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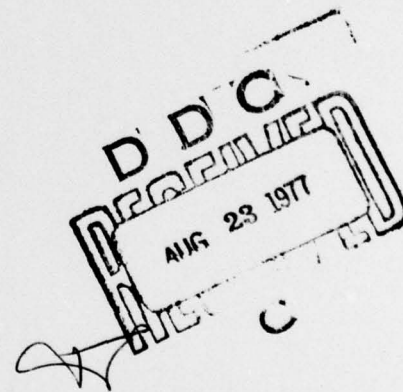
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Calculation of Gas Temperatures in N₂ Pressurization Experiments

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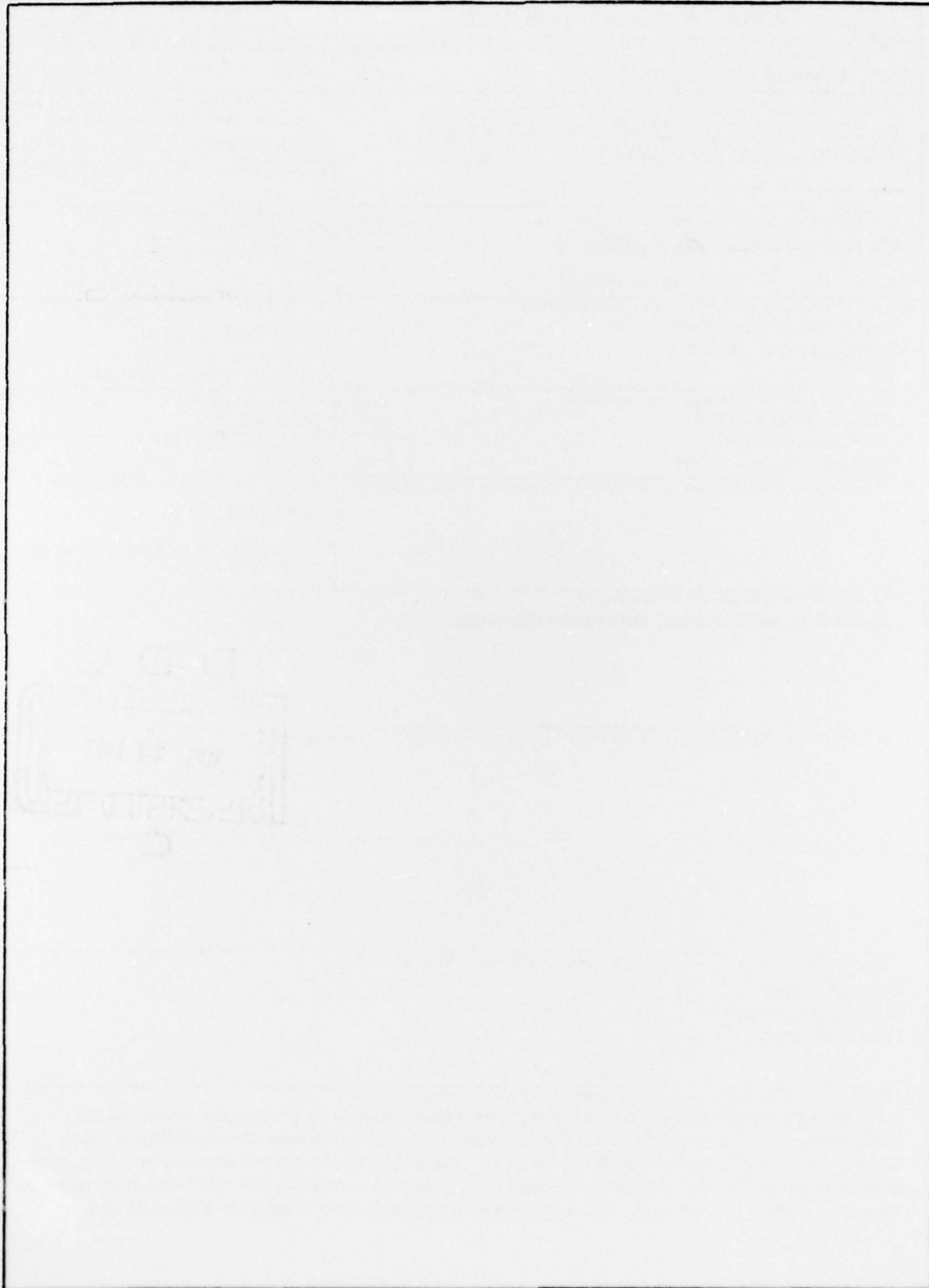
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CALCULATION OF GAS TEMPERATURES IN N₂ PRESSURIZATION EXPERIMENTS

INTRODUCTION

A series of experiments in mixing and combustion have been initiated by the Chemistry Division at NRL to look at the use of nitrogen pressurization to control fires in enclosed areas.¹ In conjunction with these experiments we have performed calculations to determine the differences between the initial and final temperatures and to determine the temperature extremes to be expected.²

Experiments using successively larger size chambers have been made to determine the acceptable range of operational parameters. Tests on chambers of one cubic meter showed that introducing nitrogen in the chamber to pressures of 1.6 - 2 atmospheres would extinguish fires in short times. However, initial tests on larger chambers, 5 - 10M³ did not confirm the small chamber results and indicated that no simple scaling laws applied. A series of mixing studies is now being carried out to clarify this problem.

