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Title:

EVALUATION OF PRESSURE RESPONSE IN THE LOS ALAMOS CONTROLLED-AIR INCINERATOR DURING THREE INCIDENT SCENARIOS

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MASTER

Los Alamos
NATIONAL LABORATORY

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EVALUATION OF PRESSURE RESPONSE IN THE LOS ALAMOS CONTROLLED AIR INCINERATOR DURING THREE INCIDENT SCENARIOS

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ABSTRACT

The Los Alamos Controlled Air Incinerator (CAI) is a system designed to accept radioactive mixed waste containing alpha-emitting radionuclides. A mathematical model was developed to predict the pressure response throughout the offgas treatment system of the CAI during three hypothetical incident scenarios. The scenarios examined included: 1) loss of burner flame and failure of the flame safeguard system with subsequent reignition of fuel gas in the primary chamber, 2) pyrolytic gas buildup from a waste package due to loss of induced draft and subsequent restoration of induced draft, and 3) accidental charging of propellant spray cans in a solid waste package to the primary chamber during a normal feed cycle.

For each of the three scenarios, the finite element computer model was able to determine the transient pressure surge and decay response throughout the system. Of particular interest were the maximum absolute pressures attainable at critical points in the system as well as maximum differential pressures across the high efficiency particulate air (HEPA) filters. Modeling results indicated that all three of the scenarios resulted in maximum HEPA filter differential pressures well below the maximum allowable levels.

INTRODUCTION

The analyses described in this paper were performed as part of an Environmental Assessment to identify and evaluate the consequences of three hypothetical incident scenarios involving operation of the Los Alamos CAI. In a companion effort (1), the probabilities of occurrence were estimated for two of the three scenarios. The consequences of greatest concern are those that can result in exposure of operating personnel and the environment to toxic and radioactive materials. Therefore, operational incidents that could potentially result in breaching of the system due to overpressurization of the combustion chambers or perforation of the high efficiency particulate air (HEPA) filters were the focus of this study. This study describes the results of modeling of three scenarios to estimate the maximum pressure that could be achieved in the CAI combustion chambers as well as the maximum differential pressure across each of the process HEPA filter banks.

DESCRIPTION OF THE CAI PROCESS

The Los Alamos CAI has been described in a previous report (2), however, a brief description of the system including offgas treatment train is provided here. The system was originally assembled as a research and development unit to demonstrate the volume reduction and stabilization of alpha-contaminated radioactive waste such as transuranic (TRU) solid waste. The system was used for more than a decade to demonstrate the safe incineration of hazardous chemical and mixed radiaoctive waste in both solid and liquid form. Beginning in 1986, the CAI underwent an extensive process upgrade to serve as a production system to treat Los Alamos-generated radioactive mixed waste.

The front end of the CAI process (Fig. 1) consists of dual combustion chambers in which solid waste packages are introduced to the primary chamber. The secondary chamber serves as an afterburner to provide complete destruction of any volatilized organic compounds. The offgas treatment system, designed for radioactive service, consists of the following control devices in order: saturation quencher, The front end of the CAI process (Fig. 1) consists of dual combustion chambers in which solid waste packages are introduced to the primary chamber. The secondary chamber serves as an afterburner to provide complete destruction of any volatilized organic compounds. The offgas treatment system, designed for radioactive service, consists of the following control devices in order: saturation quencher, high energy venturi scrubber, packed tower acid gas absorber, mist eliminator, electric reheater, two parallel banks of two HEPA filters in series, an activated carbon adsorber, a final bank of HEPA filters, continuous emissions monitors, and a facility stack.

"Place Fig. 1 here."

DESCRIPTIONS OF THE INCIDENT SCENARIOS

Flameout Scenario

This scenario involves a flame-out in the lower chamber, followed by failure to shut off flow of natural gas and a subsequent reignition of the resulting accumulated flammable gas mixture. As long as the gas temperature is above the autoignition temperature of natural gas (632 ^{o}C), flameless combustion would occur and unreacted combustible gas would not accumulate. However, this scenario assumes that a combustible mixture of natural gas and air is allowed to accumulate below the autoignition temperature and an ignition source ignites the mixture. The ignition source could be burning embers on the primary chamber hearth or the flame in the secondary chamber burner. The ignition would behave as a rapid deflagration similar to the "whoomph" that results when lighting a backyard gas grill after the propane has been turned on. Due to the rapid rate of heat release by combustion, the gas temperature would rise, the gas would expand, and the pressure would be expected to increase. The conditions required for a detonation (3), most importantly a vessel or pipe length-to-diameter ratio of more than about 10 in the high temperature zone, are not available in the CAI system.

Pyrolytic Gas Scenario

This scenario involves the introduction of a box of solid waste onto the primary chamber hearth. The box contains 100% polyethylene plastic which has the highest heating value (lower heating value = 45,759 kJ/kg) of any solid waste constituents. The box proceeds to ignite and burn. Shortly thereafter, the facility experiences a loss of electric power. In addition, the auxiliary power generation capability fails to pick up the electrical load. The result is that the combustion air supply blowers and the process induced draft blower stops operating. Also, the natural gas burners in the primary and secondary chambers shut down, losing flame. After all blowers cease operating, no additional oxygen is introduced into the CAI primary chamber. The waste box containing polyethylene, continues to burn and the polyethylene melts. All available oxygen in the chambers is consumed by the burning waste as well as pyrolytic gases evolved at the primary chamber temperature of 871 ^{o}C. Ethylene vapor (lower heating value = 47,150 kJ/kg) evolves from the molten pool of polyethylene on the hearth. The primary and secondary chambers and hot crossover duct fill with combustible species that would include carbon monoxide (CO), hydrogen (H_2), and a mixture of hydrocarbons, primarily ethylene (C_2H_4), and Nitrogen (N_2). When electric power is restored to the facility, the combustion air and induced draft blowers start to operate, thus introducing air to the primary and secondary combustion chambers. Because the gas mixture is above its autoignition temperature, the pyrolytic vapors would ignite as a flame front at each air introduction location. The rate of combustion and thus heat released would be limited by the rate of introduction of air into the system. Due to the heat released by combustion, the gas temperature would rise, the gas mixture would expand, and the pressure would be expected to increase.

Spray Can Scenario

This scenario involves the accidental charging of a waste box containing from one to five fully loaded cans of WD-40^{TM} to the CAI primary chamber hearth. The box begins to burn and the spray cans rupture. The volatile organic compounds are atomized into the oxygen rich atmosphere of the primary and secondary chamber, where instantaneous combustion results. Due to the rapid rate of heat release by combustion, the gas temperature rises, the gas expands and the pressure is expected to increase. This scenario is similar to the flameout and reignition scenario in that a combustible gas mixture is allowed to accumulate uniformly within the entire CAI hot zone volume followed by uniform instant combustion of the mixture.

DESCRIPTION OF THE MODELS

A transient model was developed for the Flameout/Reignition and Pyrolytic Gas scenarios using Microsoft QuickBasic 4.5 codes on a 486 PC. The overall structure of each code is the same, however, modifications were incorporated into each code to reflect the conditions expected in each scenario. Both models use the technique of simulating an unsteady state process by assuming quasi-steady state conditions during a small time interval. The Spray Can scenario was brought to attention and investigated over a year later and the transient model described below was not required for this scenario.

Flameout and Reignition Scenario Model

This model involves an iteration to solve for the incinerator pressure and pressures at various points downstream in the offgas system during each time interval of 0.1 sec (100 milliseconds) duration. The following discussion applies to determining steady-state conditions during each time interval.

The approach involves accounting for the amount of air introduced into the primary and secondary chambers during the time interval. The heat release and reaction stoichiometry are calculated and the inventory and composition of gaseous species is updated from the previous time interval. The gas temperature is then calculated by an energy balance using an iterative approach. The maximum pressure is first calculated using the ideal gas law for a closed system having the same volume as the combustion chambers plus quench tower and the previously calculated gas temperature. This maximum pressure serves as the starting point in a "bleed down" iteration to calculate the actual steady state chamber pressure. The cooling of the gas from the incinerator by scrubber liquid supplied to the quench tower, venturi scrubber, and absorber tower is taken into account using a cocurrent quench code.

The pressure iteration assumes a venturi scrubber discharge pressure, and calculates an offgas mass flow rate. This mass flow rate is used to calculate pressures throughout the offgas system. The iteration continues until an equilibrium is achieved between offgas mass flow rate and incinerator pressure. When the incinerator pressure iteration converges to a solution, the code performs an additional iteration to adjust the venturi discharge pressure and incinerator pressure again so that the final stack pressure is equal to atmospheric pressure. If the final calculated incinerator pressure is below the setpoint of -2 in. W.C., an additional iteration is used to adjust the I.D. blower speed downward so that the setpoint pressure is reached. New pressures throughout the offgas system are then calculated. This latter adjustment is needed only at low offgas flow rates after the pressure pulse has fully decayed.

When steady-state conditions are reached for a given time interval, the conditions from the current interval become the starting conditions for the next time interval. Because the venturi scrubber throat is the smallest restriction in the offgas system, the Mach number of the gas flowing through this point is calculated to verify that a choked flow condition is not reached.

Pyrolytic Gas Scenario Model

In this scenario model, the general model structure for calculating pressures throughout the offgas system is the same as that for the flame-out and reignition scenario. However, this model incorporates ramping up of the combustion air blowers and the induced draft blower from a static condition.

Spray Can Scenario

This analysis was concerned with determining the maximum pressure possible as a result of this incident scenario and comparing this result with that of the two other scenarios. The maximum pressure should occur rapidly at the time of spray can rupture. Thus transient pressure decay following the initial spike was not of interest in this analysis and the transient pressure model was not used.

ASSUMPTIONS USED IN THE MODELS

The more important assumptions used in these models are listed below. For brevity, a full list of process parameters (initial gas compositions, air flow rates, component dimensions, etc.) is not provided in this paper.

