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SOME ASPECTS OF SOUND ABSORPTION IN A HIGH PRESSURE GAS

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1. INTRODUCTION

Some gas-cooled nuclear reactors are contained within prestressed concrete pressure vessels. A high pressure gas, normally carbon dioxide pressurised to typically 40 bars, is used to transfer the heat generated in the reactor core to heat exchangers surrounding the core. The gas is forced to flow in a closed loop between the core and the heat exchanges by centrifugal fans. Sound pressure levels caused by these fans can exceed 160 dB. Much work has been carried out over the years to examine how the large variety of reactor components withstand this intense noise. One aspect of this work that is carried out during the design phase of a power station construction programme is the prediction of sound pressure levels and frequency spectra for the various cavities within a reactor gas circuit. Predictions are generally based on noise measurements made in earlier reactors. In addition the sound power outputs from centrifugal fans running in atmospheric air are measured for a variety of operating conditions. This information coupled with absorption and transmission characteristics for the various reactor cavities enables sound pressures to be estimated.

To protect the pressure vessel concrete from the hot reactor gas it is lined with a thermal insulation system. It forms a very large percentage of the reflecting surfaces within a reactor and therefore plays an important role in determining the absorption characteristics of reactor cavities.

This paper presents absorption measurements made on two test specimens of thermal insulation. Normal incidence measurements were made on a specimen mounted at one end of a pressurised standing wave tube. Measurements on a second specimen were made in a pressurised reverberation chamber.

2. NORMAL INCIDENCE MEASUREMENTS

2.1 Test arrangement

Fig. 1 shows the test arrangement, the specimen details being given in Fig. 2. Branch pipes in the vessel were blocked off to give a smooth circular cross section along the length of the vessel. To measure the standing wave ratio a microphone was winched along the main axis of the test vessel using an electric motor. The microphone's distance from the face of the test specimen was indicated by a precision, multiturn potentiometer attached to the electric meter. A second microphone was fixed close to the surface of the specimen. Piezo electric accelerometers were fitted to the surface (cover plate) of the specimen.

Preliminary tests on the vessel fitted with a stiff, reflective surface in place of the test specimen showed that the vessel was suitable for measuring absorption coefficients greater than 0.005 over a frequency range of 60 Hz to 240 Hz (Ref. 1).

2.2 Test procedure

The method given in Ref. 1 was followed. For each data point a sinusoidal voltage was fed to the loudspeaker. The resulting sound pressure level indicated by the "moving" microphone was noted as it was incrementally lowered.

A narrow band filter was used to ensure that only the level of the fundamental frequency was measured. Sound absorption coefficients were then calculated using the following relationship.

$$\alpha_n = \frac{4L}{(1+L)^2}$$

where

α_n = normal incidence absorption coefficient

L = standing wave ratio

L = p max/p min.

where p_{max} = maximum rms sound pressure

p_{min} = minimum rms sound pressure

If the value of p_{min} at each pressure node was not constant the correction given in Ref. 1 was applied.

The levels indicated by the other transducers were also measured.

A frequency range of 60 Hz to 240 Hz was covered at gas pressures of

$$P = 1,\ 4.5,\ 14.8,\ 21.0 \text{ bars abs. } (CO_2)$$

2.3 Results

Absorption coefficient plots are presented in Fig. 3. At atmospheric pressure a peak value of 0.32 was obtained, the plot being characteristic of a panel absorber. Normalised acceleration frequency response plots showed that the peak absorption occured at a cover plate resonance. Being nearly square the cover plate had two closely spaced "fundamental" bending modes. Out of plane vibrations for one of these modes are basically in-phase and it can be termed an umbrella resonance. The second was approximately volume cancelling and as a result was not as efficient an absorber. There was a third resonance within the frequency range covered, at about 115 Hz. Calculations suggested that the cover plate was 'rocking' on its single fixing stud at this frequency. Again this was a volume cancelling mode and not a good absorber.

Fig. 3 shows that absorption coefficients progressively increased with gas pressure, the peak value reaching .89 at a pressure of 21 bars. The absorption bandwidth was also noticably wider. Also the peak normalised vibration level reduced with increasing gas pressure.

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This test demonstrated that high absorption coefficient values are obtained at a cover plate resonance. However it covered a very limited frequency range. Testing in a reverberation chamber enables a much wider frequency range to be covered. Random incidence absorption coefficients are also obtained. Such a test is described in the next section.

3. REVERBERATION CHAMBER TESTS

The test chamber used is described in Ref. 2. It could be pressurised to 38 bars and also allowed a larger, more representative test specimen to be installed. Fig. 4 shows the specimen. It had been built primarily for high intensity acoustic response testing. Its umbrella resonance occured at about 270 Hz.

The specimen was sat on rubber isolators on the floor of the chamber. Several microphones and a small direct radiator loudspeaker were also installed. In a similar test carried out several years earlier a high intensity horn loaded noise generator had been installed but this was later found to introduce a high absorption area which reduced the accuracy of test measurements.

Test data were obtained with the vessel filled with nitrogen gas to 35 bars. For each data point, a ⅓ octave band of noise was generated, allowed to stabalise and then the source switched off. The subsequent decay of noise was measured by each of the microphones and Reverberation times were calculated and averaged. The total absorption area was then calculated using the following relationship (Ref. 3).

$$A = \frac{60V}{1.085c\ T}$$

where
- A = absorption area
- V = chamber volume
- c = speed of sound
- T = 60dB decay time.

