.0				21.0	21.0	77.5			HW	7.0	11	37	
C013	1.6	23.4				23.4	23.4	75.0			HW	43.0	192	103	
C004	1.6	23.4				23.4	23.4	75.0			HW	47.0	289	107	
C009	1.8	23.2				23.2	23.2	75.0			HW	48.0	186	110	
C014	1.9	23.1				23.1	23.1	75.0			HW	50.0	222	105	
C005	1.7	23.3				23.3	23.3	75.0			HW	50.0	190	105	

Appendix II Table 3 - Benzene/N2O/N2 with 1.5% H2O - sorted by O2 concentration DPST-89-348

Run #	Benz	N2O	O2	NO2	NO	Ttl Oxdnt	Eqvlnt N2O	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
C036	1.5	21.0				21.0	21.0	76.0		1.5	F	1.3		4	
C044	1.6	19.6				19.6	19.6	77.3		1.5	F	1.4		5	
C043	1.5	19.7				19.7	19.7	77.3		1.5	F	1.4		5	
C045	1.7	19.5				19.5	19.5	77.3		1.5	F	1.7		6	
C089	1.6	22.0				22.0	22.0	74.9		1.5	HW	31.0	52	84	
C029	1.5	20.5	0.5			21.0	21.4	76.0		1.5	F	2.0		10	
C062	1.7	20.3	0.5			20.8	21.2	75.8	0.2	1.5	F	2.3		14	
C061	1.6	20.4	0.5			20.9	21.3	75.8	0.2	1.5	F	2.5		12	
C024	1.6	17.4	1.0			18.4	19.2	78.5		1.5	F	1.2		4	
C047	1.6	18.6	1.0			19.6	20.4	77.3		1.5	F	1.6		6	
C048	1.7	18.5	1.0			19.5	20.3	77.3		1.5	F	1.7		7	
C046	1.5	18.7	1.0			19.7	20.5	77.3		1.5	F	1.7		8	
C055	1.7	19.1	1.0			20.1	20.9	76.7		1.5	F	2.0		12	
C037	1.5	20.0	1.0			21.0	21.8	76.0		1.5	HW	37.0	74	122	
C025	1.7	22.3	1.0			23.3	24.1	73.5		1.5	HW	61.0	549	92	
C050	1.8	18.6	1.5			20.1	21.3	76.6		1.5	F	2.2		11	
C049	1.5	18.5	1.5			20.0	21.2	77.0		1.5	F	2.4		11	
C056	1.7	18.6	1.5			20.1	21.3	76.7		1.5	F	3.9		16	
C052	1.6	18.7	1.5			20.2	21.4	76.7		1.5	HW	29.0	52	86	
C041	1.5	19.5	1.5			21.0	22.2	76.0		1.5	HW	34.0	88	111	
C026	1.4	16.6	2.0			18.6	20.2	78.5		1.5	F	1.2		3	
C091	1.2	18.0	2.0			20.0	21.6	76.6	0.7	1.5	F	1.4		5	
C053	1.8	18.0	2.0			20.0	21.6	76.7		1.5	F	1.8		7	
C034	1.5	17.0	2.0			19.0	20.6	77.3	0.7	1.5	F	2.2		13	
C028	1.5	17.7	2.0			19.7	21.3	77.3		1.5	F	2.4		11	
C090	1.4	17.8	2.0			19.8	21.4	76.6	0.7	1.5	F	2.5		10	
C060	1.7	17.5	2.0			19.5	21.1	76.6	0.7	1.5	F	3.0		16	
C059	1.6	17.6	2.0			19.6	21.2	76.6	0.7	1.5	F	3.0		15	

Appendix II Table 3 - Benzene/N2O/N2 with 1.5% H2O - sorted by O2 concentration DPST-89-348

Run #	Benz	N2O	O2	NO2	NO	Ttl Oxdnt	Eqvlnt	N2O	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
C033	1.5	18.0	2.0			20.0		21.6	76.3	0.7	1.5	HW	6.0		32	
C051	1.6	18.1	2.0			20.1		21.7	76.8		1.5	HW	23.0	26	76	
C057	1.6	18.2	2.0			20.2		21.8	76.0	0.7	1.5	HW	29.0	47	95	
C058	1.7	18.1	2.0			20.1		21.7	76.0	0.7	1.5	HW	32.0	53	102	
C027	1.5	19.0	2.0			21.0		22.5	76.0		1.5	F	32.0	68	126	
C066	1.5	19.5	2.0			21.5		23.0	74.8	0.7	1.5	F	36.0	103	103	Nichrome wire
C031	1.5	19.0	2.0			21.0		22.5	75.3	0.7	1.5	HW	38.0	124	107	
C067	1.5	18.8	2.0			20.8		22.4	75.5	0.7	1.5	F	39.0	136	104	Nichrome wire
C032	1.5	19.5	2.0			21.5		23.0	74.8	0.7	1.5	HW	40.0	135	96	
C030	1.5	19.0	2.0			21.0		22.5	75.3	0.7	1.5	HW	42.0	170	104	
C087	1.5	15.9	3.0			18.9		21.3	78.1		1.5	F	3.5		17	
C085	1.5	16.4	3.0			19.4		21.7	77.6		1.5	HW	54.0	281	85	
C088	1.5	12.3	5.0			17.3		21.2	79.7		1.5	F	2.8		16	
C086	1.5	12.8	5.0			17.8		21.7	79.2		1.5	HW	22.0		77	

