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INERTING AND ATMOSPHERES

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The old aphorism that an atmosphere that will sustain a fire will also sustain life, and vice versa, has been held as fact for a long, long time. Fortunately, this is not true. Fires are dependent primarily on the concentration of oxygen, whereas life is dependent on the partial pressure of oxygen. The two are not synonymous. Before discussing this in more detail, let us first consider that man seems to be ever more determined to encapsulate himself and then place the capsule in exceedingly hostile (if not immediately lethal) surroundings, be it a submarine, a space capsule, or even a high-flying aircraft. Examples of three of these capsules and their internal environments are given in Table I.

The fatal Apollo fire in 1967 in 100 percent oxygen lasted only about 15 sec (ref. 77). Fires in submarines are comparable to those we experience ourselves every day, the atmosphere being essentially air; but in the case of SeaLab, the aquanauts, wanting to smoke, could not even strike a match (ref. 78). All three of these atmospheres supported life for extended periods (the partial pressures of oxygen being close to the same), yet from a fire standpoint, the first was almost explosive and the last would not even support attempted combustion. From table I it is apparent that fire is dependent on the percent of oxygen, whereas life is dependent on the partial pressure of oxygen.

It follows, then, that in an inhabited capsule it should be possible to exercise a certain amount of willful control over fire and still maintain habitability by proper selection of the composition of the atmosphere. This leads to two concepts in the control of fires in confined spaces by controlling atmospheric composition: the first, to lower the overall potential hazard by maintaining the percent oxygen in the capsule below that of air, and the second, to provide for the emergency extinguishment of a fire by sudden flooding with nitrogen. For both cases we are very fortunate that fires are much more sensitive to changes in concentration of oxygen than people are to changes in partial pressure of oxygen. This allows for considerable flexibility in use and control of the atmosphere.

Figure 1 shows the burning rate of paper (held horizontally) as a function of oxygen concentration (refs. 79 and 80), and figure 2 shows that of a liquid fuel (kerosene) at two different total pressures (data from unpublished study by R. Corlett, University of Washington). Figure 3 shows the effect of total pressure on burning of paper at three different oxygen levels (ref. 80). It can be seen from the steepness of the lines in figures 1 and 2 that burning rate is indeed very oxygen sensitive, whereas figure 3 shows that total pressure has a much lesser effect. Slight changes in oxygen concentration also impact on fire parameters other than burning rate, for example, rate of heat release and maximum flame temperature, induction time, minimum ignition temperature, and flammability limits (ref. 81).

The concept of Oxygen Index (i.e., the lowest concentration of oxygen that will just barely support combustion of a given material) is also invoked. Some materials that might burn at 21 percent oxygen, the sea-level air concentration, might *not* at lower values (cf. table II).

It has been shown by many experimenters (refs. 82 and 83) that hydrocarbons (e.g., gasoline) will not burn below 12 to 14 percent oxygen. If the 14-percent value is selected (i.e., 7 percent less than the 21 percent of air), the argument can be made that if one were to lower the oxygen concentration to say 19 percent in a closed environment, this might represent a 2/7 drop in oxygen effectiveness, roughly 30 percent. Does this mean we could get a 30-percent protection in fire spread, heat release, etc.? This is a surprisingly large effect considering how little we changed the percent of oxygen.[1]

On the other hand, as shown in table III, man is surprisingly tolerant of changes in partial pressure. Granted that a sudden change, for example, from sea level to 3700 m, might cause "mountain sickness" in unconditioned people, adaptability to change is still surprisingly fast.

This leads to the two concepts mentioned earlier: (1) long-term protection and (2) emergency extinguishment. At the Naval Research Laboratory, for parochial reasons, we have proposed that submarines operate continuously at 19 percent oxygen (~1-atm total pressure) or slightly below, rather than the maximum 21 percent permitted now. The reason for choosing 19 percent is somewhat arbitrary - it is based on cigarettes still being able to smolder somewhat. Thus, the crew would not have to forego smoking. After all, a smoldering cigarette is also a fire, and at lower oxygen levels it too goes out, with interesting psychological effects on the crew (cf., the first sentence in this paper). For nonsmoking crews in other capsules, the 19-percent-oxygen restriction would not apply. That 19 percent oxygen is quite acceptable to submarine crews has been shown repeatedly by submarines operating under this condition for stretches of 24 hr or longer, often without the crews being aware of it. This is documented by the atmosphere habitability logs of operating submarines.