Flameout and Reignition Scenario

- The initial gas composition in the high temperature zone is assumed to be well mixed throughout the volume. The volume of initial combustible mixture is assumed to occupy the primary chamber + transition duct + 1/2 of the volume of the secondary chamber (up to the secondary burner). The balance of the high temperature volume (1/2 of the secondary chamber + hot crossover duct) is assumed to initially contain a combustion product mixture based on combustion with 10% excess air.
- Re-ignition occurs at an initial chamber temperature equal to the autoignition temperature for natural gas, 632 °C.
- The combustion reaction takes place instantly, in so far as the model is concerned, within the first time interval.
- The offgas system is the only pressure relief pathway from the CAI combustion chambers. No alternate pressure relief pathways are assumed available. Actually, the gloves on the main ram housing represent a potential pressure relief pathway into the process area. All sources of combustion air have one-way check valves in-line, hence, reverse flow of gas through these lines is highly unlikely.
- The venturi scrubber throat control valve is wide open in response to the increased gas mass flow rate because it would be attempting to maintain a constant differential pressure set point of ~ 14.9 kPa (60 in. W.C.) This represents a worst case with respect to downstream pressure rise and differential pressure across the HEPA filters.
- The induced draft blower curve (differential pressure vs. inlet volumetric gas flow rate) from the manufacturer was used in the model. The curve was fitted to a 4th order polynomial function and generalized to accommodate any conditions of gas inlet pressure, temperature, molecular weight, and motor speed.
- The induced draft blower speed remains constant at 3500 revolutions per minute throughout the duration of the run, i.e. it is assumed not to be responsive to increased pressure in the incinerator.

Pyrolytic Gas Scenario

- The initial gas composition at the time of blower restart is assumed to be 100% nitrogen (N_2). Ethylene vapor is assumed available at all times for 100% consumption of oxygen in the incoming air. No credit is taken for any ethylene vapor swept out of the chamber into the offgas system.
- The box fed to the hearth contains an initial charge of 9.07 kg of polyethylene.
- The combustion process is assumed to be oxygen-limited which means the pyrolysis/vaporization rate of polyethylene to ethylene is faster than the rate of introduction of oxygen. This assumption essentially allows the gas temperature to reach the adiabatic flame temperature of ethylene of 2357 °C.
- The initial temperature of the primary chamber is 871 °C.
- The induced draft blower requires 10 seconds to reach a maximum speed of 3500 RPM. The speed vs. time curve is assumed linear.
- The combustion air blowers require 5 seconds to reach maximum speed. This figure was chosen conservatively to allow air to enter the combustion chambers at a greater rate than the induced draft blower startup rate. The speed vs. time curves for all blowers are assumed linear.

- The steady state combustion rate for the polyethylene based on the oxygen-limited assumption is 102.9 kg/h polyethylene which corresponds to a heat release rate of 4.85×10^6 kJ/h).
- The offgas system is the only pressure relief pathway from the CAI combustion chambers. No alternate pressure relief pathways are assumed available. All sources of combustion air lines have one-way check valves in-line, hence, reverse flow of gas through these lines is highly unlikely.
- The venturi scrubber throat control valve is wide open in response to the increased gas mass flow rate because it attempts to maintain a constant differential pressure set point of ~ 14.9 kPa (60 in. W.C.). This represents a worst case with respect to downstream pressure rise and differential pressure across the HEPA filters.
- The induced draft blower curve (differential pressure vs. inlet volumetric gas flow rate) from the manufacturer was used in the model. The curve was fitted to a 4th order polynomial function and generalized to accommodate any conditions of gas inlet pressure, temperature, molecular weight, and motor speed.

Spray Can Scenario

- The composition of the gas in the chambers just prior to spray can rupture is 11.72 % CO_2, 7.85 % O_2, 24.67 % H_2O, and 55.77 % N_2.
- The typical spray can used for the analysis is a full WD-40^{TM} can with a net weight of 0.255 kg (9 oz) of contents. The composition of the contents of a WD-40^{TM} can is 25 wt% propellant, 75 wt% mineral spirits. Mineral spirits are assumed to be 100% n-Heptane. The propellant is A-70, a common mixture of light hydrocarbons.
- Heat and mass transport rates were neglected, thus, the assumption of instantaneous combustion of the released hydrocarbon with all the oxygen in the hot zone represents a worst case with regard to pressure increase.
- The maximum pressure achieved is independent of the heat release rate prior to a can rupture, i.e. the steady state heat released by natural gas and waste combustion does not affect the pressure.
- The heat released due to combustion of the volatilized hydrocarbons as a result of spray can rupture is limited to the amount of oxygen in the chamber at the time of rupture. All of the available oxygen is assumed to be consumed by combustion of the released hydrocarbons. The order of preference for hydrocarbon combustion is proportional to vapor pressure, thus the propane is assumed to burn first followed by n-butane.
- The heat absorbed by the gas mixture from combustion is by convection within the gas and not by radiation from hot refractory.

OFFGAS SYSTEM FLOW RESISTANCES

To determine intermediate pressures throughout the CAI offgas system, the system was modeled as a series of fifteen flow resistance elements as shown in Fig. 2. Some of the elements in series such as ducting, elbows, etc. were lumped together and modeled as a simple orifice equation and in others, empirical differential pressure correlations were used. Following are discussions of the specific empirical differential pressure equations and the method used to determine flow resistance coefficients.

"Place Fig. 2 here."

For the venturi scrubber (flow element no. 1), the following equation for differential pressure was used.

$$\Delta P = kQ_L m \rho^{-1} d_v^{-4} \qquad \text{(Equ. 1)}$$

For flow element numbers 2, 3, 4, 7, 8, 9, 11, 13, 14, and 15, a simple orifice equation was used to develop a relation for differential pressure as a function of mass flow rate and gas density as follows:

$\Delta P_i = k_i m^2/\rho$ (Equ. 2)

Values of k_i for each of the elements in the offgas system were derived empirically (4). For the HEPA Filter Banks (elements 5, 6, and 10 of Fig. 2), a correlation from experimental data (5) for Flanders™ 0.61 m x 0.61 m filters was used. The correlation, based on clean HEPA filter media, is as follows:

$\Delta P = a_1(m/\rho)^2 - a_2\rho(m/\rho) + a_3\rho$ (Equ. 3).

The induced draft blower curve (differential pressure vs. volumetric flow rate) was fitted to a fourth order polynomial equation of the form:

$\Delta P = a + bQ + cQ^2 + dQ^3 + eQ^4$ (Equ. 4).

MODEL RESULTS

Flameout and Reignition Scenario

Results of the Flameout/Reignition computer model are given in Figs 3 through 6. Fig. 3 shows the temperature trace versus time after reignition for three different natural gas firing rates. During reignition (first time interval of 0.1 sec), the gas temperature climbs rapidly from the autoignition temperature of natural gas to about 1,510 °C (2,750 °F) in each case. The highest temperature achieved at the highest natural gas flow rate is just under 1,927 °C (3,500 °F).

The chamber pressure versus time behavior is shown in Fig. 4. Regardless of the natural gas flow rate, the initial pressure pulse reaches about 66.9 kPa gauge pressure or 144.8 kPa absolute pressure (9.7 psig or 21 psia), then decays to a lower pressure. This is because the initial gas composition at the time of reignition is the same in each case.

The HEPA filter differential pressure versus time response is shown in Fig. 5 for each of the three HEPA filter banks and at each of the natural gas flow rates. These results are for clean HEPA filters. Again, the maximum differential pressure achieved at the time of reignition is the same regardless of the natural gas flow rate and is approximately 2.4 kPa (9.6 in. W.C.). The sudden drop in curve A at about 4.3 seconds is due to the induced draft blower reducing speed to maintain the chamber pressure at -0.50 kPa (-2 in. W.C.).

Fig. 6 shows the gas Mach number through the venturi scrubber versus time. This analysis was conducted to verify that a choke flow condition (Mach No. ≥ 1) was not experienced. Indeed the Mach number peaks at just over 0.7 and decays to a range of 0.32 to 0.49 depending on the natural gas flow rate into the combustion chambers.

"Place Figs. 3, 4, 5, 6 here."

Pyrolytic Gas Scenario

Results of the pyrolytic gas computer model are given in Figs. 7 through 9. The temperature versus time trace is shown in Fig. 7. Initially, the system is at a temperature of 871 °C (1,600 °F). As the combustion air and induced draft blowers startup, the temperature continues to rise due to combustion of pyrolytic vapors (ethylene). The maximum temperature reached is the adiabatic flame temperature for ethylene. The model reaches a temperature of 2,427 °C (4,400 °F) which is about 69 °C higher than the literature value (6) reported. The source of the disagreement is unknown, however, the higher temperature in the model is more conservative with respect to its effect on pressure.

The chamber pressure versus time behavior is shown in Fig. 8. The pressure reaches a maximum of 17.2 kPa gauge pressure (2.5 psig) in 5 seconds, then decays to atmospheric pressure by 20 seconds. The initial rise is due to an increasing rate of air introduction during the first 5 seconds with relatively little pull by the induced draft blower until nearly 10 seconds. The induced draft blower then picks up the load and restores the system to its setpoint condition.

The HEPA filter differential pressure versus time response for each of the three HEPA filter banks is shown in Fig. 9. A maximum differential pressure of about 0.75 kPa (3 in. W.C.) is experienced at 5 seconds with decay to under 0.6 kPa (2.5 in. W.C.) after 15 seconds cumulative time.

"Place Figs. 7, 8, 9 here."

Spray Can Scenario

The approach to determining the consequences of a spray can rupture and instantaneous combustion of its contents was to first calculate the resultant closed system pressure. This pressure could then be compared to the closed system pressures calculated from the other two scenarios to determine the relative pressure consequences.

Heat and mass balances were performed using HSC Chemistry^{TM} for Windows 2.0 by Outokumpu Research under two scenarios. The first case (Case A) assumes that all of the hydrocarbon material released during the spray can rupture is vaporized. The second case (Case B) assumes that only the hydrocarbon material that is burned is vaporized. In this latter case, the unburned hydrocarbon material remains on the hearth as a liquid. These cases were evaluated because they bound the conditions of an actual event.

