

THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

**GUIDE TO THE SELECTION AND
ASSESSMENT OF SILENCERS AND
ACOUSTIC ENCLOSURE**

PUBLICATION N° 161 : 1988

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PUBLICATION N° 161 : 1988
Acoustic enclosure details in 1998

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ISBN 0 85931 094 9

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THE ENGINEERING EQUIPMENT AND MATERIALS USERS ASSOCIATION

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CONTENTS

		Page Nos.
1.	INTRODUCTION	1
2.	SCOPE	3
3.	TYPES OF SILENCERS	5
3.1	Reactive Silencers	5
3.2	Absorptive Silencers	5
3.3	Reactive/Absorptive Silencers	6
3.4	Helmholtz Resonators	6
3.5	Diffuser Silencers	6
3.6	Multiple-Orifice Silencers	7
3.7	Active Noise Control (Anti-Noise)	7
4.	SILENCER APPLICATIONS	9
4.1	Venting	9
4.1.1	Continuous Venting	9
4.1.2	Infrequent or Emergency Venting	10
4.2	Flares	11
4.2.1	Elevated Flares	11
4.2.2	Ground Flares	12
4.3	Gas Turbines	12
4.3.1	Gas-Generator Intake	12
4.3.2	Power-Turbine Exhaust	13
4.4	Internal-Combustion Engines	14
4.5	Compressors and Blowers	15
4.5.1	Axial and Centrifugal Compressors	15
4.5.2	Reciprocating Compressors	16
4.5.3	Screw Compressors and blowers	16
4.5.4	Fans	16
4.6	Ventilation	17
4.6.1	Natural Ventilation	17
4.6.2	Forced Ventilation	17
4.7	Heat-Exchanger Fans	18
4.8	Combustion Plant	18
4.8.1	Natural-Draught Combustion Plant	19
4.8.2	Forced-Draught Combustion Plant	19
4.9	Electric Motors	20

5.	MECHANICAL CONSIDERATIONS	21
5.1	Corrosion	21
5.2	Erosion	21
5.3	Materials for the Absorptive Filling	22
5.4	Draining	22
5.5	Impermeable Membrane	22
5.6	Pressure Drop	23
5.7	Installations	23
5.8	Inspection and Maintenance	23
5.9	Temperature Effects	24
5.10	Integrity	25
5.11	Vibration Isolation	25
6.	ACOUSTIC REQUIREMENTS	27
6.1	Specification	27
6.1.1	General	27
6.1.2	Dynamic Insertion Loss	27
6.1.3	Sound-Power Level	27
6.1.4	Sound-Pressure Level	28
6.1.5	Narrow Band (Tonal) Noise	28
6.1.5	Details to be agreed between Purchaser and Vendor	28
6.2	Testing	29
6.2.1	Dynamic Insertion Loss	29
6.2.2	Sound-Power Level	30
6.2.3	Sound-Pressure Level	30
7.	REFERENCES	31
	APPENDICES	
A	Glossary of acoustic terms	33
B	Model data sheet for specifying a silencer	35
	FIGURES	
1	Reactive Silencer	39
2	Rectangular Absorptive Silencer	40
3	Combined Ractive and Absorptive Silencer	41
4	Form of Helholtz Resonator	42
5	Diffuser Silencer	43
6	Multihole Silencer	44

SUPPLEMENT TO PUBLICATION No. 161

March 1998.

ACOUSTIC ENCLOSURES

Prior to the publication of EEMUA Publication 161 in 1988, Publication 106 : 1985 entitled: General Specification for Silencers and Acoustic Enclosures was published. This publication itself was the successor to OCMA No. NWG-4 1979.

The consensus at that time was that the design of Acoustic enclosures was a specialist area outside the scope of EEMUA, and consequently the excellent pages on selection and general requirements, which was incorporated in Part 5 of Pub 106 were omitted.

By popular request from users and specifiers of Acoustic enclosures it has now been decided that the pages of Part 5 should be reinstated within this publication.

In order to further assist specifiers we include data extracted from EEMUA Publication No. 103 which was generally withdrawn as a separate publication in 1988. This was entitled; Preliminary Noise Enquiry - A form for Purchasers. It will be found useful when tentative requirements are being discussed with potential suppliers.

It is not intended to confuse those readers who still retain and use Pub 106. However in order not to duplicate numbers used in Publication 161, this supplement starts at Part 10 which will be found to follow Part 5 of the old Publication No.106.

