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DIRECT IN-VESSEL APPLICATIONS EXPERIMENTS
AT HARVARD AIR CLEANING LABORATORY

Progress Report
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ABSTRACT

Experimental research on emergency direct in-vessel air cleaning systems for the LMFBR is described in this second quarterly progress report. Results which characterize the aerosol from 1 lb. sodium pool fires made in a 90 m³ chamber are presented. The effective use of turbulent agglomeration to enhance aerosol sedimentation is described. The composition of the aerosol as determined by atomic absorption and chemical tests is discussed. Results from small scale sodium aerosol scavenging tests are presented, anticipating large-scale powder dispersal tests to be conducted in the chamber. Plans for testing the sonic agglomeration characteristics of sodium aerosols are discussed.

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SUMMARY OF BASELINE TESTS

In the second quarter of research we established a baseline concentration decay profile for 1 lb. sodium fires in the 90 m³ chamber at approximately 20% initial relative humidity. This baseline represents data averages from eight fires (see Figure 1). The natural decay of the aerosol by gravitational settling in the chamber gives a dose reduction factor in 2 hours of 1.45 when measured from the peak concentration point. This DRF-2 hour value corresponds closely to the stirred settling of a spherical 4 μm monodisperse aerosol particle with a true density of 1.0 gm/cm³. Scaling up the response of this aerosol for a 30 m high chamber gives a DRF-2 hour of 1.05.

The mass median diameter (MMD) and geometric standard deviation (GSD) of the baseline aerosol cloud were determined by Andersen impactor tests and found not to vary appreciably with time during the settling period as shown in Figures 2 and 3. This behavior suggests there may be processes present that are analogous to those involved in the "self-preserving" aerosol size distribution postulated by Friedlander, et al.³ For 1 lb. Na fires at 20% R.H., the average MMD was 3.2 μm and the average GSD was 1.6. These size measurements are fairly consistent with results from sodium pool fire burns conducted earlier by Atomics International (e.g., Figures A.1.10 and A.1.11 of Reference 4) where the GSD over the period covered by our measurements is in the range 1.4 to 1.6 and the MMD is slightly over 3 μm for several hundred minutes. The measured ratio of chamber floor to chamber wall mass deposits per unit area was in the range of 10 to 80. The spread was caused in part by uncertainty concerning the measurement of the very low wall deposits collected on filter papers.

TURBULENT AGGLOMERATION TESTS

The first full chamber tests of a direct precipitation method involved the use of turbulence to enhance agglomeration and speed up sedimentation. By means of a large (3000 cfm) centrifugal recirculating blower placed in the center of the chamber that was started shortly after the peak concentration was reached, we were able to achieve dramatic increases in the DRF-2 hr value. The time decay histories of these tests are presented in Figure 4. The DRF-2 hr values ranged from 4.2 to 8.2. In an effort to separate the relative effects of centrifugal air cleaning in the blower shroud from the effect of turbulence enhanced agglomeration and sedimentation, the blower was run with and without the fan shroud in place. Operation with the shroud off takes away a major surface for centrifugal deposition, though some cleaning credit must still be taken because of particle impaction on the fan blades. Removing the shroud did not, however, dramatically change the DRF-2 hr from shroud-on performance as can be seen in Figure 4.

It is likely that turbulence is causing agglomeration to proceed rapidly, with the result that large particles of the order of 100 μm or more can be seen uniformly deposited on horizontal surfaces near chamber view ports. It is difficult to determine whether most of the agglomeration occurs in the strong velocity gradients near the fan or whether induced turbulence in other parts of the chamber cause most of the agglomeration. The particle size distribution, as measured by an Andersen impactor, shows a definite decrease in MMD with time as the large agglomerates settle in the chamber (see Figure 2). The GSD also increases with time, (see Table 1). That the MMD should decrease with time is not surprising, since it is clear that turbulent agglomeration and sedimentation can rapidly deplete the larger size particles. To explain the increasing GSD, one observes that depletion of large particles because of inertial effects from turbulence is not accompanied by a proportionate loss of submicrometer particles. This results in a broadening range of the size distribution.