Final temperatures were calculated from the heat and mass balance. The calculated temperatures were then used in the ideal gas law to calculate the theoretical closed system pressures. In both Case A ("all hydrocarbons vaporized") and the Case B ("only combusted hydrocarbons vaporized"), the final temperature decreases with increasing starting quantity of hydrocarbon material. This is because the vaporization of excess hydrocarbon material requires heat which ultimately lowers the gas phase temperature within the chambers. Even though vaporization adds more kg-moles of hydrocarbon to the gas phase, the net effect is still a decrease in pressure with increasing starting quantity of hydrocarbon for both Cases A and B. For Case A, the calculated closed system pressures range from a high of 26.3 kPa (3.82 psig) for rupture of a single can of propellant to -3.1 kPa (-0.45 psig) for five cans of propellant simultaneously rupturing. This negative pressure should be interpreted as merely no increase in pressure within the chamber. For Case B, the closed system pressure is 29.7 kPa (4.31 psig) for one can of propellant to -2.0 kPa (-0.29 psig) for five cans of propellant. Table I shows the contrast between these maximum closed system pressures and those calculated in the two previous scenarios. Table I shows that the pressure consequences of the Spray Can Scenario are slightly higher than for the Pyrolytic Gas Scenario but significantly lower than for the Flameout/Reignition Scenario.

CONCLUSIONS

Based on the models developed and the scenario conditions examined in this study, the maximum CAI combustion chamber pressure expected for the flameout and reignition scenario is 66.9 kPa gauge pressure (9.7 psig) and for the pyrolytic gas scenario, 2.5 psig. Rupturing of glovebox gloves in the main waste feed ram housing is likely at these pressures. The maximum HEPA filter bank differential pressure for the flameout and reignition scenario is 2.4 kPa (9.6 in W.C.) and for the pyrolytic gas scenario, 0.75 kPa (3.0 in. W.C.) These values are well below the maximum failure differential pressures for clean Flanders^{TM} HEPA filters of about 6.9 to 10.3 kPa (27.7 to 41.5 in. W.C.). The pressure consequences of the Spray Can Scenario are slightly higher than for the Pyrolytic Gas Scenario but significantly lower than for the Flameout/Reignition Scenario.

Loaded HEPA filters should experience a higher differential pressure at a given flow rate. However, the maximum differential pressure allowable during normal operation is 1.0 to 1.25 kPa (4 to 5 in. W.C.). It is therefore not expected that the differential pressure experienced with loaded HEPA filters under these scenario conditions would exceed the failure differential pressures.

NOTATION

$a, b, c, d, e, a_1, a_2, a_3$ = constants in empirical flow equations (consistent units)
d_v = Venturi scrubber throat diameter, m
k = Constant (consistent units)
k_i = Flow resistance coefficient (consistent units)
m = Offgas mass flow rate, kg/sec
$Q = 60m/\rho$ = Volumetric flow rate of gas, m^3/sec.
Q_L = Liquid flow rate to the venturi scrubber, m^3/sec
ΔP = Differential pressure, kPa
ρ = Gas density, kg/m^3

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Figure Titles

Fig. 1. Los Alamos CAI process flow diagram.

Fig. 2. Elements in the CAI offgas system used in the model.

Fig. 3. Combustion chamber temperature response during Flameout/Reignition scenario.

Fig. 4. Combustion chamber pressure response during Flameout/Reignition scenario.

Fig. 5. HEPA filter differential pressure response during Flameout/Reignition scenario.

Fig. 6. Mach Number of gas through the venturi scrubber during Flameout/Reignition scenario.

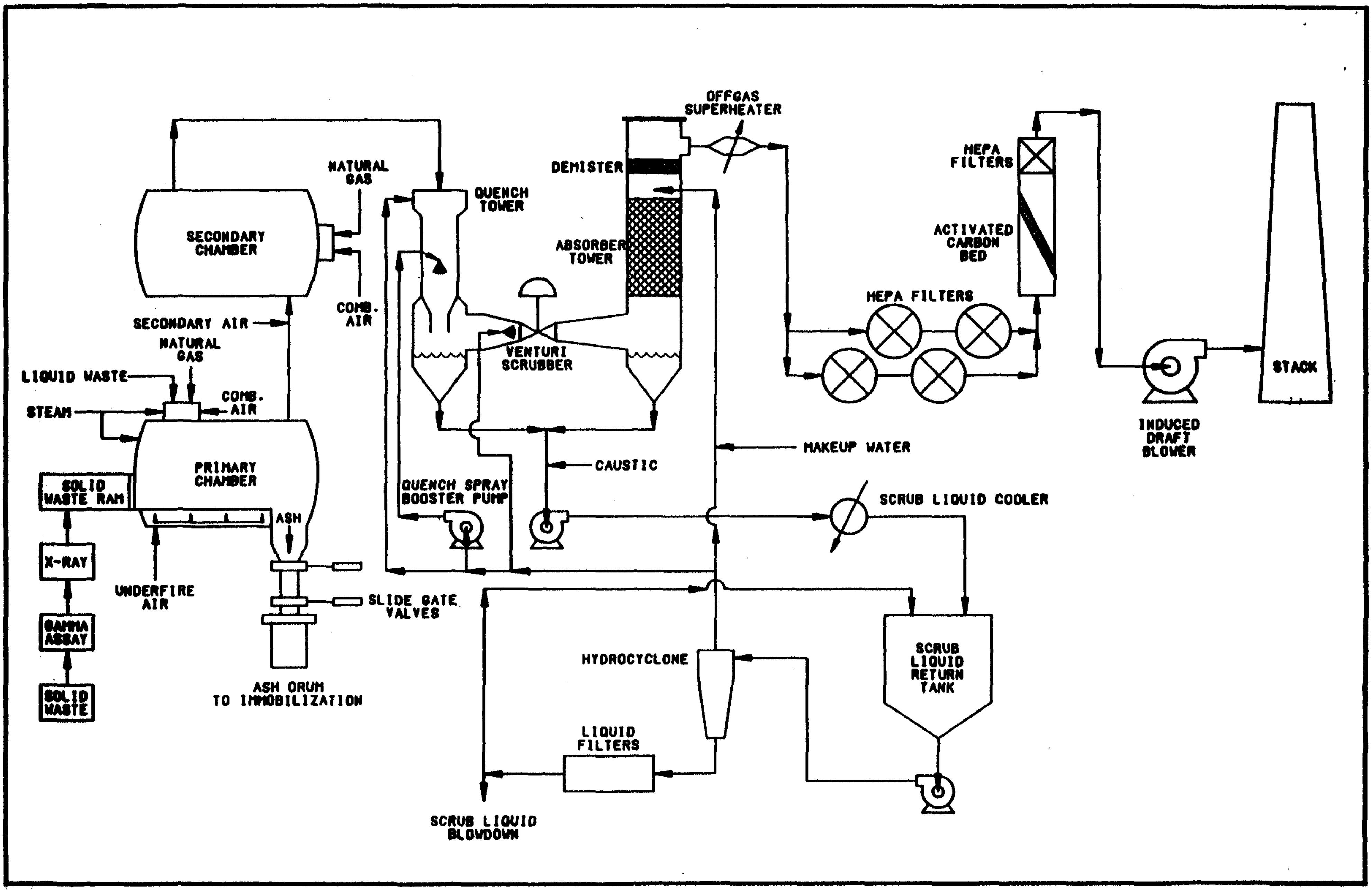
Fig. 7. Combustion chamber temperature response during Pyrolytic Gas scenario.

Fig. 8. Combustion chamber pressure response during Pyrolytic Gas scenario.

Fig. 9. HEPA filter differential pressure response during Pyrolytic Gas scenario.

Table I.
Comparison of Gauge Pressures Calculated in the Incident Scenarios

CAI Incident Scenario	Maximum Closed System Pressure kPa (psig)	Maximum Open System Pressure kPa (psig)
Flameout/Reignition	75.1 (10.9)	66.9 (9.7)
Pyrolytic Gas	21.4 (3.1)	17.2 (2.5)
Spray Can (A) (1 can)	26.3 (3.82)	--------
Spray Can (B) (1 can)	29.7 (4.31)	--------



OFFGAS SUPERHEATER
DEMISTER
NATURAL GAS
QUENCH TOWER
HEPA FILTERS
SECONDARY CHAMBER
ABSORBER TOWER
ACTIVATED CARBON BED
COMB. AIR
HEPA FILTERS
SECONDARY AIR
NATURAL GAS
VENTURI SCRUBBER
STACK
LIQUID WASTE
COMB. AIR
STEAM
INDUCED DRAFT BLOWER
MAKEUP WATER
PRIMARY CHAMBER
CAUSTIC
SOLID WASTE RAM
QUENCH SPRAY BOOSTER PUMP
SCRUB LIQUID COOLER
ASH
X-RAY
UNDERFIRE AIR
SLIDE GATE VALVES
GAMMA ASSAY
HYDROCYCLONE
SCRUB LIQUID RETURN TANK
SOLID WASTE
ASH DRUM TO IMMOBILIZATION
LIQUID FILTERS
SCRUB LIQUID BLOWDOWN