ACOUSTIC ENCLOSURES

PART 10. ACOUSTIC ENCLOSURES FOR MACHINES.

10.1 Application

Two general types of acoustic enclosure are considered in this specification.

- (a) Close fitting enclosures, where access to the machine for routine operation is from outside the enclosure and is obtained through hatches or removable panels.
- (b) Large enclosures, where the operator enters the enclosure for routine operations,

Note: the noise radiation from piping is not considered in this specification, but should not be neglected in the overall noise control design.

10.2 Acoustic Performance.

The vendor shall quote the acoustic performance of the enclosure under the design operating conditions of the machine. This shall take into consideration all apertures including those in the base of the machine. The information shall take the form of either:

- (a) The insertion loss in octave-bands from 31.5 Hz to 8 kHz,
or,
- (b) The sound power level of the enclosed equipment in octave-bands from 31.5 Hz to 8kHz.

10.3 Materials of Construction.

Unless otherwise specified by, or agreed with the purchaser, the enclosure shall be constructed from galvanised mild steel, except for sealing, the vibration damping material and materials required to make the unit impervious to moisture.

10.4 Weather and Corrosion Protection.

All steel surfaces shall have adequate weather and corrosion protection and the vendor shall provide information of the protection to be provided. The purchaser may specify a particular protection for certain locations. Designs for outdoor use should avoid horizontal roofs on which rainwater can accumulate.

10.5 Sound Absorption Filling.

As noted the general construction shall use galvanised mild steel (unless specified in other materials such as reinforced glass fibre) Glass fibre or mineral wool are the preferred materials for the absorption filling. They shall be of low resin content and mineral wool shall have a maximum chloride content of 10 ppm. Foam plastic materials are generally non preferred due to the uncertainties over the fire risk. However where the material complies with BS 476 Part 7(1997), Class 1 for surface spread of flame agreement with the purchaser may be appropriate where their application is clearly understood.

10.6 Impervious Membrane.

Unless otherwise specified the absorbent filling shall be supplied enclosed in an impervious membrane in order to prevent the possibility of hydrocarbon liquids soaking into the filling.

10.7 Assembling and Dismantling.

Where specified by the purchaser, the enclosure shall be constructed so that it can be easily and repeatedly dismantled for major overhauls of machine and can then be re-assembled without impairing its acoustic properties (and pressure sealing where purging is known to be a requirement). The design shall be such that this can be done by local personnel without specialised assistance.

10.8 Lifting Requirements.

The vendor shall indicate when lifting gear is necessary for dismantling and assembling, and shall provide lifting lugs where appropriate.

10.9 Panel Joints.

Panel joints, the joints between the enclosure and the ground, and any openings for pipes, shafts or cables shall be adequately sealed to prevent the escape of noise. Preferably, this should be done with rubber type seals, steel capping strips or purpose made seals. Mastic is to be avoided where possible.

10.10 Vibration Isolation.

The enclosure should be isolated from vibrations due to the machine or its associated pipes, cables etc.

10.11 Access Doors.

Access doors and hatches shall be hinged and their fittings shall be sufficiently robust to withstand frequent opening and closing. they shall have adequate seals which will retain a good fit after frequent use and can easily be replaced.

10.12 Panic-action Doors.

For large enclosures it shall always be possible to open the doors from the inside regardless of external door catches or fastenings. The position of doors shall be clearly marked, both inside and outside.

10.13 Ventilation and Purging.

Enclosures may need to be ventilated or purged to remove dissipated heat or for other considerations such as removal of flammable vapours. In cases where ventilation equipment is not being supplied as part of the contract, the vendor will nevertheless indicate the minimum and maximum pressures that the enclosure is designed to withstand safely during any ventilation and/or purging procedures. Where the contract includes the means for purging and/or pressurisation the purchaser shall specify the heat dissipation requirements and information relevant to dispersal of flammable vapours. The ventilation shall be adequately silenced.

10.14 Details to be agreed between Purchaser and Vendor.

The following details shall be agreed:

- (a) Dimensions of enclosure.
- (b) The required acoustic performance.
- (c) Position of observation windows.
- (d) Position of doors or hatches.
- (e) Ventilation, including details of heat dissipation of the equipment and possible presence of flammable vapours, and silencing of the ventilation system.
- (f) Openings for pipes, shafts, cables etc.
- (g) Connections to external acoustic lagging used for pipework.
- (h) The positioning or repositioning of instruments, where necessary.
- (i) Lighting requirements both internal and external.
- (j) Weights of demountable sections, access doors and balance weights (if any).
- (k) The absorption material to be used and details of the impervious membrane.
- (l) Minimum (below atmosphere) and maximum (above atmosphere) operating pressures for the enclosure.
- (m) Operating environment, indoors, outdoors, climate, ambient temperature range, wind speed etc.