Appendix II Table 4 - Benzene/N2O/N2 with 1.5% H2O - sorted by equivalent N2O DPST-89-348

Run #	Benz	N2O	O2	NO2	NO	Ttl Oxdnt	Eqvlnt N2O	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
C024	1.6	17.4	1.0			18.4	19.2	78.5		1.5	F	1.2		4	
C045	1.7	19.5				19.5	19.5	77.3		1.5	F	1.7		6	
C044	1.6	19.6				19.6	19.6	77.3		1.5	F	1.4		5	
C043	1.5	19.7				19.7	19.7	77.3		1.5	F	1.4		5	
C026	1.4	16.6	2.0			18.6	20.2	78.5		1.5	F	1.2		3	
C048	1.7	18.5	1.0			19.5	20.3	77.3		1.5	F	1.7		7	
C047	1.6	18.6	1.0			19.6	20.4	77.3		1.5	F	1.6		6	
C046	1.5	18.7	1.0			19.7	20.5	77.3		1.5	F	1.7		8	
C034	1.5	17.0	2.0			19.0	20.6	77.3	0.7	1.5	F	2.2		13	
C055	1.7	19.1	1.0			20.1	20.9	76.7		1.5	F	2.0		12	
C036	1.5	21.0				21.0	21.0	76.0		1.5	F	1.3		4	
C060	1.7	17.5	2.0			19.5	21.1	76.6	0.7	1.5	F	3.0		16	
C059	1.6	17.6	2.0			19.6	21.2	76.6	0.7	1.5	F	3.0		15	
C049	1.5	18.5	1.5			20.0	21.2	77.0		1.5	F	2.4		11	
C062	1.7	20.3	0.5			20.8	21.2	75.8	0.2	1.5	F	2.3		14	
C088	1.5	12.3	5.0			17.3	21.2	79.7		1.5	F	2.8		16	
C087	1.5	15.9	3.0			18.9	21.3	78.1		1.5	F	3.5		17	
C028	1.5	17.7	2.0			19.7	21.3	77.3		1.5	F	2.4		11	
C050	1.8	18.6	1.5			20.1	21.3	76.6		1.5	F	2.2		11	
C056	1.7	18.6	1.5			20.1	21.3	76.7		1.5	F	3.9		16	
C061	1.6	20.4	0.5			20.9	21.3	75.8	0.2	1.5	F	2.5		12	
C090	1.4	17.8	2.0			19.8	21.4	76.6	0.7	1.5	F	2.5		10	
C052	1.6	18.7	1.5			20.2	21.4	76.7		1.5	HW	29.0	52	86	
C029	1.5	20.5	0.5			21.0	21.4	76.0		1.5	F	2.0		10	
C091	1.2	18.0	2.0			20.0	21.6	76.6	0.7	1.5	F	1.4		5	
C053	1.8	18.0	2.0			20.0	21.6	76.7		1.5	F	1.8		7	
C033	1.5	18.0	2.0			20.0	21.6	76.3	0.7	1.5	HW	6.0		32	
C051	1.6	18.1	2.0			20.1	21.7	76.8		1.5	HW	23.0	26	76	

Appendix II Table 4 - Benzene/N2O/N2 with 1.5% H2O - sorted by equivalent N2O DPST-89-348

Run #	Benz	N2O	O2	NO2	NO	Ttl Oxdnt	Eqvlnt N2O	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
C058	1.7	18.1	2.0			20.1	21.7	76.0	0.7	1.5	HW	32.0	53	102	
C086	1.5	12.8	5.0			17.8	21.7	79.2		1.5	HW	22.0		77	
C085	1.5	16.4	3.0			19.4	21.7	77.6		1.5	HW	54.0	281	85	
C057	1.6	18.2	2.0			20.2	21.8	76.0	0.7	1.5	HW	29.0	47	95	
C037	1.5	20.0	1.0			21.0	21.8	76.0		1.5	HW	37.0	74	122	
C089	1.6	22.0				22.0	22.0	74.9		1.5	HW	31.0	52	84	
C041	1.5	19.5	1.5			21.0	22.2	76.0		1.5	HW	34.0	88	111	
C067	1.5	18.8	2.0			20.8	22.4	75.5	0.7	1.5	F	39.0	136	104	Nichrome wire
C027	1.5	19.0	2.0			21.0	22.5	76.0		1.5	F	32.0	68	126	
C031	1.5	19.0	2.0			21.0	22.5	75.3	0.7	1.5	HW	38.0	124	107	
C030	1.5	19.0	2.0			21.0	22.5	75.3	0.7	1.5	HW	42.0	170	104	
C066	1.5	19.5	2.0			21.5	23.0	74.8	0.7	1.5	F	36.0	103	103	Nichrome wire
C032	1.5	19.5	2.0			21.5	23.0	74.8	0.7	1.5	HW	40.0	135	96	
C025	1.7	22.3	1.0			23.3	24.1	73.5		1.5	HW	61.0	549	92	