It has been proposed that thermocouples be used to measure temperature in these initial mixing studies. For thermocouples to work we require a sufficient temperature difference between the incoming gas and the gas initially in the tank. If the difference is too small, the signal to noise ratio in the thermocouples will not be sufficient to make meaningful measurements possible.

The calculation presented below determines these temperature differences for the extremes of unmixed and uniformly mixed gases in

Note: Manuscript submitted June 13, 1977.

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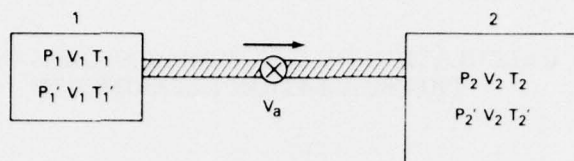


Fig. 1 — Schematic of the pressurization experiment showing the high pressure tank (Volume 1) and the test chamber (Volume 2). The valve (V_a) controls the final pressure (P_2') in the test chamber.

the experimental chamber. We find that as long as the initial temperature in the high pressure tank is less than in the experimental chamber, the temperature difference should be sufficient for temperature to be used as a diagnostic.

EXPERIMENTAL SET-UP

The experimental system is shown schematically in Fig. (1). The smaller tank is at a high pressure, between 5 and 10 atmospheres, and the larger test chamber is initially at atmospheric pressure. The valve (V_a) releases the gas in Volume 1 which then flows into Volume 2 until the valve is closed. Typically (V_a) might be closed when $P_2' \approx 2$ atmospheres.

The incoming gas will be cooler than the surrounding resident gas due to expansion at the nozzles. If the temperature difference is large enough, thermocouples can be used to determine the degree of mixedness of the gases. The calculations described in the next section yield limits on these temperature differences.

CALCULATION

The model which we are considering bounds the temperature change by two limits. The first is complete mixing and equilibration of the incoming and resident gases. We calculate the average temperature of the combined gas in the large tank (V_2) assuming complete mixing and fast temperature and pressure equilibration. In the second case, we assume adiabatic compression of the resident gas by the incoming gas (piston effect). We calculate the temperature difference between the initial gas and the incoming gas assuming that they do not mix but that the pressure equilibrates adiabatically. During the initial pressurization, we expect the second limit to be correct. The first limit is reached after long times (slow gas flow).

The initial pressures, temperatures and volumes, P_1 , T_1 , V_1 , and P_2 , T_2 , V_2 are known. We also know the final volumes and the pressure in the second tank when the valve is closed (primed quantities).

Numbers being considered for the current experiment are

$$V_1 = 2 \text{ M}^3$$

$$P_2 = 1 \text{ atmosphere}$$

$$P_2' = 2 \text{ atmospheres}$$

$$V_2 = 5 \text{ M}^3$$

$$T_2 = 290^\circ\text{K}.$$

Conservation of mass implies

$$\rho_1 V_1 + \rho_2 V_2 = M = \rho_1' V_1 + \rho_2' V_2, \quad (1)$$

where ρ represents the mass density and M is the total mass of the gases in the system. Conservation of energy yields

$$P_1 V_1 + P_2 V_2 = E = P_1' V_1 + P_2' V_2, \quad (2)$$

where E is the total thermal energy of the gases. M and E are given by the initial conditions. Since the process is adiabatic in Tank 2,

$$P_2 / \rho_2^\gamma = \text{constant} = P_2' / (\rho_2')^\gamma, \quad (3)$$

where $\gamma = C_p / C_v = 7/5$ for air. For the limit of completely mixed gases, these equations are sufficient to find the ratio of final to initial temperatures in tank 2.

$$\frac{T_2'}{T_2} = \frac{P_2' V_2}{\left(\frac{T_2}{T_1} P_1 V_1 + P_2 V_2 \right) - \frac{T_2}{T_1} P_1 V_1 \left(\frac{P_1 V_1 + P_2 V_2 - P_2' V_2}{P_1 V_1} \right)^{1/\gamma}} \quad (4)$$

As an example, consider the simplification of Eq. (4) if $T_1 = T_2$ and $P_2' = 2P_2$. This yields

$$\frac{T_2'}{T_2} = \frac{2P_2 V_2 / P_1 V_1}{(P_1 V_1 + P_2 V_2) / P_1 V_1 - ((P_1 V_1 - P_2 V_2) / P_1 V_1)^{1/\gamma}} \quad (5)$$

where $1/\gamma = 0.71$ for air. Given the experimental parameters mentioned earlier and $T_1 = T_2 = 290^\circ\text{K}$, Eq. (5) is plotted in Fig. (2) as a function of P_1 .