The bottom line is that we can indeed slow fires down markedly by diluting the atmosphere with an inert gas, such as nitrogen, as long as we stay within physiologically acceptable levels. This buys time, if nothing else, and could spell the difference between an incident and a disaster.

In connection with the concept of sudden extinguishment, our Laboratory has proposed a system that, in the event of a runaway fire in a submarine, will dump 50 kPa (0.5 atm) of nitrogen suddenly into the compartment (ref. 84). Table IV shows the concept. Adding 0.5-atm nitrogen raises the total pressure to 1.5 atm. The concentration of oxygen drops to 14 percent, but the partial pressure of oxygen stays the same. As stated earlier, 14 percent oxygen is in the ball park for the oxygen index for hydrocarbons (ref. 82), and many other combustibles, so the fire should go out. However, experimentation has shown there is a marked scaling effect (ref. 85), as seen in figure 4, but even Class B (liquid fuel) fires are extinguished at about a total pressure increase

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[1]It is recognized that scientifically this is spurious reasoning, but the interesting fact is that what limited data are available tend to bear these numbers out (e.g., figs. 1 and 2).

of 0.7 atm in large chambers. In our diving community this is equivalent to only about 6.7 m (22 ft) of water. The penalty for this system in space applications is that the tankage needed to carry this extra nitrogen would add weight to a capsule. An advantage, however, is that, unless very toxic fire gases are produced, the crew could still live in this atmosphere. This has been demonstrated using rats as test subjects in a chamber in which a sizeable jet fuel fire was extinguished with nitrogen with no ill effects on the rats (ref. 86). Fortunately, or not, we must recognize that the physiology of rats and humans is not that different, so we should be able to extrapolate these results to humans.

Two very significant problems we have demonstrated with fires in confined spaces are that fires get out of hand very much faster than in more normal environments and that temperatures quickly reach lethal levels (ref. 87). Figure 5 shows data for hull insulation fires in a 325-m^3 chamber. The contrast between open and closed hatch operations is very real, and certainly air temperatures of 700 to 800 °C, even for a few seconds, are quickly lethal. (Most previous and extensive "closed" fire experiments have not been performed in hermetically sealed compartments and, therefore, we have been consistently misled about the true ferocity of such fires).

It must be emphasized, of course, that all these experiments and discussions are based on normal gravity. What the effects of low gravity would be remains to be determined.

TABLE I. - ENCAPSULATED ENVIRONMENTS

Capsule	Total pressure		Oxygen,[a] vol %	Oxygen partial pressure[b]	
	kPa	atm		kPa	atm
Apollo	30	0.3	100	30	0.3
Submarine	100	1.0	21	20	.2
Sealab II	710	7.0	4	30	.3

[a]Fires depend on minimum oxygen concentrations.
[b]Human life depends on minimum oxygen partial pressure.

TABLE II. - OXYGEN INDICES

Filter paper	18.2
Cotton	18.6
Rayon	18.9
Sugar	22.0
Red oak	22.7
Wool	23.8
3/4-in. plywood . . .	24.3
3/8-in. plywood . . .	29.2

TABLE III. - OXYGEN PARTIAL PRESSURE IN INHABITED ATMOSPHERES

	Oxygen partial pressure		Elevation	
	kPa	atm	m	ft
Apollo, takeoff mode	110	1.09	----	------
Apollo, flight mode	30 to 37	0.3 to 0.37	----	------
Sea level	21	.21	0	0
Denver, Colorado	18	.175	1520	5 000
Quito, Ecuador	15	.15	2800	9 300
La Paz, Bolivia	14	.134	3660	12 000
Pikes Peak, Colorado	13	.123	4300	14 100

TABLE IV. - EFFECT OF NITROGEN ADDITION

	Capsule pressure		Oxygen, vol %	Oxygen partial pressure	
	kPa	atm		kPa	atm
Start	101	1.0	21	20	0.2
Add N_2	51	.5	--	--	---
Final	[a]152	[a]1.5	14	20	.2

[a]Equivalent to 4.9 m (16 ft) water.