Fig 1

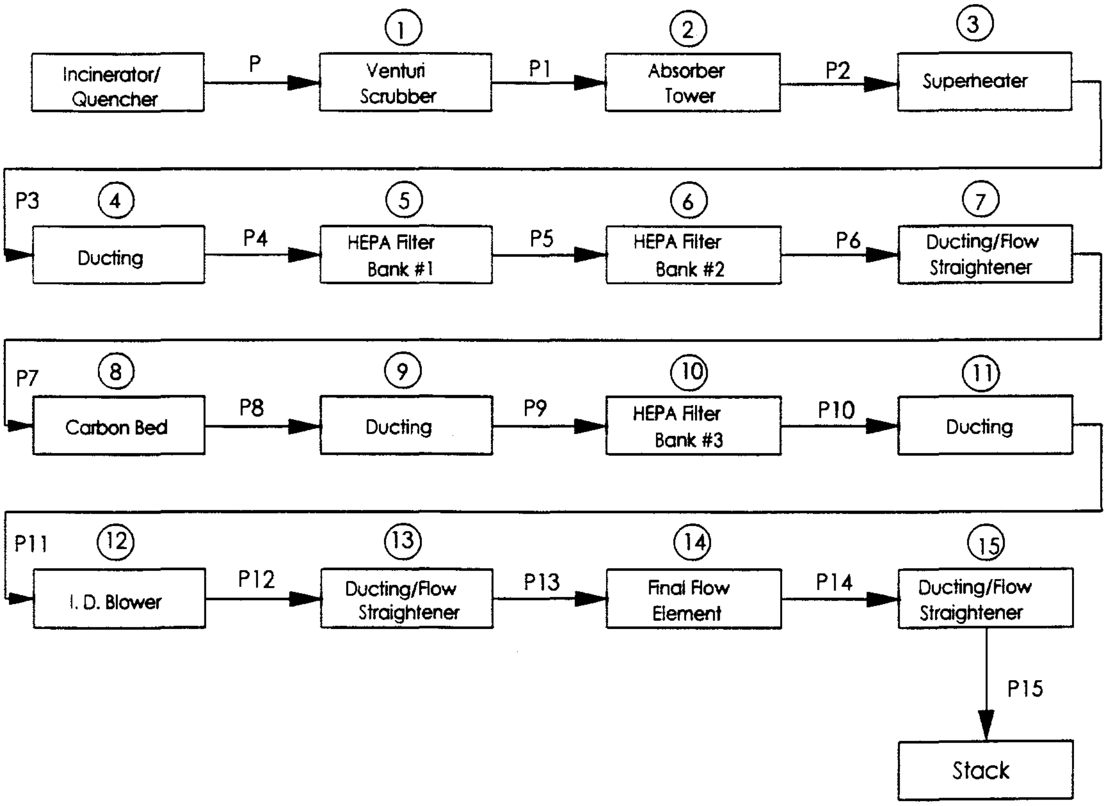
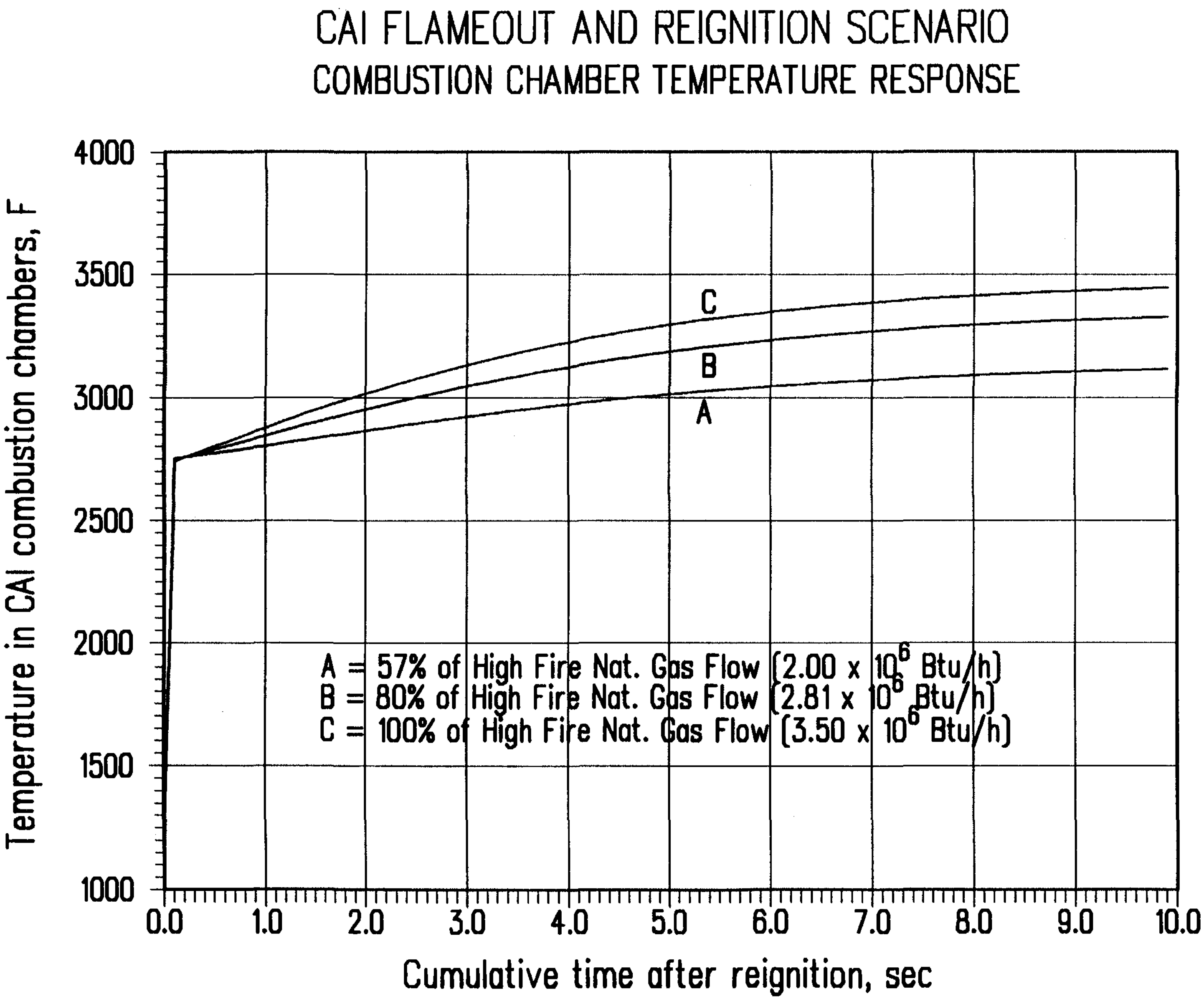

Incinerator/ Quencher
P
1
Venturi Scrubber
P1
2
Absorber Tower
P2
3
Superheater
P3
4
Ducting
P4
5
HEPA Filter Bank #1
P5
6
HEPA Filter Bank #2
P6
7
Ducting/Flow Straightener
P7
8
Carbon Bed
P8
9
Ducting
P9
10
HEPA Filter Bank #3
P10
11
Ducting
P11
12
I. D. Blower
P12
13
Ducting/Flow Straightener
P13
14
Final Flow Element
P14
15
Ducting/Flow Straightener
P15
Stack

