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DIRECT IN-VESSEL APPLICATIONS EXPERIMENTS
AT HARVARD AIR CLEANING LABORATORY

PROGRESS REPORT

For period July 1, 1976 - September 30, 1976

MASTER

E. F. Mallove, W. C. Hinds, and K. W. First

Harvard University
School of Public Health
665 Huntington Ave.
Boston, MA 02115

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ABSTRACT

Continuing research at Harvard Air Cleaning Laboratory on direct in-vessel emergency air cleaning systems for the LMFBR is described. The objective of these systems is to reduce the two-hour integrated dose leaking from a containment vessel by rapidly reducing the aerosol concentration within the containment. The reduction in concentration is achieved by direct action on the entire containment volume rather than by more conventional recirculating clean-up loops.

A high concentration sodium aerosol test is described in which induced turbulent agglomeration dramatically enhances sedimentation and yields a two-hour dose reduction factor (DRF) of 56 for a 4 meter high vessel. Attempts to achieve DRF(2-hr.) greater than 10 by increasing the powder dispersal rate in aerosol scavenging tests are also described. It was found that a combination of systems operating simultaneously, i.e. induced turbulent agglomeration and powder scavenging, yielded better performance than either mechanism alone under identical sodium aerosol conditions. A DRF(2-hr.) of 20 was achieved in one test in which turbulence and powder dispersal were combined vs. an average DRF(2-hr) of 8 for turbulent agglomeration alone and 7 for powder dispersal alone.

The construction of a pulse jet engine and acoustic transmission duct for irradiating a reverberant test cell with high intensity sound is described. Sound pressure levels up to 150 dB, sufficient to agglomerate dense aerosols, were demonstrated. A successful acoustic transmission method that prevented heat and exhaust gases from the jet from affecting the experimental aerosol is described. Plans for improving jet performance preparatory to full scale tests with sodium aerosols are discussed.

I. INTRODUCTION

The period covered by this quarterly progress report on direct application in-vessel emergency air cleaning systems research for the LMFBR is from July 1, 1976 through September 30, 1976. During this time, further tests were conducted with powder dispersal scavenging, turbulence enhanced agglomeration, and combinations of those approaches. A pulse jet engine and acoustic transmission duct for irradiating the entire 90m³ test chamber with high intensity sound was constructed and successfully tested with no sodium aerosol in the chamber. A more thorough treatment of the entire test program, including full scale acoustic agglomeration tests to be conducted later in 1976, will appear in the final program report (December 31, 1976).

II. POWDER DISPERSAL TESTS

Further tests were performed with the promising direct air cleaning mechanism of scavenging with dispersed powders. Several attempts were made to test the effect of substantially increasing the usual 1.5 kg/min dispersal rate of crushed limestone. In the first test, R-27, we eliminated the usually employed Acrison Model 120 dust feeder and manually dumped 50 lb. bags of crushed limestone in rapid succession into a funnel directed toward the 16" flat-plate rotary spreader. An effective dispersal rate of 50 lb./min. was thereby achieved. Overloading the rotary dust spreader at this flow rate apparently choked its operation due to insufficient electric motor power, and most of the limestone dropped not far from the periphery of the disc. Only a very small reduction in the natural base line settling mass concentration of the sodium aerosol was therefore observed. The need for greater dispersion and a more controlled feed rate was indicated by this test.

A new auger and surrounding feed tube was purchased for the Acrison 120 dust feeder which extends the maximum dispersal rate from 1.5 kg/min. to 15 kg/min. Test R-37 was conducted with the new auger feed at 3 kg/min. with crushed limestone. The rotary spreader malfunctioned and stopped early during this test and again the natural baseline settling of the sodium aerosol, as determined by atomic absorption spectrophotometry, was only slightly affected. There are good prospects that when uniform dispersion of crushed limestone at these higher rates is achieved, a dose reduction factor (DRF) in a two-hour period of greater than 10 could be attained readily. The peak performance with limestone powder scavenging was previously found to be about $DRF(2\text{-hr.}) = 7$ in test R-26. Approximately the same performance level of aerosol scavenging would be expected for a 30 m high vessel as for a 4 m vessel with the same areal mass loading of the rapid settling 200 μm scavenging particles employed. This is because the time taken for a 200 μm particle to settle 30 meters is less than one minute, an interval substantially less than the 2 hour clearance period of interest.