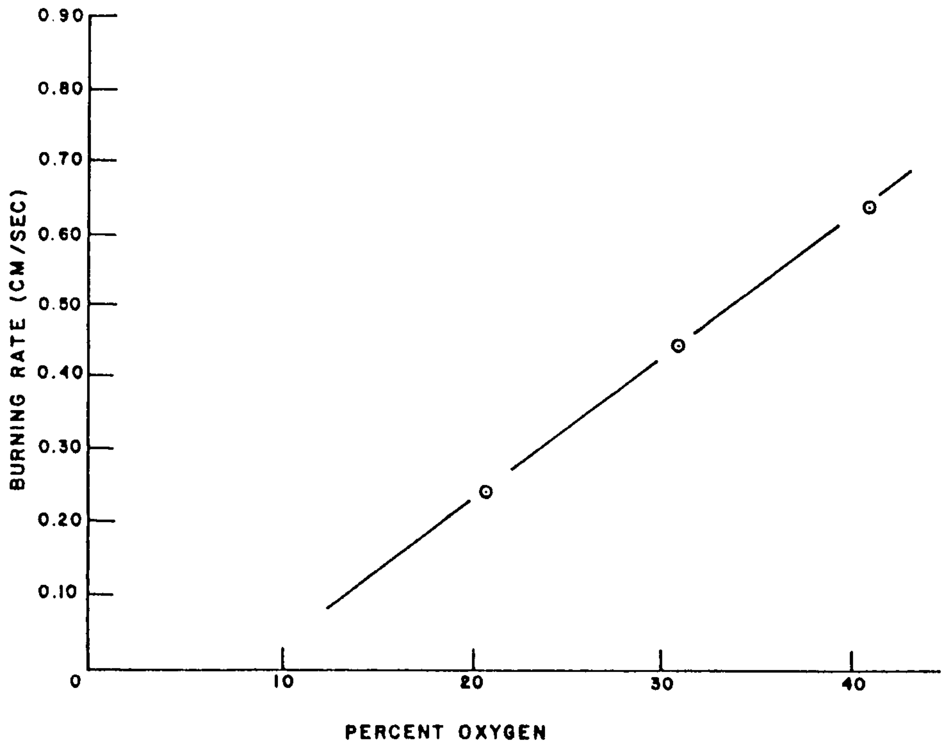

Figure 1. - Burning rate of paper as a function of oxygen concentration at 101 kPa (1 atm).

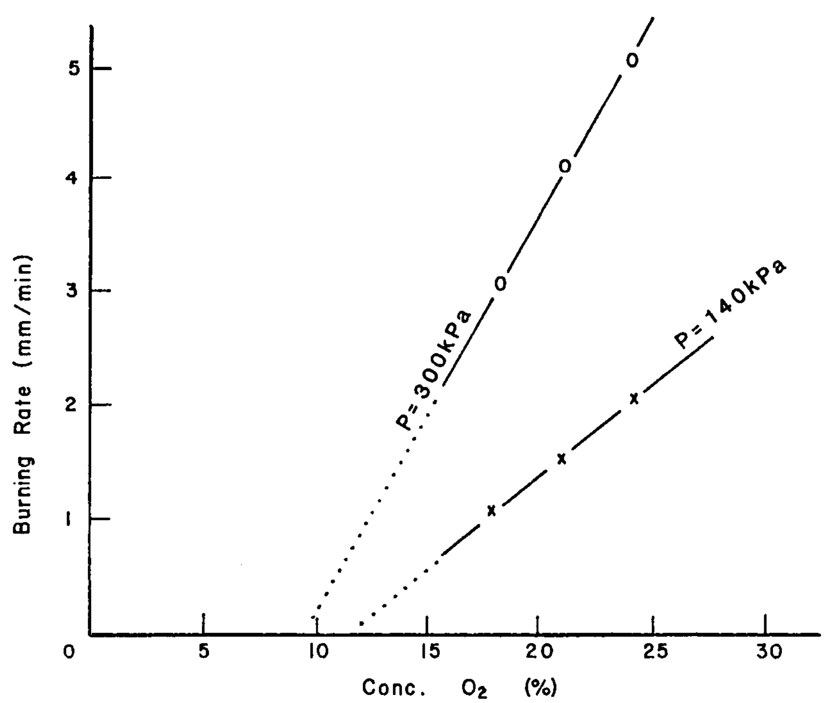

Figure 2. - Burning rate of kerosene as a function of oxygen concentration.