The turbulence tests demonstrate that DRF-2hr values near the design level of 10 are readily achievable for vessels 4 meters in height. Simple scale-up to containment vessel dimensions would likely yield less dramatic DRF's unless more energetic, smaller scale turbulence was induced.

CHEMICAL COMPOSITION OF THE AEROSOL

Chemical and physical tests were performed to determine the composition of some of the filter samples. Sodium deposit measurements indicated high ratios of total sample mass to sodium mass; ratios often much larger than would be associated with a nonhydrated sodium compound. The conclusion is that a large percentage of the sodium compounds on the filter sample (see Table 2) is hydrated. The data indicate the presence of mixtures of the following compounds: Na_2CO_3 , $\text{Na}_2\text{CO}_3 \cdot 7 \text{H}_2\text{O}$, and $\text{Na}_2\text{CO}_3 \cdot 10 \text{H}_2\text{O}$. Tests for sodium peroxide (Na_2O_2) indicated the presence of less than 0.5% of that compound. Nearly all the non-water fraction of each filter deposit was in the form of Na_2CO_3 with a negligible amount as NaOH . Apparently the chamber contains sufficient natural CO_2 (~50 gm) to stoichiometrically produce the level of Na_2CO_3 deposits seen on our filters for the 1 lb. sodium burns. The reaction of carbonate formation from the initial sodium oxide and sodium superoxide combustion products is:

and

followed by,

We have tested filter samples from a recent 4 lb. burn and found that the samples show significant sodium oxide and sodium hydroxide content since the available chamber CO_2 of about 50 gm had been exhausted in the initial carbonate formation.

AEROSOL SCAVENGING TESTS

We are in the process of completing experimental work with turbulence effects which was started early because of its promise and ease of implementation. We next intend to study inert dust injection as a means of gravimetrically scavenging the sodium aerosol. Theoretical studies indicate that the optimum scavenging particle size for the sodium aerosol is in the range 200 to 400 μm for dense metallic particles and nearer 600 μm for particles with density close to 1.0 gm/cm^3 . We acquired an Acrisonic Model 120 dust feeder which will deliver dust to a rotary dust dispenser near the chamber ceiling to produce uniform distribution throughout the volume. Inasmuch as Na_2CO_3 is a major compound formed when small amounts of sodium are burned in a large chamber, it would be preferable to use calcium carbonate rather than sodium carbonate for the scavenging dust experiments to be able to distinguish the two chemically for mass measurements of settling progress. Because sodium carbonate is the recommended fire suppressant for sodium fires, dust experiments will be conducted with this powder, also, and the results judged by noting the relative rate of opacity clearing.

Some tests were made to determine the scavenging efficiency of iron and lead shot with respect to the sodium aerosol at conditions near peak concentration. The shot, dropped from a hole in the chamber ceiling, fell 7 feet into a cup containing de-ionized water that was placed underneath a vertical sampling port in the test bay. Analyzing the water for sodium and taking into account the increased ratio of aerosol compound mass to sodium mass gave a measure of scavenging efficiency. The data from these tests, shown in Table 3, do not always correspond to the Langmuir scavenging efficiency for spheres quoted by Fuchs because the spheres do not reach terminal velocity instantly.¹ Langmuir Scavenging Efficiency:

$$\epsilon = \frac{(\text{Stk})^2}{(\text{Stk} + .25)^2}$$

$$\text{where } \text{Stk} = \frac{2\tau V_o}{D_s}$$

τ = aerosol relaxation time

V_o = settling velocity of scavenging particles

D_s = diameter of scavenging particles

Further tests are needed to resolve questions about the scavenging results. Before conducting full chamber scavenging tests we would like to know how well the Langmuir formula applies to sodium aerosols in order to optimize scavenging particle diameter.

ACOUSTIC AGGLOMERATION TESTS PLANNED

We have surveyed the literature on acoustic agglomeration of aerosols in an effort to determine its applicability to the task at hand. An information gathering visit was made to Dr. David Scott's group at the University of Toronto which has been conducting sonic agglomeration experiments using progressive saw-tooth waveforms instead of the usually employed standing waves. The most important finding was that the University of Toronto people view "acoustic turbulence" as a more important mechanism of sonic agglomeration than linear oscillatory relative motion between different sized particles². Our aim is to plan for acoustic agglomeration experiments to be done in our chamber, making good use of input from Scott and others at Toronto. We have purchased a Dyna-Jet pulse jet engine for the purpose of planning for sonic agglomeration experiments.