Commercially available children's playbox sand was also used in one test of powder dispersal scavenging. During a one-pound sodium fire (R-32) in which a peak aerosol mass concentration of 1.54 gm/m³ was reached, sand was dispersed by the Acrison feeder and rotary spreader at 1.6 kg/min. The mass median diameter (MMD) of the sand particles by sieve analysis was found to be 300 μm , whereas the MMD of crushed limestone was 200 μm . A DRF(2-hr) of only 2.3 was achieved in the R-32 sand dispersal test, an indication of the not unexpected decrease in the scavenging efficiency per unit mass injected for the larger sand particles. A total of 150 lb. of sand was dispersed in the latter test.

Table 1 summarizes experimental conditions and data from successful scavenging tests conducted to date. From the calculated two-hour dose reduction factors it was possible to determine an "effective" particle scavenging efficiency for each test. The simple model on which the effective efficiency calculation is based, assumes that scavenging particles are spread uniformly across the chamber. The model also assumes monodisperse scavenging particles of size equal to the sieved particle mass median diameter (MMD). Neither of these assumptions was valid in practice. Therefore, effective efficiencies above and below the true individual particle scavenging efficiency could occur. In this manner, effective scavenging could even exceed 1.0, as was the case during part of test R-26 when limestone dispersion was only 0.13 kg/min. Mass subsidence effects due to high concentrations of scavengers, uneven spreading by the rotor, and clumping of limestone (incomplete dispersion) are the responsible non-ideal effects.

Effective scavenging efficiency, ϵ , is calculated from a simple exponential attenuation model and the decay constant, λ , for exponential decline is implied by the experimentally determined DRF(2-hr.):

$$\frac{c(t)}{C_0} = \text{EXP}\left[-\frac{3}{2} \frac{M}{P_s} \frac{\epsilon h}{D_s V} t\right] = e^{-\lambda t} \quad (1)$$

$$\text{DRF}(2\text{-hr}) = \frac{\lambda t}{1 - e^{-\lambda t}} \text{ For } t = 2 \text{ hrs.} \quad (2)$$

The experimentally found DRF(2-hr) determines λ in Equation (2).

Use of equation (1) then gives the effective efficiency as

$$\epsilon = \frac{-2}{3} \frac{P_s}{M} \frac{D_s V}{h} \lambda$$

where P_s = bulk density of scavenging particles
 M = mass injection rate of scavenging particles
 D_s = MMD of scavenging particles
 V = test chamber volume
 h = chamber height

In both test R-25 and R-26 when the feed rate of limestone was 1.5 kg/min., the determined effective efficiencies were of the same order, 0.30 and 0.36, respectively. If the bulk of sodium aerosol particles are 3 to 4 μm , as our previous data seem to indicate, the Langmuir theoretical collection efficiency for spherical 200 μm scavengers lies between 0.2 and 0.35. The lower limestone injection rate test at 0.13 kg/min. yielded an effective collection efficiency of 2.3. This efficiency was calculated by again assuming D_s to be 200 μm . The fact that the efficiency is greater than 1.0 seems to indicate that much of the aerosol collection was accomplished by the scavenger fraction less than 200 μm . The theoretical collection efficiency of, for example, a 100 μm scavenger for 3-4 μm aerosol particles is still a fairly substantial 0.15 to 0.30. Perhaps the decreased mass subsidence effects at the lower dispersal rate permits much more efficient utilization of the broad range of scavengers. The theoretical collection efficiency of 300 μm sand particles would be between 0.2 and 0.4, so the experimentally determined value of 0.11 seems to result from non-uniform dispersal and more of the scavenging burden being shifted to particles smaller than 300 μm .

III. TURBULENT AGGLOMERATION TESTS

Two tests of enhanced turbulent agglomeration were performed under conditions not previously attempted. In test R-38 depicted in Figure 1, 3 lbs. of sodium were burned and the pool fire was augmented by blowing compressed air over the molten sodium. These conditions resulted in a peak aerosol mass concentration of 12 gm/m^3 , 40 minutes after initiation of the fire. The 3000 cfm recirculating blower with shroud in-place was started at $t=43$ minutes when the concentration was still near 12 gm/m^3 . An abrupt concentration fall-off yielded a DRF(2-hr) of 56. This experiment and turbulence tests previously conducted at high peak mass concentrations show a trend toward higher DRF's with increasing peak mass concentrations (see Table 2). Theoretical formulations of turbulent agglomeration ¹ predict this behavior as well. Turbulent agglomeration methods will therefore be especially suitable for treating HCDA accidents which involve high concentration sodium aerosols, but will be less effective for lower concentration aerosols stemming from smaller fires.