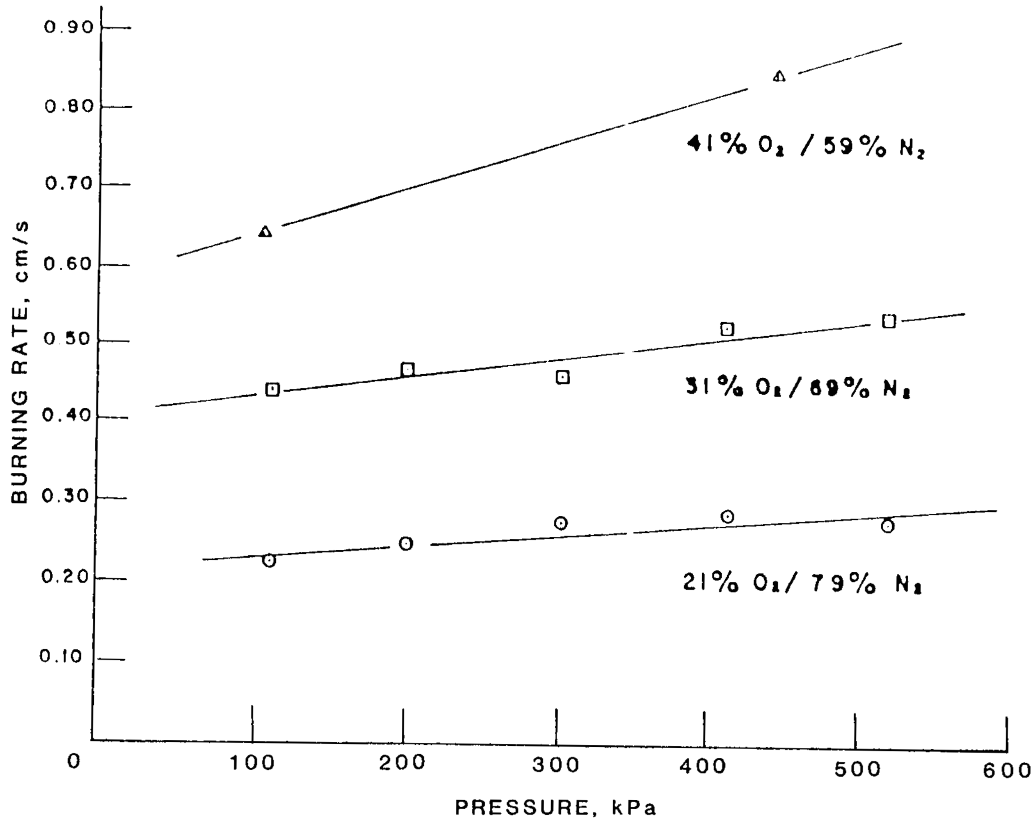

Figure 3. - Burning rate of paper as a function of oxygen concentration and pressure.