Run #	Benz	N2O	O2	NO2	NO	Ttl Oxdnt	Eqvlnt N2O	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
C022	1.5	18.5				18.5	18.5	68.0		12.0	F	1.2		4	
C023	1.6	18.4				18.4	18.4	68.0		12.0	F	1.4		4	
C021	1.3	18.7				18.7	18.7	68.0		12.0	F	1.4		5	
C064	1.6	18.1	2.0			20.1	21.7	65.6	0.7	12.0	F	1.5		5	
C017	1.8	23.2				23.2	23.2	63.0		12.0	F	1.8		7	
C020	1.4	18.6				18.6	18.6	68.0		12.0	F	2.0		4	
C019	1.9	23.1				23.1	23.1	63.0		12.0	F	2.0		9	
C018	1.7	23.3				23.3	23.3	63.0		12.0	F	2.0		10	
C016	1.6	23.4				23.4	23.4	63.0		12.0	F	2.0		7	
C002	1.5	28.5				28.5	28.5	58.0		12.0	HW	60.0	588	106	
C006	1.3	28.7				28.7	28.7	58.0		12.0	HW	63.0	556	123	
C003	1.7	28.3				28.3	28.3	58.0		12.0	HW	64.0	746	112	

Table 6 - Benzene/N2O/N2 with 20 to 22% H2O

Run #	Benz	N2O	O2	NO2	NO	Ttl Oxdnt	Eqvlnt	N2O	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
C065	1.6	20.1	2.0			22.1		23.6	55.6	0.7	20.0	F	0.6		2	
C093	1.2	16.8	2.0			18.8		20.4	57.3	0.7	22.0	F	1.0		4	
C095	1.2	18.3	2.0			20.3		21.9	55.8	0.7	22.0	F	1.0		4	
C070	1.9	21.1	2.0			23.1		24.6	52.3	0.7	22.0	F	1.0		3	
C072	1.9	20.1	2.0			22.1		23.6	53.3	0.7	22.0	F	1.3		5	
C071	1.7	21.3	2.0			23.3		24.8	52.3	0.7	22.0	F	1.5		8	
C092	1.6	16.4	2.0			18.4		20.0	57.3	0.7	22.0	F	1.7		9	
C094	1.6	17.9	2.0			19.9		21.5	55.8	0.7	22.0	F	1.8		5	
C080	2.0	19.0	2.0			21.0		22.5	54.3	0.7	22.0	F	3.0		17	
C083	1.8	19.7	2.0			21.7		23.2	53.8	0.7	22.0	HW	31.0	62	82	
C076	2.0	21.0	2.0			23.0		24.5	52.3	0.7	22.0	HW	33.0	97	93	
C073	1.7	23.6	2.0			25.6		27.1	50.0	0.7	22.0	HW	35.0	106	89	
C081	2.0	20.0	2.0			22.0		23.5	53.3	0.7	22.0	HW	37.0	106	95	
C084	1.9	19.6	2.0			21.6		23.1	53.8	0.7	22.0	HW	38.0	117	94	
C082	1.9	20.1	2.0			22.1		23.6	53.3	0.7	22.0	HW	40.0	120	93	
C078	2.0	20.3	2.0			22.3		23.8	53.0	0.7	22.0	HW	47.0	200	86	
C077	2.0	20.5	2.0			22.5		24.0	52.8	0.7	22.0	HW	47.0	213	88	
C079	1.9	21.1	2.0			23.1		24.6	52.3	0.7	22.0	HW	48.0	246	82	
C074	2.2	21.8	2.0			23.8		25.3	51.3	0.7	22.0	HW	48.0	303	81	
C075	2.1	21.4	2.0			23.4		24.9	51.8	0.7	22.0	HW	52.0	282	95	
C068	1.6	75.7	2.0			77.7		78.1		0.7	20.0	HW	94.0	1833	133	
C069	1.6	75.7	2.0			77.7		78.1		0.7	20.0	HW	125.0	3255	153	