Fig. 2



CAI FLAMEOUT AND REIGNITION SCENARIO
COMBUSTION CHAMBER TEMPERATURE RESPONSE

Fig 3

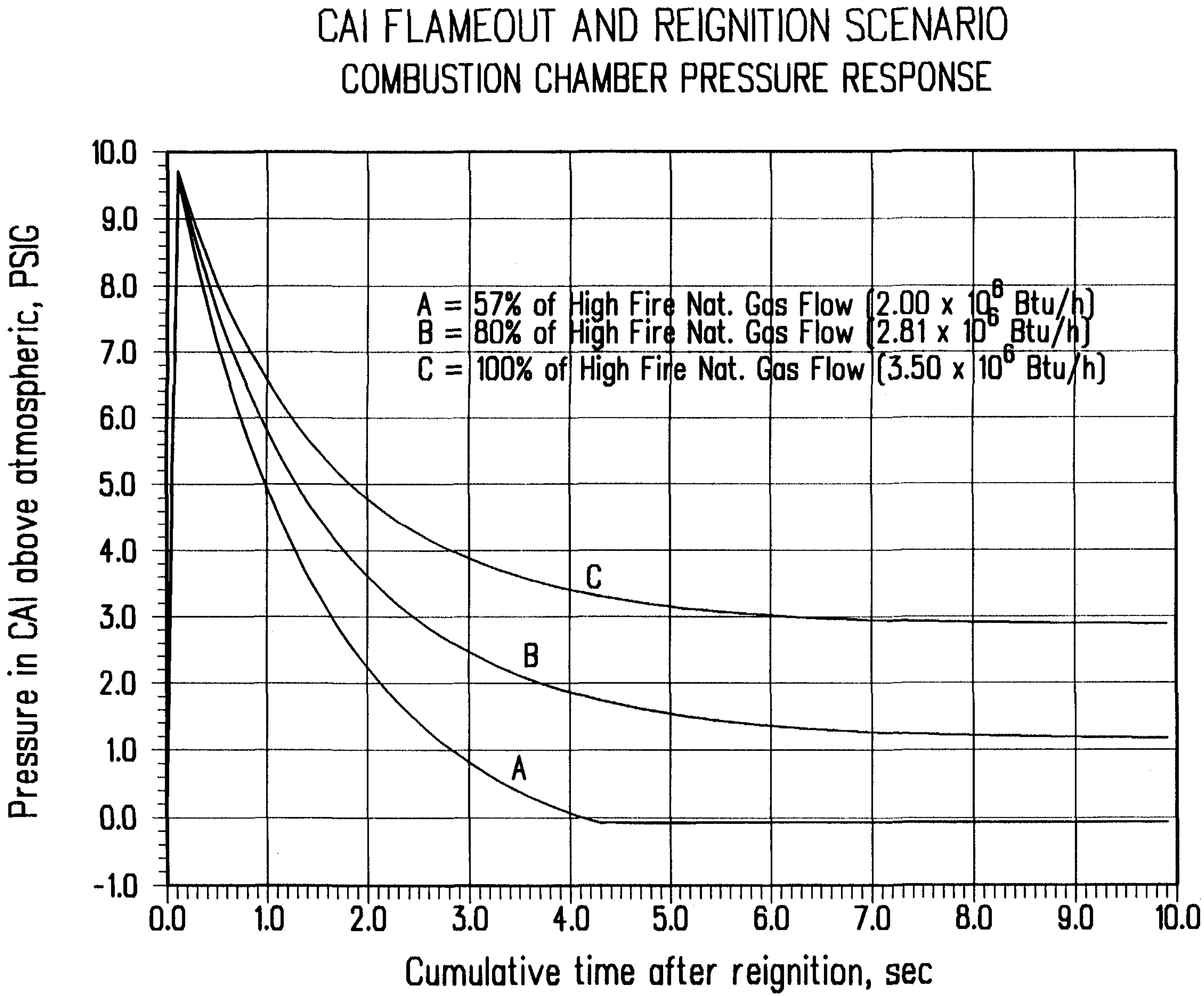
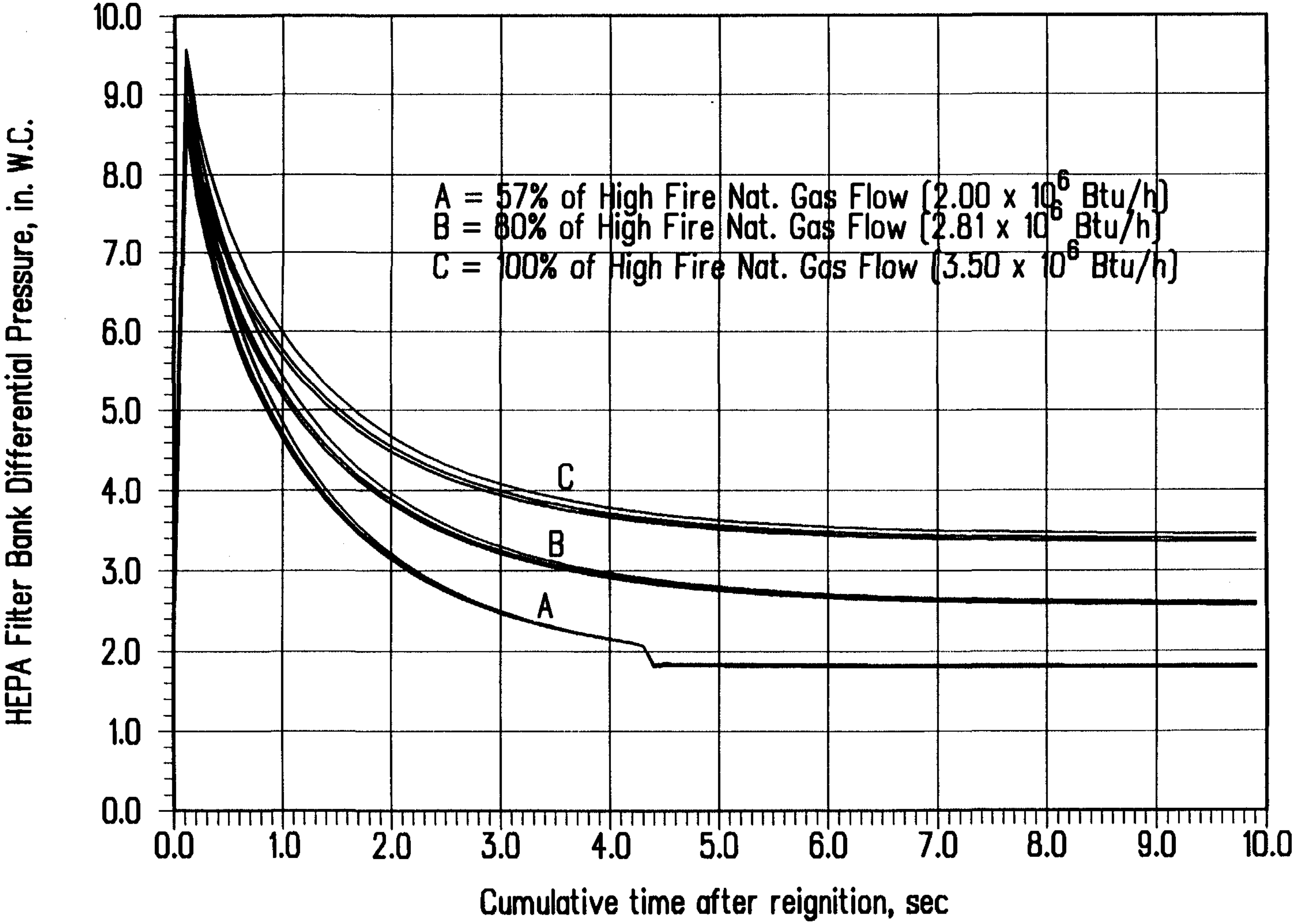
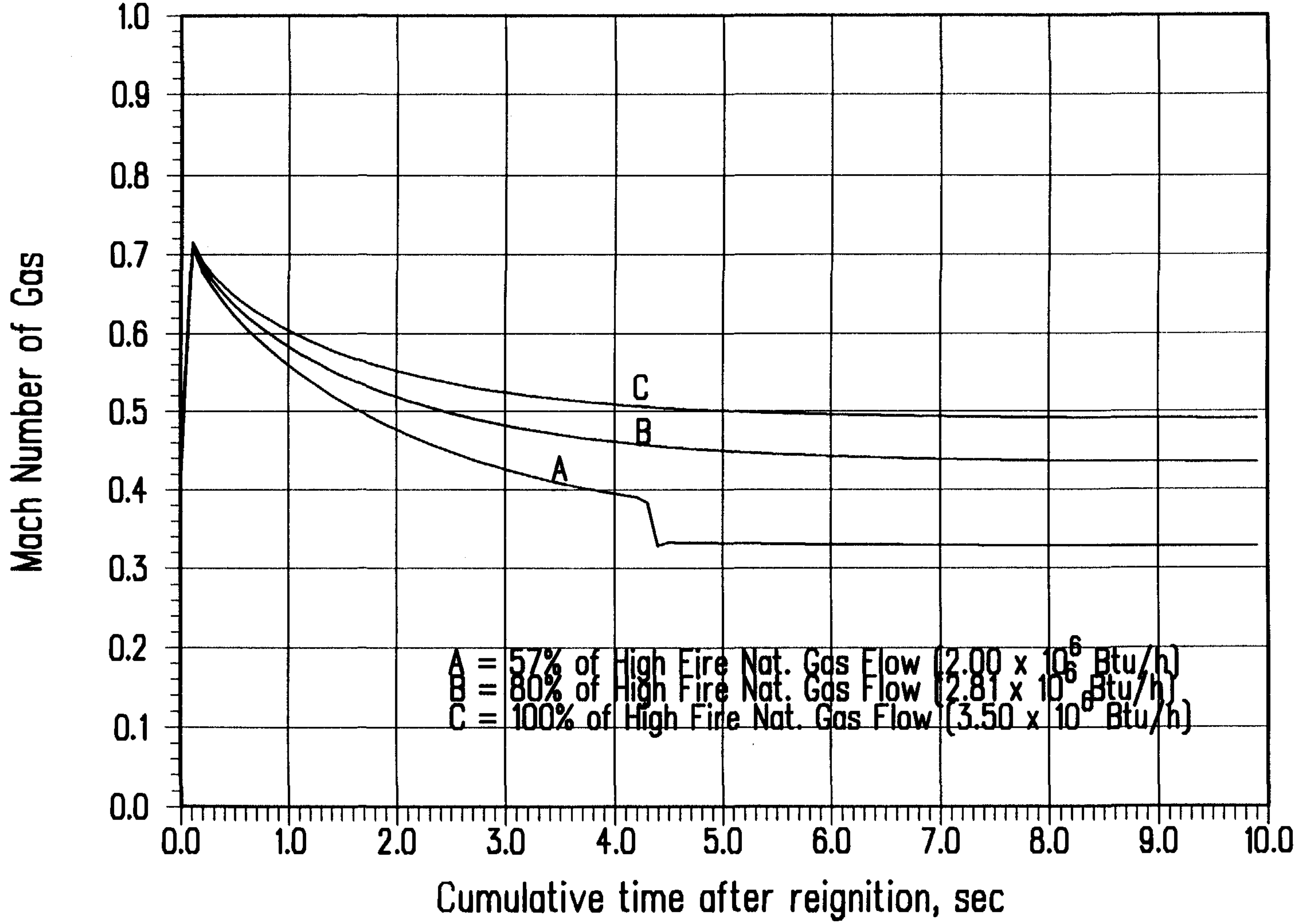

CAI FLAMEOUT AND REIGNITION SCENARIO
COMBUSTION CHAMBER PRESSURE RESPONSE
A = 57% of High Fire Nat. Gas Flow (2.00×10^6 Btu/h)
B = 80% of High Fire Nat. Gas Flow (2.81×10^6 Btu/h)
C = 100% of High Fire Nat. Gas Flow (3.50×10^6 Btu/h)
A
B
C
Pressure in CAI above atmospheric, PSIG
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Cumulative time after reignition, sec

FIG 4



CAI FLAMEOUT AND REIGNITION SCENARIO
HEPA FILTER DIFFERENTIAL PRESSURE VS. TIME

Fig 5



CAI FLAMEOUT AND REIGNITION SCENARIO
MACH NUMBER OF GAS THROUGH VENTURI SCRUBBER

A = 57% of High Fire Nat. Gas Flow (2.00×10^6 Btu/h)
B = 80% of High Fire Nat. Gas Flow (2.81×10^6 Btu/h)
C = 100% of High Fire Nat. Gas Flow (3.50×10^6 Btu/h)