The specimen was then removed and the measurements repeated to provide the absorption areas for the empty chamber. Absorption areas for the specimen were then calculated as the difference between the two absorption areas. Table 1 presents these values.

Table 1 Absorption areas.

⅓ Oct. band Hz.	Absorption area, ft^2 Av	As	As/Ao	⅓ Oct band Hz	Absorption area, ft^2 Av	As	As/Ao
80	0.79	1.38	0.074	630	3.27	7.61	0.406
100	(1.05)	(0.71)	(0.038)	800	4.38	7.81	0.416
125	0.89	1.57	0.084	1000	4.68	8.28	0.442
160	1.42	1.93	0.103	1250	5.18	7.65	0.408
200	1.25	4.00	0.213	1600	4.89	7.12	0.380
250	2.17	11.9	0.634	2000	4.96	6.95	0.371
315	2.24	8.46	0.451	2500	5.15	7.09	0.378
400	2.40	5.96	0.318	3150	5.15	6.97	0.372
500	3.43	6.66	0.355				

where

Av = Absorption area for empty vessel
As = Absorption area calculated for the specimen
Ao = active surface area of the specimen.

The last column shows that absorption coefficients were highest in the 250Hz and 315Hz ⅓ octave bands as was expected for a specimen with cover plate resonances at about 270 Hz. What was surprising was the high values obtained at 400 Hz and above. Accelerometers measuring the cover plate out-of-plane movements indicated that the cover plate vibration were not sufficient to provide these high absorption values.

The permeable nature of the overlapping foil layers below the cover plates could have allowed some addition absorption that would not occur for a normal panel absorber.

4. DISCUSSION

The results of the normal incidence test showed that the resistive component of the Acoustic Impedance increased by 375% when the gas pressure increased from 1 bar to 21 bars. Its value at the latter pressure, in normalised form was $\frac{R}{A\rho c} = 1.97$ at 155 Hz.

It is important to understanding why such a large increase occured as it plays a major role in determining the absorption characteristics. There are several sources of damping within the specimen as follows

a) damping at the cover plate/stud clamping detail.

b) viscous damping in the gas layer between the cover plate and the hot face foil system beneath.

c) viscous damping associated with gas 'leaking' through hot face foil overlaps into the thermal insulation beneath.

d) cover plate vibrations forcing gas to move through the fibrous thermal insulation blanket beneath the cover plate. The resulting viscous forces would set up resistive pressures on the underside of the hot face system.

No work has yet been carried out by the authors company to determine which of the above mechanisms are important.

The work has shown that the thermal insulation absorbs sound well in the high gas pressure environment of a nuclear reactor and should be one of the primary considerations when assessing the high intensity sound pressures in the gas circuit. When measuring absoprtion coefficients they should where possible be made at representative gas conditions.

5. REFERENCES

1. ASTM C384-58 (1958) Standard method of test for impedance and absorption of acoustical materials by the tube method.

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3. BS 3638, 1963 Measurement of sound absorption coefficients in a reverberation room.

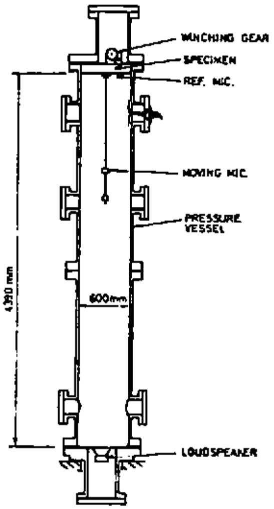

Fig. 1 Standing Wave Tube: Test Arrangement.

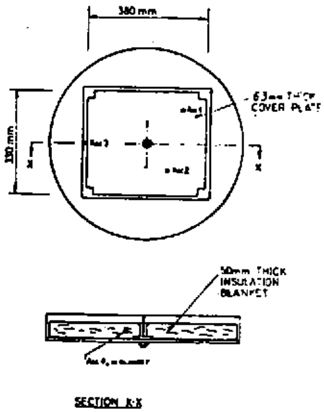

Fig. 2 Specimen for Standing Wave Tube Test

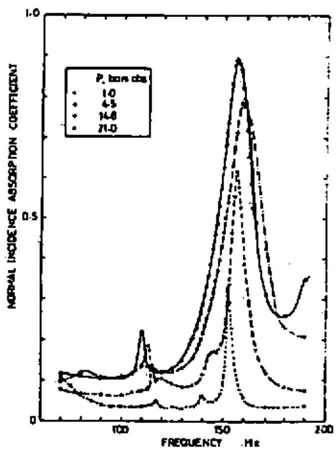

Fig. 3 Normal Incidence Absorption Coefficients

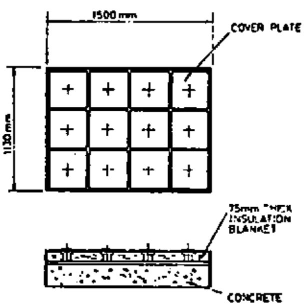

Fig. 4 Specimen for Reverberation Chamber Test