Turbulent agglomeration test, R-34, was performed with the blower shroud exhaust pointed down toward an impaction surface within several inches of the outlet. A DRF(2-hr.) of 7.6 was achieved, a value which is in the range of DRF's obtained with the shroud pointed up or removed entirely. Since very little impaction deposit was observed near the blower outlet, this is a further piece of evidence that most of the cleaning effect in these tests is in fact due to enhanced sedimentation by turbulent agglomeration rather than by centrifugal air cleaning in the blower or impaction on the floor.

IV. COMBINED POWDER DISPERSAL AND TURBULENCE TESTS

Several tests were done which combined the cleaning mechanisms of scavenging and turbulent agglomeration. In both test R-29 and R-31, 1 lb. of sodium was burned under standard conditions, after which turbulence and scavenging with crushed limestone (MMD = 200 μ m) were applied; first, successively and then, simultaneously. In R-29 the blower was turned on for 8 minutes after a peak concentration of 1.5 gm/m³ had been reached. Immediately after the blower was shut down, 200 lbs. of limestone powder was dispersed at 1.5 kg/min. The objective was to "grow" larger target aerosol particles which would be more readily collected by the scavenging limestone particles. A DRF (2-hr.) of only 5.1 was achieved, a smaller figure than to be expected from either turbulence or powder dispersal tried separately. Turbulent agglomeration apparently reduced the mean aerosol particle size rapidly (due to greatly enhanced sedimentation), which then made powder scavenging less successful on the bulk of the remaining aerosol.

Test R-31, on the other hand, was dramatically successful, showing that combining simultaneously turbulent agglomeration and powder dispersal scavenging could lead to a DRF (2-hr) greater than those attainable with either mechanism separately. Figure 2 illustrates the decline of suspended sodium mass (measured spectrophotometrically from filter samples) during test R-31 in which a DRF (2-hr) of 20 was attained. The blower was operated continuously from t=31 minutes, when the total aerosol concentration was about 2 gm/m³, and 200 lbs. of crushed limestone was dispersed at 1.5 kg/min.

The increased relative motion between scavenging particles and aerosol particles produced by the turbulence along with better dispersion of dust because of turbulence most likely explains the improved DRF in this test.. Normally, DRF's for turbulent agglomeration and scavenging, performed separately under the same conditions, would both be about 8.

V. HIGH INTENSITY ACOUSTIC FIELD GENERATION

The potential advantages of acoustic agglomeration for a direct-acting emergency air cleaning system have drawn increasing attention ^{2,3}. Sonic fields exceeding sound pressure levels roughly 140 dB are known to produce striking rapid coagulation effects on high concentration aerosols. Most experimental data and theoretical treatments have dealt with standing sound waves in specially tuned columns. Direct application of sonic agglomeration to a large, irregularly shaped containment vessel atmosphere could not be achieved conveniently with standing waves. It is more appropriate to envision a high intensity reverberant acoustic field throughout the vessel. Such a field could be produced by an high intensity sound source such as sirens, pulse jets, or whistles. Non-standing wave fields, or progressive acoustic waves, are from theoretical considerations thought to "sweep" the aerosol particle size distribution and bring about other kinetic motion and coagulation between a broad range of size classes.

Following the novel experimental approach of David Scott⁴ at the University of Toronto in Canada, we selected pulse jet engines as convenient and efficient high intensity sound generators. A special test geometry was required to irradiate the test chamber volume with high intensity sound and not to simultaneously disturb the aerosol with large scale turbulence, heating, and chemical interference from the jet exhaust. The latter factors would make it impossible to separate the sought-after effects of sonic agglomeration from interference effects. Figure 3 illustrates the experimental arrangement in which a U-shaped duct commuting with the atmosphere external to the chamber encloses the pulse jet engine. Gasoline, compressed air, and a high voltage spark for starting the jet are fed to the engine by narrow gauge rubber tubes and wire. The crucial sound transmission element is the 2 ft. long by 8" diameter tube of 2 mil thick stainless steel foil which surrounds the engine. The Dyna Jet "Red Head" pulse jet engine^{*} that was employed produces a 240 Hz finite amplitude wave train which, due to the associated 1.5 meter wave length, penetrates the flexible foil membrane with little alternation.

A lengthy series of tests was required to operate the pulse jet at high sound levels. The jet requires a very lean gasoline-air mixture to yield high sound levels, but such operation, when prolonged, leads to component failure because of the high combustion temperature.