Fig 6

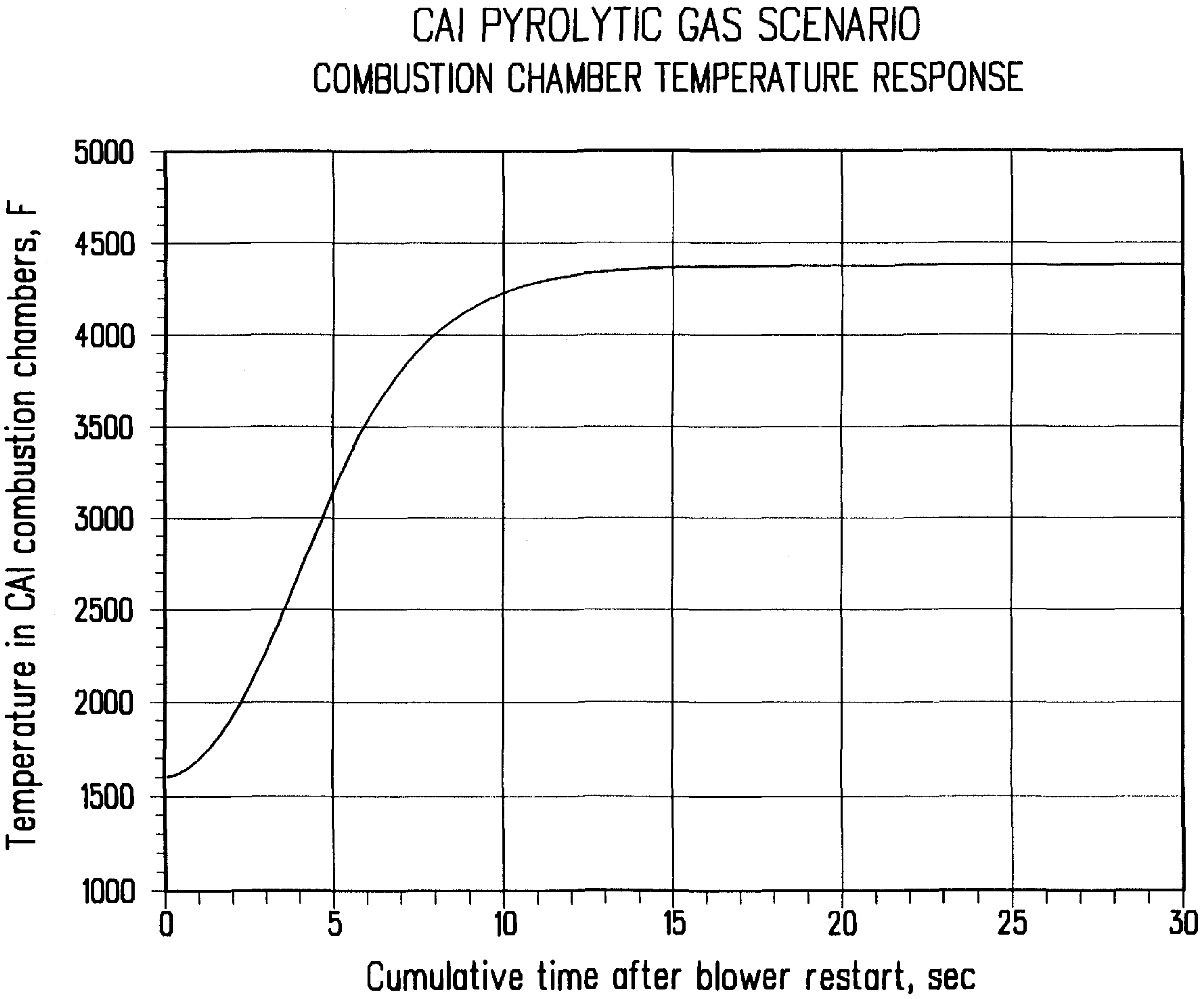
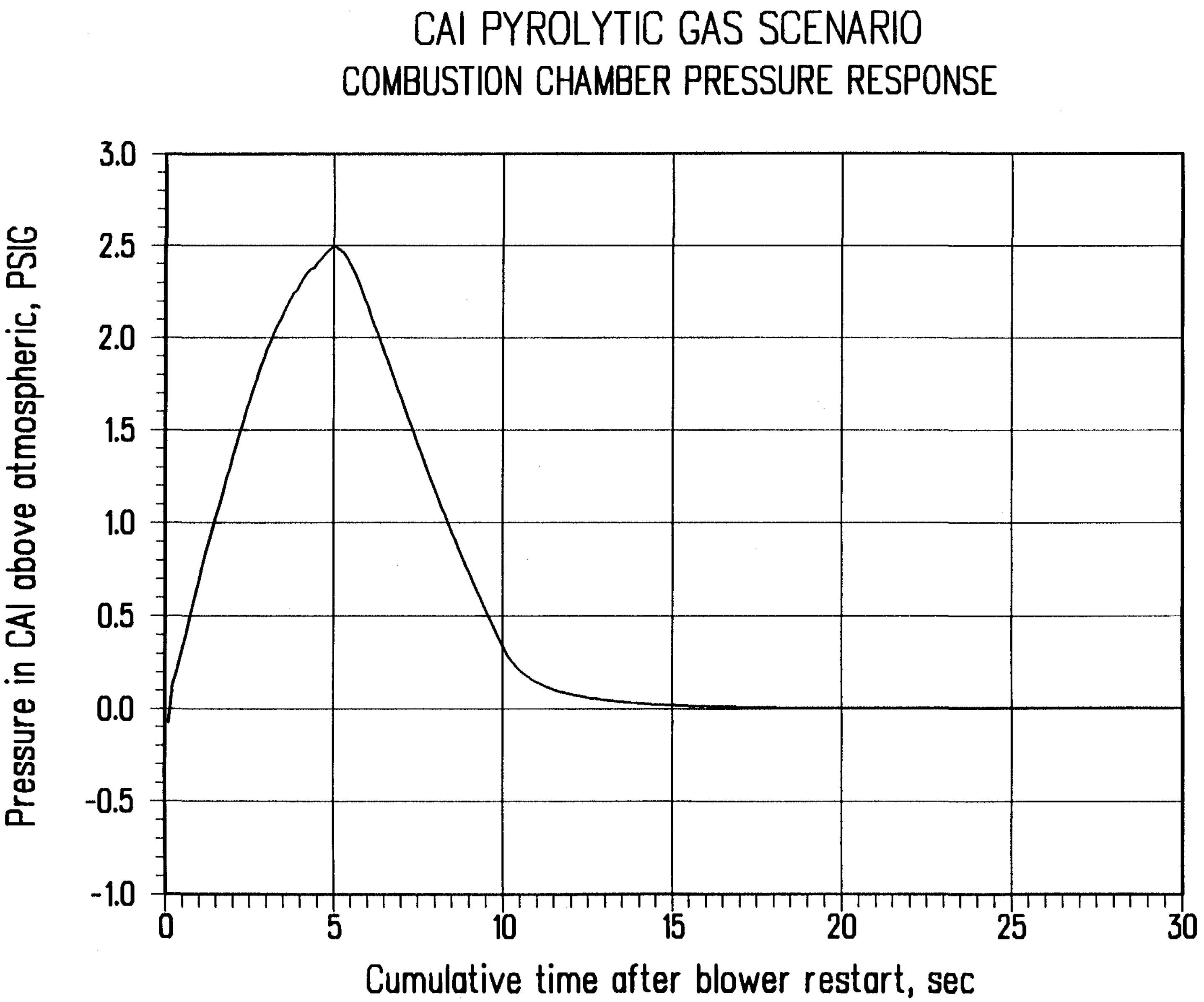

CAI PYROLYTIC GAS SCENARIO
COMBUSTION CHAMBER TEMPERATURE RESPONSE
Temperature in CAI combustion chambers, F
5000
4500
4000
3500
3000
2500
2000
1500
1000
0
5
10
15
20
25
30
Cumulative time after blower restart, sec