Table 7 - Benzene/CO2/N2 with 1.5% H2O

Run #	Benz	N2O	O2	NO2	NO	Ttl Oxdnt	Eqvlnt	N2O	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
B036	1.6	25.4	2.0			27.4		28.8	7.5	62.0	1.5	F	1.1		4	
B008	2.8	25.7	2.0			27.7		29.1	7.5	60.5	1.5	F	1.2		3	
B034	2.2	23.8	2.0			25.8		27.3	7.5	63.0	1.5	F	1.5		5	
B032	1.6	26.4	2.0			28.4		29.8	7.5	61.0	1.5	F	1.6		7	
B003	2.8	25.2	2.0			27.2		28.6	7.5	61.0	1.5	F	2.0		7	
B011	2.5	25.5	2.0			27.5		28.9	7.5	61.0	1.5	F	2.0		8	
B037	1.4	25.6	2.0			27.6		29.0	7.5	62.0	1.5	F	2.0		9	
B005	2.7	25.8	2.0			27.8		29.2	7.5	60.5	1.5	F	2.4		11	
B039	1.6	25.9	2.0			27.9		29.3	7.5	61.5	1.5	F	2.9		13	
B009	2.5	25.6	2.1			27.7		29.2	7.8	60.5	1.5	F	3.0		12	
B038	1.8	25.7	2.0			27.7		29.1	7.5	61.5	1.5	F	3.2		19	
B041	1.6	26.4	2.0			28.4		29.8	7.5	61.0	1.5	F	3.6		24	
B035	2.2	24.8	2.0			26.8		28.2	7.5	62.0	1.5	F	4.0		20	
B040	1.8	26.2	2.0			28.2		29.6	7.5	61.0	1.5	F	5.5		30	
B006	2.6	25.8	2.0			27.8		29.2	7.5	60.6	1.5	F	11.0	12	61	
B004	2.8	26.2	2.0			28.2		29.6	7.5	60.0	1.5	F	11.0	12	61	
B033	2.2	25.8	2.0			27.8		29.2	7.5	61.0	1.5	HW	27.0	31	109	
B010	2.5	26.0	2.0			28.0		29.4	7.5	60.5	1.5	HW	33.0	53	146	
B007	2.6	26.4	2.0			28.4		29.8	7.5	60.0	1.5	HW	33.0	50	135	
B001	3.0	29.0	2.0			31.0		32.4	7.5	57.0	1.5	HW	49.0	224	114	
B002	2.8	27.2	2.0			29.2		30.6	7.5	59.0	1.5	HW	54.0	483	103	

Table 8 - Benzene/CO2/N2 with 22% H2O

Run #	Benz	N2O	O2	NO2	NO	Ttl Oxdnt	Eqvlnt N2O	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
B031	2.0	23.0	2.0			25.0	26.5	7.5	43.5	22.0	F	1.5		7	
B028	1.6	22.9	2.0			24.9	26.4	7.5	44.0	22.0	F	2.0		8	
B022	2.0	24.0	2.0			26.0	27.5	7.5	42.5	22.0	F	2.0		8	
B023	2.3	25.2	2.0			27.2	28.6	7.5	41.0	22.0	F	2.0		8	
B030	1.4	23.6	2.0			25.6	27.1	7.5	43.5	22.0	F	2.4		10	
B025	1.8	23.7	2.0			25.7	27.2	7.5	43.0	22.0	F	2.5		10	
B029	1.6	23.4	2.0			25.4	26.9	7.5	43.5	22.0	F	2.7		13	
B012	2.8	27.2	2.0			29.2	30.6	7.5	38.5	22.0	F	3.0		13	
B021	2.2	23.8	2.0			25.8	27.3	7.5	42.5	22.0	F	3.4		18	
B018	2.3	24.7	2.0			26.7	28.1	7.5	41.5	22.0	F	4.5		23	
B024	1.8	24.2	2.0			26.2	27.6	7.5	42.5	22.0	F	13.0		72	
B026	1.6	24.4	2.0			26.4	27.8	7.5	42.5	22.0	HW	27.0	37	110	
B027	1.6	23.9	2.0			25.9	27.4	7.5	43.0	22.0	HW	30.0	43	111	
B015	2.7	26.3	2.0			28.3	29.7	7.5	39.5	22.0	HW	33.0	50	100	
B020	2.1	24.9	2.0			26.9	28.3	7.5	41.5	22.0	HW	36.0	89	121	
B019	2.1	24.9	2.0			26.9	28.3	7.5	41.5	22.0	HW	36.0	89	124	
B017	2.4	25.6	2.0			27.6	29.0	7.5	40.5	22.0	HW	38.0	100	114	
B014	2.0	28.0	2.0			30.0	31.4	7.5	38.5	22.0	HW	39.0	137	105	
B016	2.2	26.8	2.0			28.8	30.2	7.5	39.5	22.0	HW	45.0	180	105	
B013	2.8	29.2	2.0			31.2	32.5	7.5	36.5	22.0	HW	51.0	225	106	