REFERENCES

1. Fuchs, N.A., The Mechanics of Aerosols, New York, Pergamon Press, 1964.
2. Rennick, Donald F. and Scott, David S., "Interactions Between Aerosols and Single and Multiple Finite-Amplitude Acoustic Fields," University of Toronto, Mechanical Engineering Department, to be published.
3. Lai, F.S., Friedlander, S.K., Pich, J., and Hidy, G.M., "The Self-Preserving Particle Size Distribution for Brownian Coagulation in the Free-Molecule Region," Journal of Colloid and Interface Science, Vol. 39, No. 2, May 1972, p. 395.
4. Gieseke, James A., Behn, Robert C., Chace, Allan S., and Reed, Larry D., "Analytic Studies of Aerosol Behaviour Predictions for Fast Reactor Safety," Topical Report, Task 56, Battelle Columbus Laboratories, 1975.

Table 1

VARIATION OF GSD DURING TURBULENCE TESTS

<u>Run #</u>	<u>Time of Sample (Minutes)</u> <u>from Burn Start</u>	<u>GSD</u>	<u>Blower Start Time</u> <u>(minutes)</u>
R-14	75	1.82	40
	168	2.13	
	263	3.64	
R-15	91	1.68	55
	197	1.81	
R-16	45	1.69	38
	217	1.75	

Table 2

RATIO OF TOTAL FILTER DEPOSIT MASS TO SODIUM MASS

<u>Run</u>	<u>Time of Sample</u> (minutes after burn start)	<u>M_{tot}/M_{Na}</u>	<u>% of Deposit Mass</u> <u>Assumed to be H₂O</u> (assumes primary com- pound is Na ₂ CO ₃)
R-12	11.5	2.82	18.3
	21.5	4.20	45.1
	31.5	4.62	50.1
	61.5	4.41	47.7
	145.5	5.53	58.3
	181.5	5.80	60.3
	241.5	4.36	47.1
	338.0	5.29	56.4
	1375.0	4.65	50.4
R-13	12.5	3.62	36.3
	21.5	3.53	34.7
	31.5	3.42	32.6
	41.5	3.57	35.5
	59.5	4.72	51.2
	143.5	2.96	22.2
	171.5	2.96	22.2
	233.5	2.97	22.4
	299.5	2.93	21.4
	349.5	5.98	61.5
R-16	22.5	2.92	21.1
	143.0	7.04	67.3
R-18	159	2.64	12.7

Table 3

RESULTS OF SCAVENGING EFFICIENCY TESTS

<u>Run #</u>	<u>Aerosol Mass Concentration During Test</u>	<u>Diameter of Shot</u>	<u># of Shot Collected</u>	<u>Sodium Mass Collected</u>	<u>Ratio Compound Mass to Na Mass Assumed</u>	<u>Calculated Scavenging Efficiency</u>	<u>Theoretical Scavenging Efficiency</u>
R-12 (Iron Shot) 183 cm drop height	2.0 gm/m ³	600 µm	53	0.0117 mg	3-4	0.63-0.85	0.6
R-15 (Iron Shot) 221 cm drop	2.0 gm/m ³	600 µm	1200	0.0607 mg	3-4	0.12-0.16	0.6
R-16 (Iron Shot) 221 cm drop	2.0 gm/m ³	600 µm	1180	0.0468 mg	3-4	0.095-0.13	0.6
R-19-(A) (Lead Shot)	1.2 gm/m ³	1270 µm	33	.0076 mg	3-4	0.21-0.28	
(B)	"	"	83	.0120 mg	3-4	0.13-0.17	

FIGURE 1.

BASELINE CONCENTRATION DECAY PROFILES FOR 1LB. Na

FIGURE 2.

ANDERSON IMPACTOR MMD FOR ALL 1 LB. SODIUM BURNS

FIGURE 3.

ANDERSON IMPACTOR GSD FOR ALL 1LB, SODIUM BURNS (BASELINE)

FIGURE 4.

TURBULENT AGGLOMERATION TESTS