With the foil transmission membrane removed, sound pressure levels up to 148 dB were recorded with a B+K instruments sound meter operating in the flat response.

*Curtis Dyna - Products Corporation, Westfield, Indiana,
46074.

The concept of a metal foil acoustic transmission membrane was proved feasible during the short operating time (several minutes) before either the combustion inlet flapper valves or combustion chamber itself failed under heat stress. The foil transmitted sound adequately and did not overheat or tear. Measuring the sound level in the chamber during operation with the foil in place gave sound levels roughly only 10 dB less than with the foil off. However, only a less reliable sound meter was available for the foil in-place test so the measurement is uncertain. It is possible that much less than a 10 dB reduction occurred.

It became apparent that a more reliable pulse jet engine would be required to allow prolonged exposure of the aerosol to high intensity sound. An engine of more heat resistant construction which operates with "aerodynamic" valves rather than mechanical valves has been special-ordered from the metallurgy section of the Ontario Research Foundation near Toronto, Canada. This pulse jet, which proved itself in other sonic agglomeration tests ⁴, uses propane for fuel rather than gasoline. When the engine is received it will be interfaced with the existing acoustic test set-up and will be operated with a sodium fire in the chamber.

REFERENCES

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2. Hilliard, R.K., McCormack, J.D., and Postma, A.K., "Evaluation of Air Cleaning System Concepts for Emergency Use in LMFBR Plants", Hanford Engineering Development Laboratory Report TC-536, (December 22, 1975).
3. Scott, D.S. (editor), "Research Interest-Activities Summaries on Acoustic-Aerosol Interactions", from a technical discussion session held during the 82nd National Meeting of the American Institute of Chemical Engineers, Atlantic City, N.J., August 30 - September 1, 1976.
4. Scott, D.S., "A New Approach to the Acoustic Conditioning of Industrial Aerosol Emissions", Journal of Sound and Vibration, Vol. 43, No. 4, 1975, 607-619.

TABLE 1

POWDER DISPERSAL TEST CONDITIONS AND SCAVENGING EFFICIENCY

<u>Test #</u>	<u>Scavenging Particles</u>	<u>Dispersal Rate</u>	<u>DRF(2-hr)</u>	<u>Effective Scavenging Efficiency</u>
R-25	Limestone, 200 μ m MMD	1.5 kg/min.	6.0	0.30
R-26A	Limestone, 200 μ m MMD	0.13 kg/min.	4.1	2.3
R-26B	Limestone, 200 μ m MMD	1.5 kg/min.	7.2	0.36
R-32	Sand, 300 μ m MMD	1.6 kg/min.	2.3	0.11

TABLE 2

EFFECTIVENESS OF TURBULENT AGGLOMERATION WITH RESPECT TO

SODIUM AEROSOL PEAK MASS CONCENTRATION

<u>Test #'s</u>	<u>Peak Mass Concentration (GM/M³)</u>	<u>DRF(2-hr)</u>
14,15,16,18,19,34,	1.2 - 2.3	4.2 - 8.2
20,21,22	3.6 - 4.6	25 - 40
38	12	56

FIGURE 1

TURBULENT AGGLOMERATION TEST AT HIGH
MASS CONCENTRATION

BLOWER START

DRF(2-HR) = 56

TOTAL AEROSOL MASS CONCENTRATION GM/CM^3

0.1

1.0

10.0

10^2

0

50

100

150

200

250

300

350

TIME AFTER INITIATION OF TEST (MINUTES)

FIGURE 2

TEST COMBINING TURBULENCE AND
LIMESTONE POWDER DISPERSAL

FIGURE 3
ACOUSTIC AGGLOMERATION TEST CONFIGURATION

FIGURE 4

DYNA JET "RED HEAD" PULSE JET ENGINE

Financial Statement of Estimated Costs

Special Research Support Agreement

Harvard University

Contract No. E(11-1)-2801

For the Period September 1, 1975 through January 1, 1977

1. Estimated Total Project Costs for the Current Period	\$88,221
2. Total Amount Chargeable to ERDA (Approved Support Percentage = 100% of Item 1)	\$88,221
3. Cumulative Support Costs	\$ 0
4. Estimated Total Cumulative Support Costs	\$88,221
5. Cumulative Support Ceiling	\$88,221
6. Anticipated Difference Between the Estimated Total Cumulative Support Costs and the Cumulative Support Ceiling	\$ 0