Run #	Benz	N2O	O2	NO2	NO	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
A006	5.0	57.5				37.5			HW	188.0	1,340	144	
A007	5.0	45.0				50.0			HW	180.0		157	ΔP estimated
A022	9.0	43.3		43.3	4.6				HW	173.0	9,111	240	
A023	7.6	65.8		21.9	4.6				HW	143.0	8,333	216	
A024	10.3	21.3		64.0	4.5				HW	153.0	8,929	236	
A025	6.2	89.1		0.0	4.7				HW	79.0	7,692	195	
A026	11.5	0.0		84.1	4.4				HW	160.0	8,636	335	
A031	4.5	21.6		21.6	2.3	50.0			HW	103.0	2,500	196	
A032	4.0	19.5		19.5	2.0	55.0			HW	78.0	750	221	
A033	1.8	8.7		8.7	0.9	80.0			HW	0.0	0	8	
A034	2.7	13.0		13.0	1.4	70.0			F	46.0	1,471	129	
A035	2.2	10.8		10.8	1.1	75.0			HW	61.0	4,167	183	
A036	1.8	8.7		8.6	0.9	80.0			HW	58.0	1,567	218	
A037	0.5	2.2		2.1	0.2	95.0			F	0.0		2	
A038	0.9	4.3		4.3	0.5	90.0			F	0.0		5	
A039	1.3	6.5		6.5	0.7	85.0			F	0.0		5	
A040	20.0	80.0							F	0.0		2	
A041	10.0	90.0							F	65.0	1,282	273	
A042	10.0	90.0							F	61.0	1,020	238	
A043	5.0	95.0							F	38.0	512	177	
A044	15.0	85.0							F	0.0		3	
A045	1.2	17.6				51.1		30.1	F	0.0		2	
A046	1.6	24.7				43.6		30.1	F	0.0		4	
A047	2.6	38.8				28.5		30.1	F	32.0	461	153	
A048	2.1	31.7				36.0		30.1	F	0.0		2	
A049	2.8	42.2				35.0		20.0	HW	35.0	4,332	175	
A050	2.2	32.8				45.0		20.0	HW	15.0	185	110	
A051	1.6	23.4				55.0		20.0	F	0.0		2	
A052	1.9	28.1				50.0		20.0	F	0.0		2	
A053	2.4	35.3				32.2		30.1	HW	27.0	294	141	
A054	1.6	23.4				65.0		10.0	F	0.0		2	
A055	1.9	28.1				60.0		10.0	F	0.0		2	
A056	2.2	32.8				55.0		10.0	HW	14.0	147	107	
A057	3.1	46.9				50.0			HW	33.0	467	192	
A058	2.8	42.2				55.0			HW	33.0		163	
A059	2.8	42.0				55.0			HW	21.0	1,020	124	
A060	2.8	42.0				55.0			HW	27.0	279	161	
A061	1.9	28.1				70.0			F	0.0		2	
A062	2.2	32.8				65.0			F	12.0	98	98	

Run #	Benz	N2O	O2	NO2	NO	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
A063	1.2	17.8		0.2	0.7	80.0			F	0.0		2	
A064	1.9	26.7		0.3	1.1	70.0			F	0.0		1	
A065	2.5	35.6		0.4	1.5	60.0			HW	15.0	240	110	
A066	2.3	27.9				70.0			F	0.0		2	
A067	1.6	28.4				70.0			F	0.0		2	
A068	2.7	38.3		0.4	1.6	57.0			HW	24.0	431	141	
A069	1.5	33.5				65.0			HW	24.0	175	142	
A070	1.2	18.8				80.0			HW	0.0		2	
A071	1.2	28.8				70.0			HW	30.0	93	82	
A072	0.3	29.7				70.0			F	0.0		2	
A073	0.8	19.2				80.0			F	0.1		4	
A074	0.8	29.3				70.0			F	0.4		7	
A075	1.0	24.0				75.0			F	0.2		5	
A076	1.6	34.6		0.4	1.5	50.0		12.0	HW	24.0	176	157	
A077	1.3	30.1		0.3	1.3	55.0		12.0	HW	20.0	147	147	
A078	0.9	21.0		0.2	0.9	65.0		12.0	F	0.2		5	
A079	1.1	25.5		0.3	1.1	60.0		12.0	HW	18.0	128	133	
A080	1.1	26.9				60.0		12.0	HW	18.0	137	133	
A081	0.9	22.1				65.0		12.0	HW	16.0	84	99	
A082	0.7	17.3				70.0		12.0	F	0.0		3	
A086	1.5	18.6				80.0			F	0.0	0	0	
A087	1.4	23.6				75.0			F	0.0			
A089	1.5	28.5				70.0			HW	17.0	96	127	
A090	1.5	23.5				75.0			F	0.0			
A091	1.3	23.8				75.0			F	0.0		3	
A095	2.2	32.8				65.0			F	0.0		3	
A098	1.4	33.6				53.0		12.0	HW	25.0	309	89	ΔP>25, dp/dt>309
A099	1.2	23.8				63.0		12.0	F	1.0		3	
A100	1.8	44.6				45.7		7.9	HW	50.0	2,406	148	ΔP>50
A101	1.4	33.6				45.0		20.0	HW	25.0	1,059	122	ΔP>25
A102	1.2	28.8				50.0		20.0	HW	56.0	340	92	
A103	1.2	28.8				58.0		12.0	HW	2.0		3	
A104	1.2	23.8				55.0		20.0	HW	4.0	7	9	
A105	1.2	33.8				65.0			HW	34.0	74	109	
A106	1.3	33.7				65.0			HW	38.0	100	109	
A107	1.4	33.6				65.0			HW	64.0	457	110	
A113	1.8	23.2				63.0		12.0	HW	42.0	187	91	
A114	1.8	23.2				75.0			HW	57.0	360	101	
A115	1.8	23.2				55.0		20.0	HW	3.0	1	8	