Fig 7



CAI PYROLYTIC GAS SCENARIO
COMBUSTION CHAMBER PRESSURE RESPONSE

Fig 8

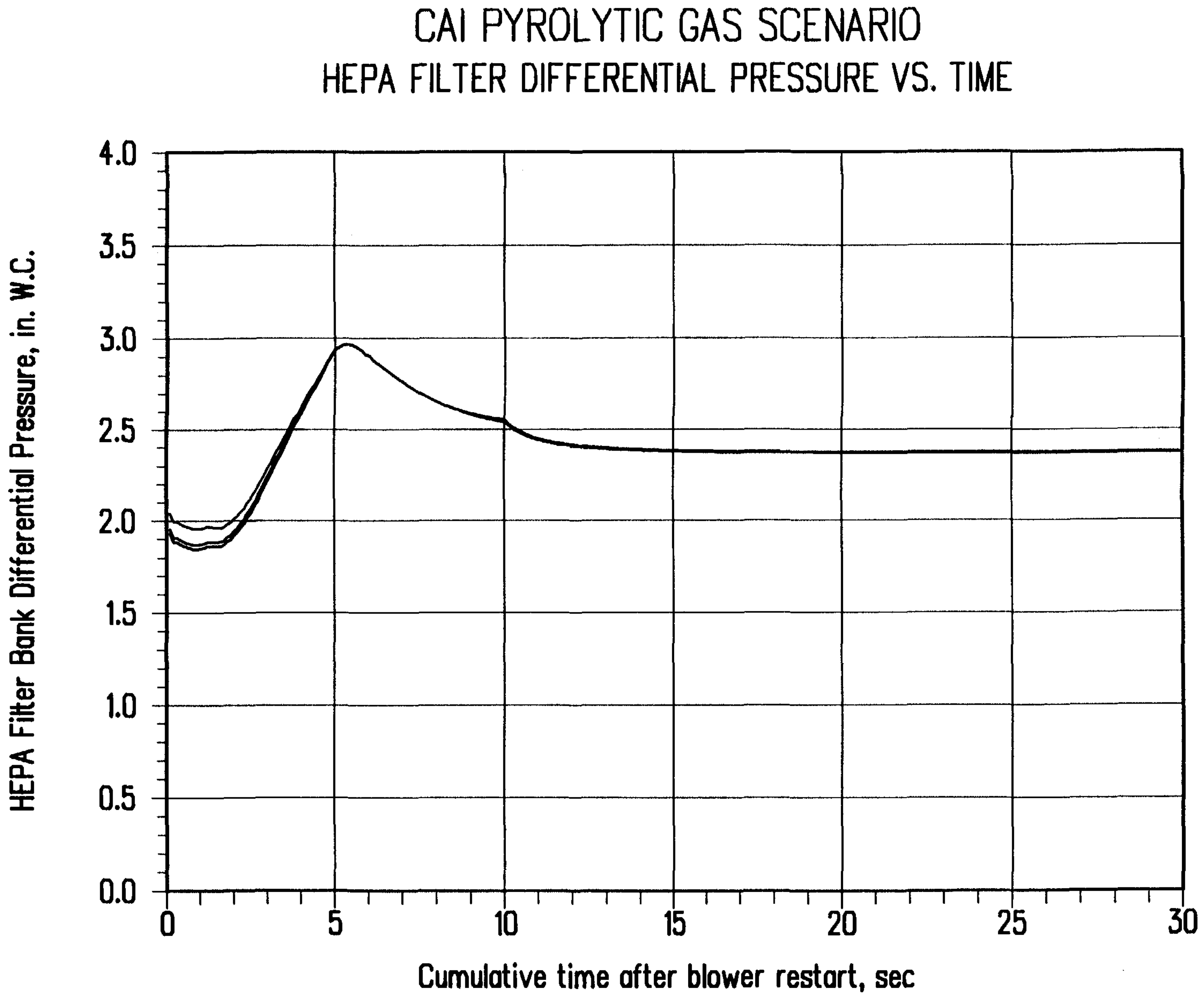

CAI PYROLYTIC GAS SCENARIO
HEPA FILTER DIFFERENTIAL PRESSURE VS. TIME
HEPA Filter Bank Differential Pressure, in. W.C.
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
Cumulative time after blower restart, sec

Fig 9

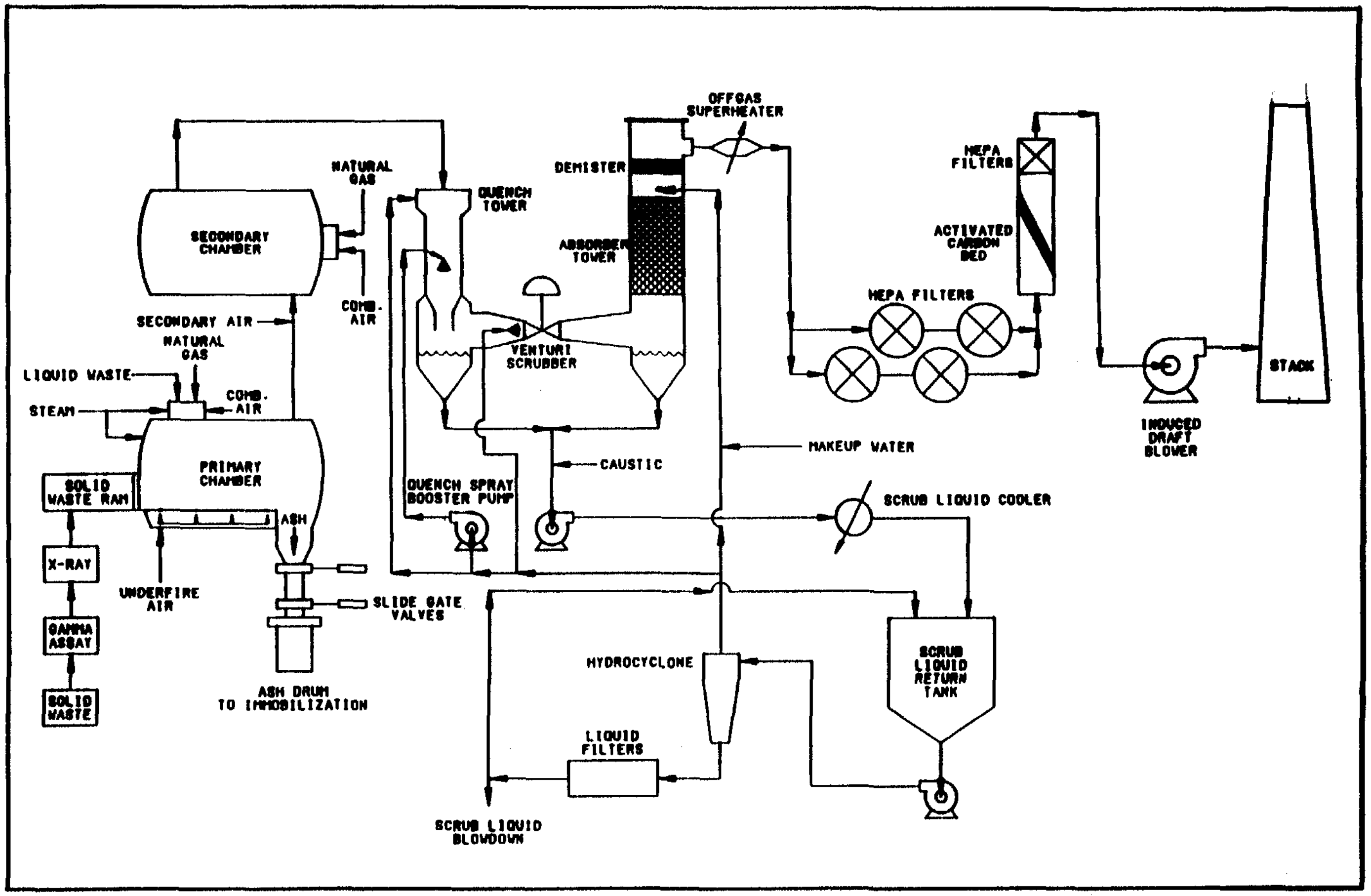

OFFGAS SUPERHEATER
NATURAL GAS
DEMISTER
HEPA FILTERS
QUENCH TOWER
SECONDARY CHAMBER
ACTIVATED CARBON BED
ABSORBER TOWER
COMB. AIR
HEPA FILTERS
SECONDARY AIR
NATURAL GAS
VENTURI SCRUBBER
STACK
LIQUID WASTE
COMB. AIR
STEAM
INDUCED DRAFT BLOWER
MAKEUP WATER
PRIMARY CHAMBER
CAUSTIC
SOLID WASTE RAM
QUENCH SPRAY BOOSTER PUMP
SCRUB LIQUID COOLER
ASH
X-RAY
UNDERFIRE AIR
SLIDE GATE VALVES
GAMMA ASSAY
HYDROCYCLONE
SCRUB LIQUID RETURN TANK
SOLID WASTE
ASH DRUM TO IMMOBILIZATION
LIQUID FILTERS
SCRUB LIQUID BLOWDOWN

Fig 1

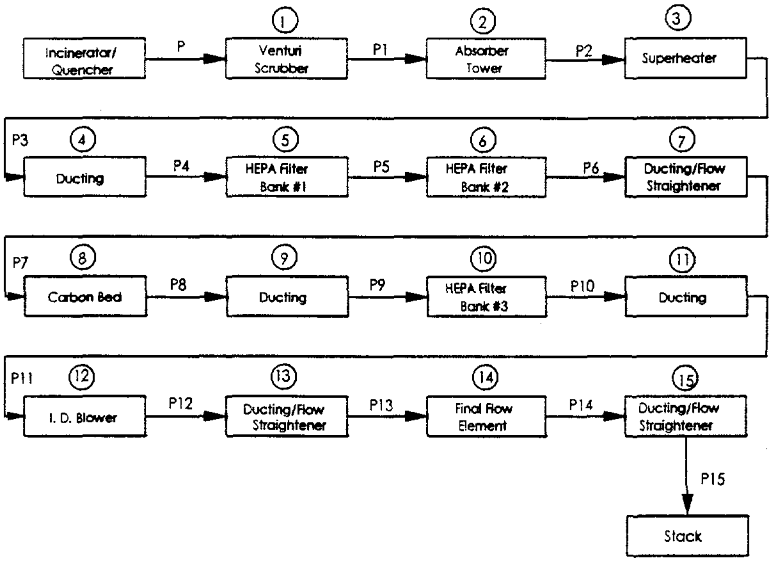
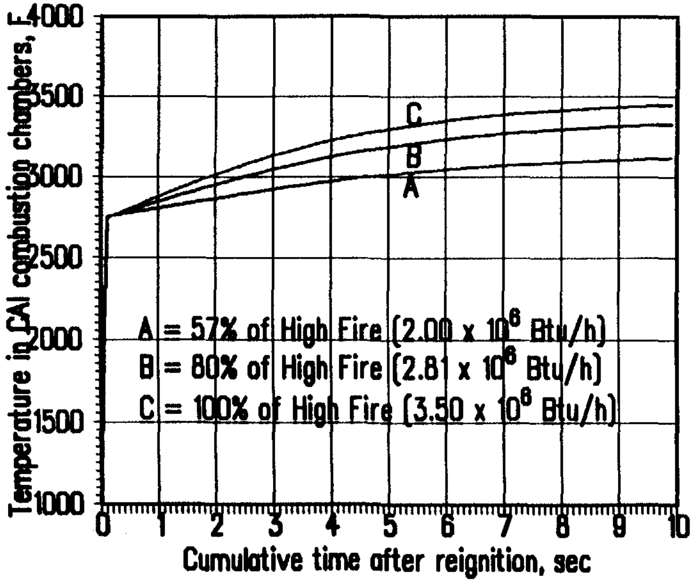
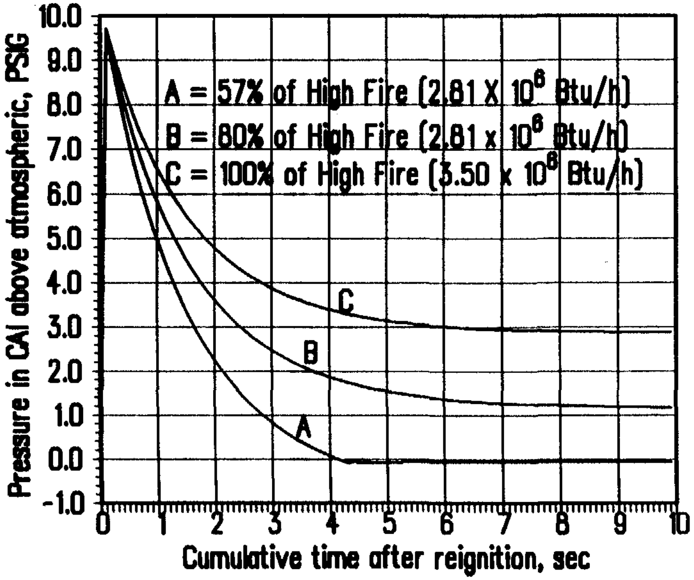