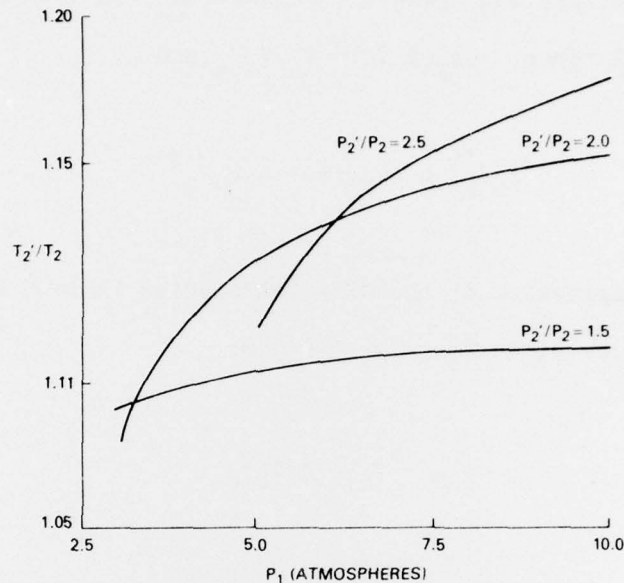


Fig. 2 — Ratio of final to initial temperature in tank #2 as of function of P_1 (initial pressure in tank 1) and P_2' , the final pressure in tank 2

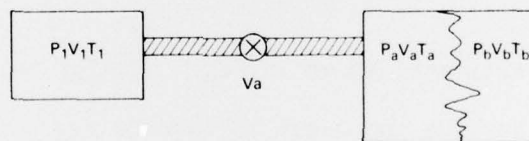


Fig. 3 — Schematic of adiabatic compression without mixing of gases

Thus the final temperature of the mixed gases in equilibrium can be as much as 15% higher than it was initially.

The next question is what is the expected maximum temperature difference between the two gases if they do not mix immediately. Consider the incoming gas to be separated at all times from the gas which is initially resident in tank 2. The initial gas is compressed adiabatically as if it were separated by a flexible membrane from the incoming gas as shown in Fig. (3).

We assume here that pressure equilibrates in tank 2, that is $P_a = P_b$ at all times. Using $V_2 = V_a + V_b$ and

$$P_b V_b^\gamma = \text{constant} = P_2 V_2^\gamma \quad (6)$$

(adiabatic compression of the original species in tank 2), together with mass conservation ($m_2 = m_a + m_b$) or

$$\rho_2 V_2 = \rho_a V_a + \rho_b V_b \quad (7)$$

we arrive at

$$\frac{T_b}{T_a} = \frac{(P_2'/P_2)(T_2/T_2') - 1}{(P_2'/P_2)^{1/\gamma} - 1} \quad (8)$$

Thus we have an estimate, shown in Fig. (4), for the maximum temperature difference for the two gases in tank 2.

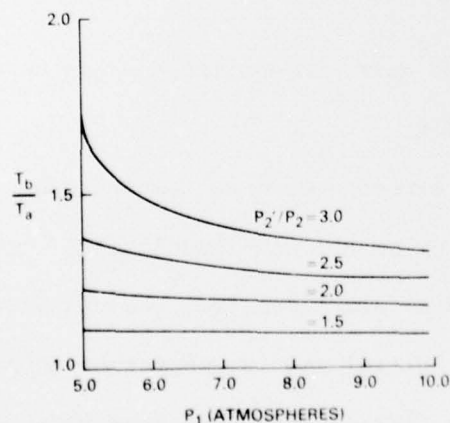


Fig. 4 -- The ratio of temperature of the gas resident in tank 2 (T_b) to the incoming gas (T_a). This ratio is shown as a function of the initial pressure in tank 1 (P_1) and the final pressure in tank 2 (P_2').

Finally, Fig. (5) shows the effect on the ratio (T_b/T_a) , for a given set of initial and final pressures, and various combinations of initial temperatures (T_2/T_1) . Thus

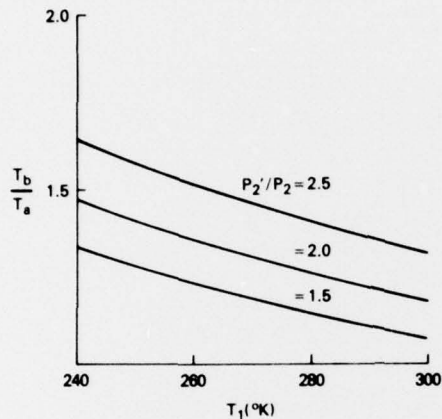


Fig. 5 — The ratio of temperature of the gas resident in tank 2 (T_b) to the incoming gas (T_a). This ratio is shown as a function of the initial temperature in tank 1 (T_1) and final pressure in tank 2 P_2' .

as long as T_1 is less than T_2 , the temperature difference should be sufficient that temperature can be used as a diagnostic in these preliminary nitrogen pressurization experiments.

Acknowledgment

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2. J. Stone, Private communication.