Run #	Benz	N2O	O2	NO2	NO	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
A116	1.5	28.5				58.0		12.0	HW	64.0	781	125	
A117	1.5	28.5				50.0		20.0	HW	63.0	204	113	
A118	1.4	28.6				50.0		20.0	HW	66.0	561	110	
A119	1.4	28.6				50.0		20.0	HW	46.0	139	86	
A120	2.4	35.6				50.0		12.0	HW	15.0	50	158	
A142	5.0	45.0				50.0			HW	156.0	7,123	141	
A143	1.8	23.2					63.0	12.0	F	1.0		4	
A144	2.0	23.0					63.0	12.0	F	0.0		2	
A145	2.3	27.7					58.0	12.0	HW	3.0	3	8	
A146	2.5	27.5					58.0	12.0	HW	5.0	6	17	
A147	1.2	18.8				68.0		12.0	F	1.0	0	2	
A148	1.4	18.6				68.0		12.0	HW	40.0	100	87	ΔP estimated
A150	1.4	18.6				68.0		12.0	F	1.0			
A151	1.4	18.6				68.0		12.0	F	1.0			
A153	1.4	28.5				58.1		12.0	F	0.0			
A154	1.5	28.5				58.0		12.0	F	0.0			
A155	5.0	45.0				50.0			HW	168.0	9,328	171	
B001	3.0	29.0	2.0			7.5	57.0	1.5	HW	49.0	224	114	
B002	2.8	27.2	2.0			7.5	59.0	1.5	HW	54.0	483	103	
B003	2.8	25.2	2.0			7.5	61.0	1.5	F	2.0		7	
B004	2.8	26.2	2.0			7.5	60.0	1.5	F	11.0	12	61	
B005	2.7	25.8	2.0			7.5	60.5	1.5	F	2.4		11	
B006	2.6	25.8	2.0			7.5	60.6	1.5	F	11.0	12	61	
B007	2.6	26.4	2.0			7.5	60.0	1.5	HW	33.0	50	135	
B008	2.8	25.7	2.0			7.5	60.5	1.5	F	1.2		3	
B009	2.5	25.6	2.1			7.8	60.5	1.5	F	3.0		12	
B010	2.5	26.0	2.0			7.5	60.5	1.5	HW	33.0	53	146	
B011	2.5	25.5	2.0			7.5	61.0	1.5	F	2.0		8	
B012	2.8	27.2	2.0			7.5	38.5	22.0	F	3.0		13	
B013	2.8	29.2	2.0			7.5	36.5	22.0	HW	51.0	225	106	
B014	2.0	28.0	2.0			7.5	38.5	22.0	HW	39.0	137	105	
B015	2.7	26.3	2.0			7.5	39.5	22.0	HW	33.0	50	100	
B016	2.2	26.8	2.0			7.5	39.5	22.0	HW	45.0	180	105	
B017	2.4	25.6	2.0			7.5	40.5	22.0	HW	38.0	100	114	
B018	2.3	24.7	2.0			7.5	41.5	22.0	F	4.5		23	
B019	2.1	24.9	2.0			7.5	41.5	22.0	HW	36.0	89	124	
B020	2.1	24.9	2.0			7.5	41.5	22.0	HW	36.0	89	121	
B021	2.2	23.8	2.0			7.5	42.5	22.0	F	3.4		18	
B022	2.0	24.0	2.0			7.5	42.5	22.0	F	2.0		8	