MODEL DATA SHEET FOR ACOUSTIC ENCLOSURES.

PART 1. INFORMATION TO BE SUPPLIED BY THE PURCHASER.

A. EQUIPMENT TO BE SILENCED		Plant: Type of equipment: Item/tag No:								
B. ACOUSTIC DATA * Delete as required										
1) Noise emission of unsilenced equipment.										
Octave-band centre frequency (Hz)	31.5	63	125	250	500	1k	2k	4k	8k	
* Sound-power level of driver (dB)										
* Sound-power level of gearbox (dB)										
* Sound-power level of driven unit (dB)										
* Sound-power level of complete unit (dB)										
Sound-pressure level (dB)										
2. Required acoustic Performance of Equipment										
* Silenced sound-power level (dB)										
* Silenced sound-pressure level (dB)										
* Insertion loss (dB)										
Designated measuring positions to be shown on a dimensioned sketch attached to enquiry.										
C. EQUIPMENT DETAILS.										
	Equipment Type	Manufacturer	Model/ type	R/min	Power (kW)	Operating Temp °C	Heat release (kJ/h)	Medium handled by equipment		
Driver										
Gearbox										
Driven										
D. ACCESS, Drawing to be attached.					E. VENTILATION/LIGHTING.					
1. For personnel: Yes/no.					1. Ventilation to be supplied by: Vendor/purchaser.					
2. Observation windows: Yes/no.					2. Type of ventilation: Forced/natural/induced.					
3. Access doors: Yes/no.					3. Number of air changes per hour:					
4. Removable panels: Yes/no.					4. Spare fan required: Yes/no.					
5. Minimum clearance between equipment and enclosure:					5. Lighting required: Yes/no. (give details)					
					6. Area classification, or explosion protection type required for fan motors and/or lighting.					
F. CONSTRUCTION. Drawing to be attached.					G. SAFETY.					
1. Operating environment(climate):					1. Is gas-monitoring system required: Yes/no.					
2. Is construction single composite, lift off type: Yes/no.					2. Is it to be supplied by: Vendor/others.					
3. Maximum weight if relevant: (Kg)					3. Is a Fire-fighting system required: Yes/no.					
4. Is impervious membrane required: Yes/no.					4. Is it to be supplied by: Vendor/others.					
5. Openings for pipes, shafts,cables etc. (See drawing).										
6. Connections for external lagging (See drawing).										
7. Design internal pressure: (bar.abs)										
H. REMARKS.										
1. Noise level measurements to be agreed between vendor and purchaser.										
2. Sound Pressure levels to be quoted with reference to $2 \times 10^{-5} \text{ N/m}^2$.										
3. Sound-power levels to be quoted with reference to 10^{-11} W .										

MODEL DATA SHEET FOR ACOUSTIC ENCLOSURES.

PART 2. INFORMATION TO BE SUPPLIED BY THE VENDOR

A. DESIGN DETAILS.

1. A drawing showing dimensions, materials of construction, windows and access to the interior.
2. Type of absorption filling, method of retention and impervious membrane.
3. Surface protection, external and internal.
4. Assembly and dismantling details and lifting arrangements.
5. Method used to seal panel joints.
6. Total transport weight. To include all items to be supplied.
7. Method adopted to achieve vibration isolation from internal equipment and pipework.
8. Details of access door construction. To show panic access details, hinges and catches.

B. GUARANTEED ACOUSTIC PERFORMANCE. * Delete as required

Octave-band centre frequency. (Hz)	31.5	63	125	250	500	1k	2k	4k	8k
1. * Sound-power level of silenced equipment. (dB)									
2. * Sound-pressure level of silenced equipment. (dB)									
3. * Insertion loss. (dB)									

4. Designated measuring positions to be shown on a dimensioned sketch to be attached.
5. Validity of acoustic data. Is this based on: (a) estimates or (b) on measured values.
6. Details of noise measuring procedures used is also to be included.

C. RELEVANT NOTES AND REMARKS.

PRELIMINARY NOISE ENQUIRY

The details considered here enable a dialogue to be established between Purchaser and potential Vendor. The preliminary details to be supplied will assist the user to assess the noise of equipment which may be purchased. This is particularly important where it is likely to be operated in a noise sensitive environment. It will also assist in making decisions as to the need for sound reduction measures.

