GASEOUS CONTROL OF NUCLEAR REACTORS

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In place of rod control of nuclear reactor power, which has a series of disadvantages (large vertical clearance, unequal heat release, need for vertical reactor configuration), gaseous control may be used [1]. In this case, a gaseous medium or aerosol with a high thermal neutron absorption cross section is introduced into the control channels (tubes). The control process is then reduced to changing the pressure of the gas or aerosol.

The principal problem in designing a working gaseous control system is the choice of neutron-absorbing material, which must exist in the gaseous state up to pressures of at least the order of $8 \cdot 10^6$ N/m² and be stable at high temperatures and under intense γ-irradiation.

Careful analysis of known materials shows that these requirements are satisfied by only a few, namely, the boron hydrides, mercury, BCl_3, BF_3, He^3, and also Gd and Sm (or Sm^{149}) as the solid components of aerosols. Their properties as thermal neutron absorbers (not including scattering effects) are shown in the table. For compounds, the macroscopic absorption cross section is given by

$$\Sigma_a = 0{,}0071\,(m\,\sigma_{a1} + n\,\sigma_{a2} + \ldots)\,\frac{p}{T}\,. \tag{1}$$

Boron hydrides [2] are unstable above 150-200°C; the separated boron settles on the walls of the tubes making control difficult. However, the decomposition process may be retarded at high pressures (this awaits experimental conformation). The use of mercury (or Li^6) requires the introduction of a special preheating arrangement, a serious complication. Thus, at present, the only possible absorbers are BCl_3, BF_3 [1, 2, 3], and He^3 [4]; Gd and Sm [6] may be used in aerosols.

Absorption Properties of Various Materials

Material	Chemical formula	Absorption cross section: barns × 10^{-4}	Absorption cross section: Σ_a, $m^{-1} \cdot 100^{-1}$ at $9{,}81 \cdot 10^4$ N/m² and 20°C	Absorption cross section: Σ_a, $m^{-1} \cdot 100^{-1}$ at $9{,}81 \cdot 10^6$ N/m² and 20°C	t,°C: Melting	t,°C: Boiling	Remarks
Xenon-135	Xe^{135}	350,000	85.000	8500,000	—	— 268.9	Ar 13.3 N/m²
Hexaborane-10	$B_6^{10}H_{12}$	2,394	0,580	58,000	—	0	
Pentaborane-10	$B_5^{10}H_9$	1.995	0.484	48.400	— 46.6	60	
Tetraborane-10	$B_4^{10}H_{10}$	1,596	0.387	38.700	— 120.8	18	
Diborane-10	$B_2^{10}H_6$	0.798	0,194	19.360	— 165.5	— 92.5	
Helium-3	He^3	0,520	0,125	12.500	— 111.7	— 107.8	
Hexaborane	B_6H_{12}	0,453	0,111	11.130	—	0	Ar 13.3 N/m²
Boron-10 trichloride	$B^{10}Cl_3$	0.4085	0.099	9.900	—	12.5	Ar 10^4 N/m²
Boron-10 trifluoride	$B^{10}F_3$	0.399	0.097	9.670	—	— 101	
Pentaborane	B_5H_9	0,378	0.092	9,200	— 46.6	60	
Tetraborane	B_4H_{10}	0,303	0,073	7,340	— 120.8	18	
Diborane	B_2H_6	0,151	0.0365	3,650	— 165.5	— 92.5	Ar 10^4 N/m²
Boron trichloride	BCl_3	0,085	0.021	2.070	—	12.2	
Boron trifluoride	BF_3	0,0755	0.018	1.834	—	— 101	
Gadolinium	Gd	4.600	1405.000	1405.000	1350	3000	
Samarium-149	Sm^{149}	5.000	500.000	500,000	1052	1900	
Samarium	Sm	0.650	164.000	164.000	1052	1900	
Mercury	Hg	0,038	15.450	15.450	— 38.9	357.2	
Boron-10	B^{10}	0,399	552.000	552,000			
Boron-10 carbide	B_4^{10}		472,000	472,000			
Boron	B	0.075	96.600	96.600			
Boron carbide	B_4C		82.600	82.600			

Note: Data for B^{10}, $B_4^{10}C$, B, and B_4C, used in the manufacture of control rods, are shown for comparison.

BCl_3 is stable at high temperatures, does not react with stainless steel, gives off chlorine under neutron irradiation, and does not attack other media. Its critical temperature is 179°C, but it is anticipated that the boiling point at pressures of 30-40 · 10^5 N/m^2 in tank storage will be above normal, so that heating of the tube system outside the reactor may be required.

BF_3 has critical parameters -12.26°C and 49 · 10^5 N/m^2; it is stable with respect to temperature, at least up to 650° C, and does not react with steel when completely dry. Neutron absorption by boron is accompanied by production of lithium, which then reacts with fluorine forming LiF. To prevent corrosion of the tubes, an additive (e. g., ethylene) that will take up free fluorine may be introduced.

He^3 is stable at high temperatures and in all other respects is the most favorable gaseous absorber. Its production presents no difficulty: apart from a series of nuclear reactions, samples of helium strongly enriched in He^3 may be obtained from natural helium by gaseous diffusion and also by a method based on the superfluidity of helium. Neutron absorption in He^3 yields $_1H^3$ and liberates about 0.75 MeV, which corresponds to 20.2 billion joules per kg He^3.

The properties of gadolinium and samarium are given in [6] and elsewhere, and a description of the mechanics of aerosols in [5], etc.

Approximate calculations for some special cases show that when a control rod is replaced by a gas, the diameter of the gas channel must be commensurate with the diameter of the control rod channel (for equal lengths).

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EXACT NUMERICAL SOLUTIONS OF THE BOUNDARY LAYER EQUATIONS FOR PSEUDO-PLASTIC FLUIDS

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The equation of the three-dimensional nonstationary boundary layer for fluids with rheology governed by a power law was derived in [1-3]. We shall consider certain exact solutions of self-similar problems of the boundary layer equations of pseudo-plastic fluids.

Flat permeable plate. We shall seek a solution of the two-dimensional stationary problem in the form

$$u = U_\infty \frac{dF}{d\eta} = U_\infty F', \quad \eta = y \left[\frac{U_\infty^{2-n} \rho}{n(n+1)kx} \right]^{\frac{1}{n+1}}, \qquad (1)$$

$$v = \frac{1}{1+n} x^{-\frac{n}{1+n}} \left[n(1+n) U_\infty^{2n-1} \frac{k}{\rho} \right]^{\frac{1}{1+n}} (\eta F' - F).$$

Then the equations of motion and the boundary conditions are

$$|F''|^{n-1} F''' + FF'' = 0,$$

$$F(0) = N, \quad F'(0) = 0, \quad \lim_{\eta \to \infty} F' = 1. \qquad (2)$$

Numerical integration of system (2) enables one to determine the friction losses. The total friction drag