Run #	Benz	N2O	O2	NO2	NO	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
B023	2.3	25.2	2.0			7.5	41.0	22.0	F	2.0		8	
B024	1.8	24.2	2.0			7.5	42.5	22.0	F	13.0		72	
B025	1.8	23.7	2.0			7.5	43.0	22.0	F	2.5		10	
B026	1.6	24.4	2.0			7.5	42.5	22.0	HW	27.0	37	110	
B027	1.6	23.9	2.0			7.5	43.0	22.0	HW	30.0	43	111	
B028	1.6	22.9	2.0			7.5	44.0	22.0	F	2.0		8	
B029	1.6	23.4	2.0			7.5	43.5	22.0	F	2.7		13	
B030	1.4	23.6	2.0			7.5	43.5	22.0	F	2.4		10	
B031	2.0	23.0	2.0			7.5	43.5	22.0	F	1.5		7	
B032	1.6	26.4	2.0			7.5	61.0	1.5	F	1.6		7	
B033	2.2	25.8	2.0			7.5	61.0	1.5	HW	27.0	31	109	
B034	2.2	23.8	2.0			7.5	63.0	1.5	F	1.5		5	
B035	2.2	24.8	2.0			7.5	62.0	1.5	F	4.0		20	
B036	1.6	25.4	2.0			7.5	62.0	1.5	F	1.1		4	
B037	1.4	25.6	2.0			7.5	62.0	1.5	F	2.0		9	
B038	1.8	25.7	2.0			7.5	61.5	1.5	F	3.2		19	
B039	1.6	25.9	2.0			7.5	61.5	1.5	F	2.9		13	
B040	1.8	26.2	2.0			7.5	61.0	1.5	F	5.5		30	
B041	1.6	26.4	2.0			7.5	61.0	1.5	F	3.6		24	
C002	1.5	28.5				58.0		12.0	HW	60.0	588	106	
C003	1.7	28.3				58.0		12.0	HW	64.0	746	112	
C004	1.6	23.4				75.0			HW	47.0	289	107	
C005	1.7	23.3				75.0			HW	50.0	190	105	
C006	1.3	28.7				58.0		12.0	HW	63.0	556	123	
C007	3.2	23.3				74.0			F	1.5			
C008	1.3	18.7				80.0			F	1.0		6	
C009	1.8	23.2				75.0			HW	48.0	186	110	
C010	1.6	18.4				80.0			HW	1.0		5	
C011	1.4	18.6				80.0			F	1.3		8	
C012	1.5	18.5				80.0			F	1.4		6	
C013	1.6	23.4				75.0			HW	43.0	192	103	
C014	1.9	23.1				75.0			HW	50.0	222	105	
C015	1.4	18.6				80.0			F	0.7		3	
C016	1.6	23.4				63.0		12.0	F	2.0		7	
C017	1.8	23.2				63.0		12.0	F	1.8		7	
C018	1.7	23.3				63.0		12.0	F	2.0		10	
C019	1.9	23.1				63.0		12.0	F	2.0		9	
C020	1.4	18.6				68.0		12.0	F	2.0		4	
C021	1.3	18.7				68.0		12.0	F	1.4		5	

Run #	Benz	N2O	O2	NO2	NO	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
C022	1.5	18.5				68.0		12.0	F	1.2		4	
C023	1.6	18.4				68.0		12.0	F	1.4		4	
C024	1.6	17.4	1.0			78.5		1.5	F	1.2		4	
C025	1.7	22.3	1.0			73.5		1.5	HW	61.0	549	92	
C026	1.4	16.6	2.0			78.5		1.5	F	1.2		3	
C027	1.5	19.0	2.0			76.0		1.5	F	32.0	68	126	
C028	1.5	17.7	2.0			77.3		1.5	F	2.4		11	
C029	1.5	20.5	0.5			76.0		1.5	F	2.0		10	
C030	1.5	19.0	2.0			75.3	0.7	1.5	HW	42.0	170	104	
C031	1.5	19.0	2.0			75.3	0.7	1.5	HW	38.0	124	107	
C032	1.5	19.5	2.0			74.8	0.7	1.5	HW	40.0	135	96	
C033	1.5	18.0	2.0			76.3	0.7	1.5	HW	6.0		32	
C034	1.5	17.0	2.0			77.3	0.7	1.5	F	2.2		13	
C035	1.5	21.0				77.5			HW	7.0	11	37	
C036	1.5	21.0				76.0		1.5	F	1.3		4	
C037	1.5	20.0	1.0			76.0		1.5	HW	37.0	74	122	
C039	1.5	19.7				78.8			F	1.2		5	
C040	1.6	19.6				78.8			F	1.3		5	
C041	1.5	19.5	1.5			76.0		1.5	HW	34.0	88	111	
C042	1.7	19.5				78.8			F	1.5		5	
C043	1.5	19.7				77.3		1.5	F	1.4		5	
C044	1.6	19.6				77.3		1.5	F	1.4		5	
C045	1.7	19.5				77.3		1.5	F	1.7		6	
C046	1.5	18.7	1.0			77.3		1.5	F	1.7		8	
C047	1.6	18.6	1.0			77.3		1.5	F	1.6		6	
C048	1.7	18.5	1.0			77.3		1.5	F	1.7		7	
C049	1.5	18.5	1.5			77.0		1.5	F	2.4		11	
C050	1.8	18.6	1.5			76.6		1.5	F	2.2		11	
C051	1.6	18.1	2.0			76.8		1.5	HW	23.0	26	76	
C052	1.6	18.7	1.5			76.7		1.5	HW	29.0	52	86	
C053	1.8	18.0	2.0			76.7		1.5	F	1.8		7	
C054	1.6	19.2	1.0			76.6		1.6	F	1.7		9	
C055	1.7	19.1	1.0			76.7		1.5	F	2.0		12	
C056	1.7	18.6	1.5			76.7		1.5	F	3.9		16	
C057	1.6	18.2	2.0			76.0	0.7	1.5	HW	29.0	47	95	
C058	1.7	18.1	2.0			76.0	0.7	1.5	HW	32.0	53	102	
C059	1.6	17.6	2.0			76.6	0.7	1.5	F	3.0		15	
C060	1.7	17.5	2.0			76.6	0.7	1.5	F	3.0		16	
C061	1.6	20.4	0.5			75.8	0.2	1.5	F	2.5		12	