Incinerator/ Quencher
P
①
Venturi Scrubber
P1
②
Absorber Tower
P2
③
Superheater
P3
④
Ducting
P4
⑤
HEPA Filter Bank #1
P5
⑥
HEPA Filter Bank #2
P6
⑦
Ducting/Flow Straightener
P7
⑧
Carbon Bed
P8
⑨
Ducting
P9
⑩
HEPA Filter Bank #3
P10
⑪
Ducting
P11
⑫
I. D. Blower
P12
⑬
Ducting/Flow Straightener
P13
⑭
Final Flow Element
P14
⑮
Ducting/Flow Straightener
P15
Stack

Fig 2



Temperature in CAI combustion chambers, F
4000
3500
3000
2500
2000
1500
1000
0
1
2
3
4
5
6
7
8
9
10
Cumulative time after reignition, sec
C
B
A
A = 57% of High Fire (2.00 x 10^6 Btu/h)
B = 80% of High Fire (2.81 x 10^6 Btu/h)
C = 100% of High Fire (3.50 x 10^6 Btu/h)

Fig 3



A = 57% of High Fire (2.81 X 10^6 Btu/h)
B = 80% of High Fire (2.81 x 10^6 Btu/h)
C = 100% of High Fire (3.50 x 10^6 Btu/h)
A
B
C
Pressure in CAI above atmospheric, PSIG
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
0
1
2
3
4
5
6
7
8
9
10
Cumulative time after reignition, sec

Fig 4

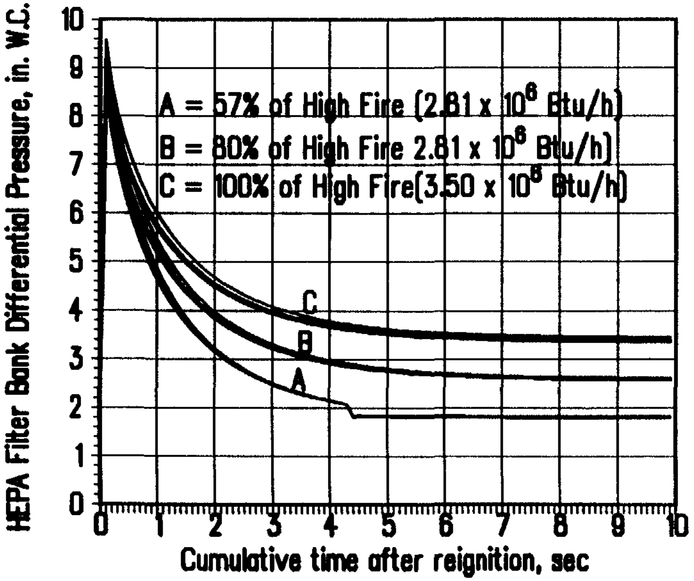

HEPA Filter Bank Differential Pressure, in. W.C.
10
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
9
10
Cumulative time after reignition, sec
A = 57% of High Fire (2.81 x 10^6 Btu/h)
B = 80% of High Fire 2.81 x 10^6 Btu/h)
C = 100% of High Fire(3.50 x 10^6 Btu/h)
C
B
A

Fig 5

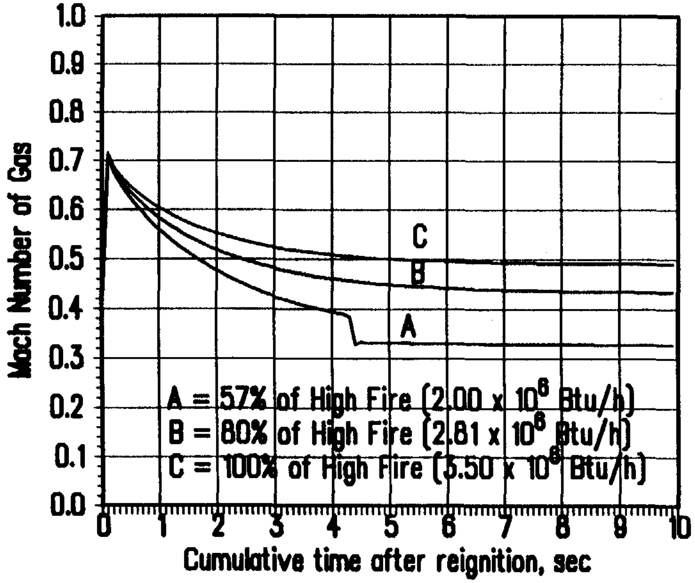

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Mach Number of Gas
0
1
2
3
4
5
6
7
8
9
10
Cumulative time after reignition, sec
C
B
A
A = 57% of High Fire (2.00 x 10^6 Btu/h)
B = 80% of High Fire (2.81 x 10^6 Btu/h)
C = 100% of High Fire (3.50 x 10^6 Btu/h)

Fig 6

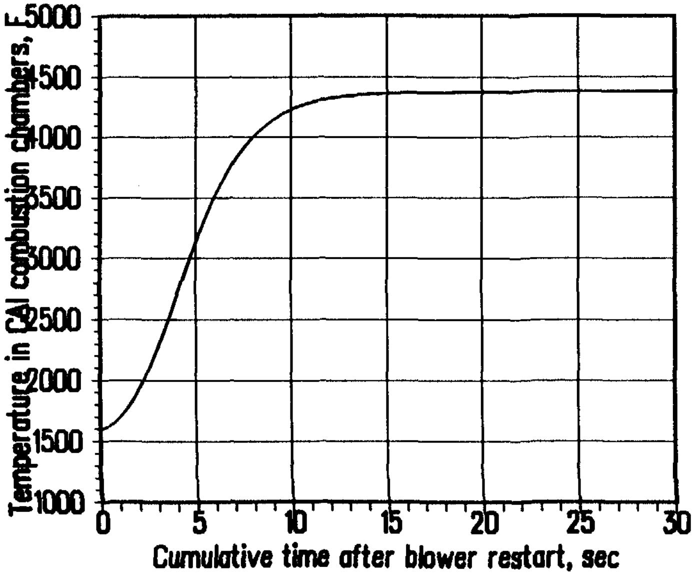

Temperature in CAI combustion chambers, F
5000
4500
4000
3500
3000
2500
2000
1500
1000
0
5
10
15
20
25
30
Cumulative time after blower restart, sec

Fig 7

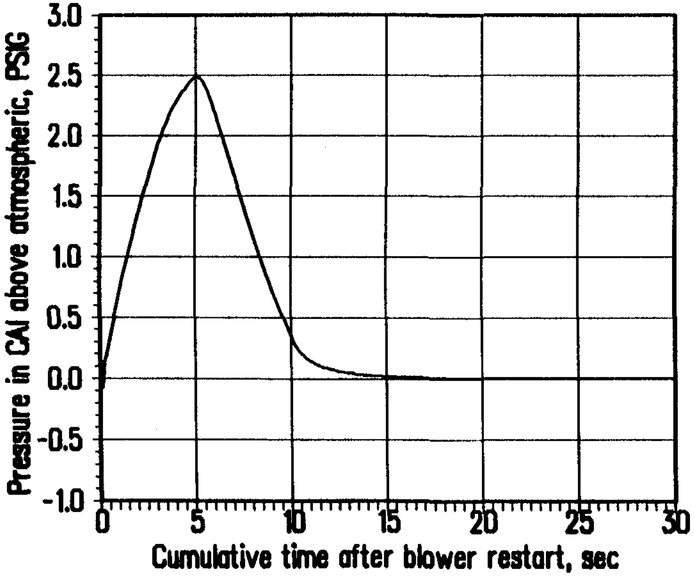

3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
Pressure in CAI above atmospheric, PSIG
0
5
10
15
20
25
30
Cumulative time after blower restart, sec

Fig 8

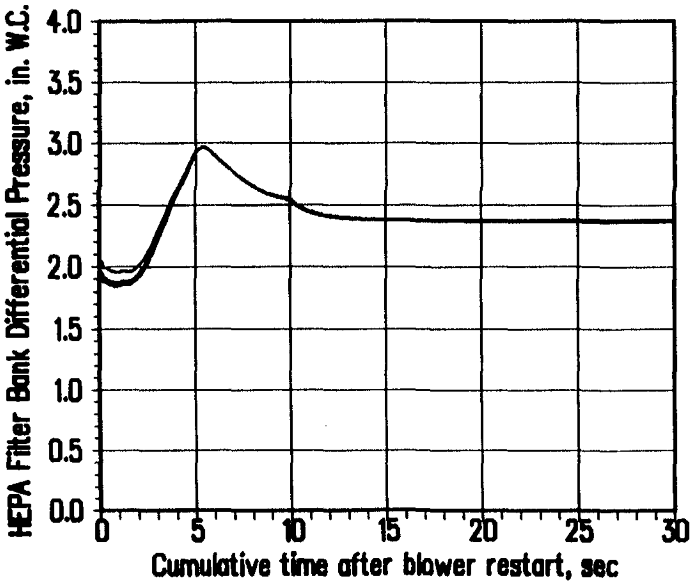

HEPA Filter Bank Differential Pressure, in. W.C.
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
Cumulative time after blower restart, sec

Fig 9