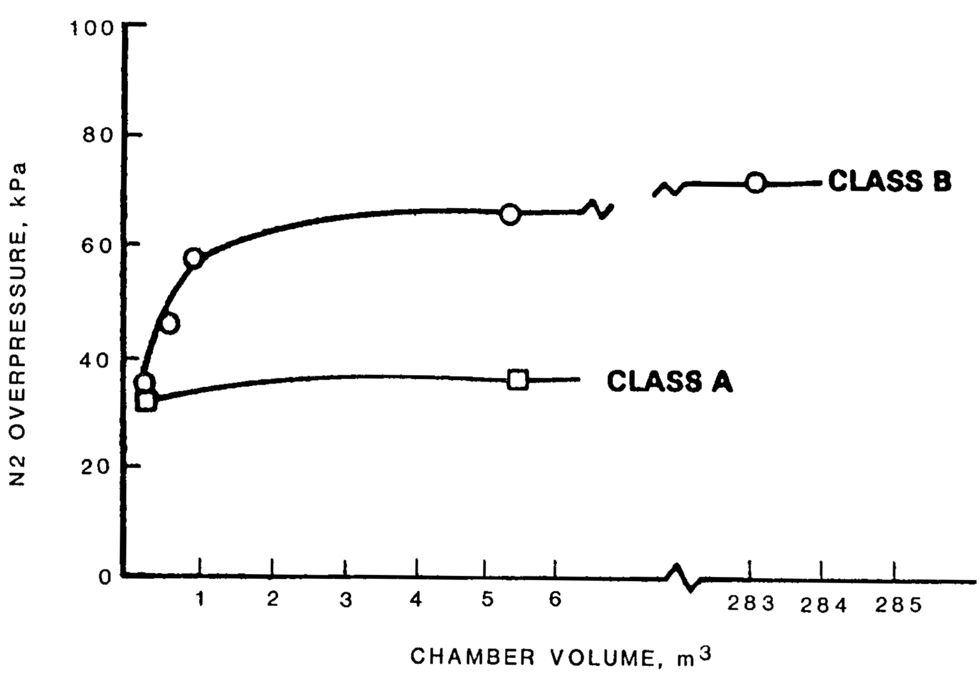

Figure 4. - Nitrogen overpressure necessary to extinguish Class A and Class B fires in various-sized chambers.

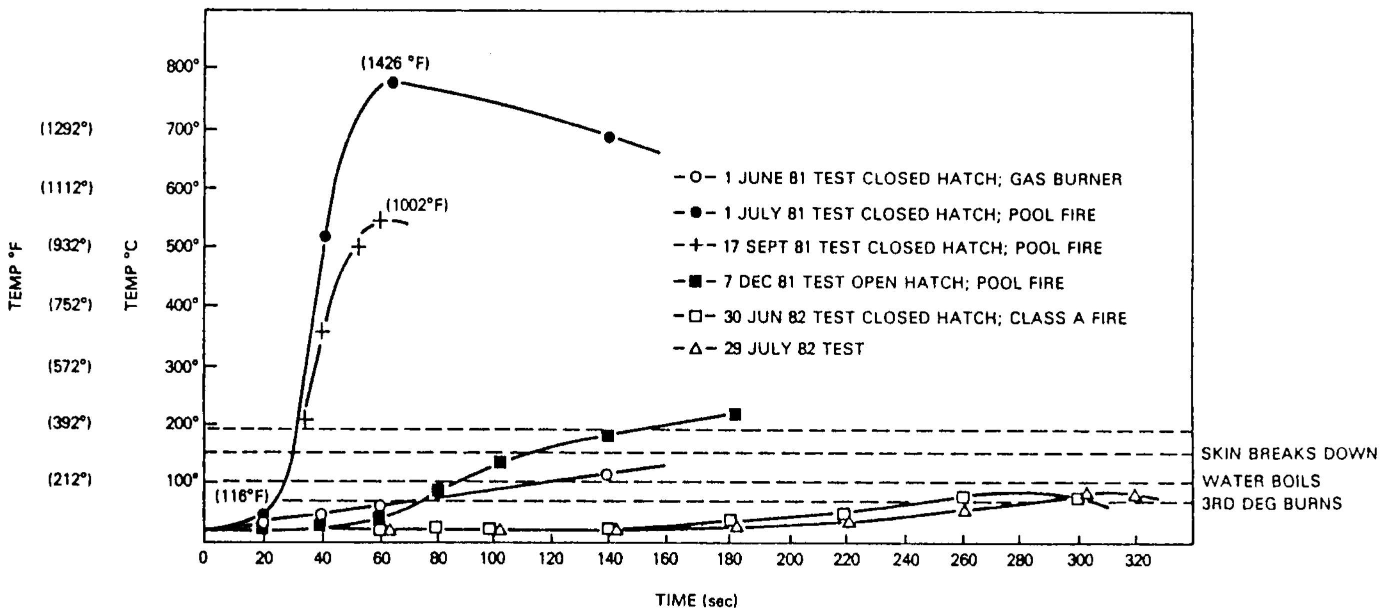

Figure 5. - Temperature histories in various tests in 352-m^3 chamber.