Run #	Benz	N2O	O2	NO2	NO	N2	CO2	H2O	HW/F	ΔP	dP/dt	ΔT	Comments
C062	1.7	20.3	0.5			75.8	0.2	1.5	F	2.3		14	
C063	1.6	18.1	2.0			74.6	0.7	3.0	F	4.4		22	
C064	1.6	18.1	2.0			65.6	0.7	12.0	F	1.5		5	
C065	1.6	20.1	2.0			55.6	0.7	20.0	F	0.6		2	
C066	1.5	19.5	2.0			74.8	0.7	1.5	F	36.0	103	103	Nichrome wire
C067	1.5	18.8	2.0			75.5	0.7	1.5	F	39.0	136	104	Nichrome wire
C068	1.6	75.7	2.0				0.7	20.0	HW	94.0	1,833	133	
C069	1.6	75.7	2.0				0.7	20.0	HW	125.0	3,255	153	
C070	1.9	21.1	2.0			52.3	0.7	22.0	F	1.0		3	
C071	1.7	21.3	2.0			52.3	0.7	22.0	F	1.5		8	
C072	1.9	20.1	2.0			53.3	0.7	22.0	F	1.3		5	
C073	1.7	23.6	2.0			50.0	0.7	22.0	HW	35.0	106	89	
C074	2.2	21.8	2.0			51.3	0.7	22.0	HW	48.0	303	81	
C075	2.1	21.4	2.0			51.8	0.7	22.0	HW	52.0	282	95	
C076	2.0	21.0	2.0			52.3	0.7	22.0	HW	33.0	97	93	
C077	2.0	20.5	2.0			52.8	0.7	22.0	HW	47.0	213	88	
C078	2.0	20.3	2.0			53.0	0.7	22.0	HW	47.0	200	86	
C079	1.9	21.1	2.0			52.3	0.7	22.0	HW	48.0	246	82	
C080	2.0	19.0	2.0			54.3	0.7	22.0	F	3.0		17	
C081	2.0	20.0	2.0			53.3	0.7	22.0	HW	37.0	106	95	
C082	1.9	20.1	2.0			53.3	0.7	22.0	HW	40.0	120	93	
C083	1.8	19.7	2.0			53.8	0.7	22.0	HW	31.0	62	82	
C084	1.9	19.6	2.0			53.8	0.7	22.0	HW	38.0	117	94	
C085	1.5	16.4	3.0			77.6		1.5	HW	54.0	281	85	
C086	1.5	12.8	5.0			79.2		1.5	HW	22.0		77	
C087	1.5	15.9	3.0			78.1		1.5	F	3.5		17	
C088	1.5	12.3	5.0			79.7		1.5	F	2.8		16	
C089	1.6	22.0				74.9		1.5	HW	31.0	52	84	
C090	1.4	17.8	2.0			76.6	0.7	1.5	F	2.5		10	
C091	1.2	18.0	2.0			76.6	0.7	1.5	F	1.4		5	
C092	1.6	16.4	2.0			57.3	0.7	22.0	F	1.7		9	
C093	1.2	16.8	2.0			57.3	0.7	22.0	F	1.0		4	
C094	1.6	17.9	2.0			55.8	0.7	22.0	F	1.8		5	
C095	1.2	18.3	2.0			55.8	0.7	22.0	F	1.0		4	