The importance of correct noise assessment is emphasised, particularly in the light of proposed legislation. The added impact of an additional item of noisy equipment in an enclosed space, or where it may contribute to neighbourhood noise, should not be overlooked.

It is not intended that the replies have a contractual basis at this stage, but they may subsequently be incorporated into any form of contract resulting from this preliminary survey. Consequently they should be capable of verification.

1) EQUIPMENT.

Description: _____

Supplier: _____

Type: _____

Power (kW): _____

Approx. dimensions: _____

- 2) SOUND PRESSURE LEVELS:
- a) At 1 metre from surface: _____ (dB)
- b) At nearest operator: _____ (dB)
(if distance known)

3) TYPE OF NOISE.

- (a) Does it contain pure tones or narrow band components which are a noticeable feature of the total noise as judged by ear (e.g. whine or hum)? Yes, _____
No, _____
- (b) Does it contain impulsive components (e.g. clanks or bangs)? Yes, _____
No, _____

4) TEST CONDITIONS.

- (a) Under what conditions was the equipment operating during the noise tests.
Append a list to include speed, power and any other relevant detail.
- (b) The maximum noise may not occur at maximum load.
Append details relevant to occurrence of maximum noise level
- (c) Environmental conditions during test: (i) Open air.
Give approximate dimensions if (ii) or (iii) (ii) In large factory.
(iii) In relatively small room

5) NOISE MEASUREMENT METHOD.

What noise level test method was used to establish the figures provided?

6) OTHER EQUIPMENT.

Do you supply this type of equipment in other versions having different noise levels?

1. INTRODUCTION

Industrial installations use silencers for a wide variety of applications to reduce the noise from machines and fluid-flow systems. They may range from devices small enough to hold in the hand - for use with pneumatic systems or the exhausts of small internal-combustion engines - to installations weighing several tonnes for large steam vents in power stations or the exhausts of gas-turbine generators. In all these applications, the essential feature of a silencer is that it allows the flow of a gas and reduces the transmission of acoustic energy; it may therefore be distinguished from an acoustic enclosure, where gas flow, say, for cooling or purging, is a secondary feature.

The primary purpose of a silencer is to reduce noise to some required level, so the correct specification of its acoustic properties is the essential aspect of its purchase. Other aspects, however, can be equally important; for example, its operational life, its possible effect on the fluid flow, its safety features in pressure systems, its compatibility with the fluid and operation of the plant. The significance of these factors will depend upon the particular application. If the silencer itself is expensive, or if its replacement causes an expensive shutdown of the plant, the operating life will be of importance and this will mean a careful specification of the materials of construction, its weather protection in outdoor operation, and its ease of replacement. If it is associated with expensive equipment, the effect of damage to the equipment caused by any disintegration of the silencer must be considered. So a careful specification of the construction of the silencer can be as important as its acoustic specification.

A silencer may be installed to reduce the noise level inside a plant, for hearing conservation or to improve speech communication; or it may be installed to reduce environmental noise to avoid annoyance to neighbours. In either case, the silencer will be required to reduce the noise level in dB(A) at one or more locations. But if the noise source contains tonal components these will require additional consideration so that they are reduced to a level where they are masked by the broad-band noise. This is discussed in Section 6.1.5 and it means that the acoustic properties of silencers have to be specified in more detail.

There are various types of silencers and it is useful to have a basic understanding of how they operate and the typical applications in which they are used, so that the appropriate type can be selected for a particular application. Section 3 of this guide therefore gives a brief description of the different basic types for the benefit of the non-specialist engineer.

The structure of this guide is based mainly on the applications for which silencers may be used, and for each application there is a summary of the main features of the silencer which must be considered in its selection. Many of these features are common to different applications and they are only given as headings to avoid repetition in the appropriate sections; a more detailed discussion of the mechanical considerations is given in Section 5.

Section 6 gives details of the acoustic requirements which are necessary for specifying a silencer for a particular application; it indicates the acoustic parameters to be specified and methods for testing the silencer when it is in operation.

Appendix A gives a glossary of the acoustic terms used in this document, and Appendix B gives a model specification for a silencer to provide a guide for a purchase specification.

It is not intended that this guide should be a textbook on the detailed design of silencers; this is an aspect which is best left to the manufacturer and specialist acoustics engineer. But by giving a better understanding of their acoustic and mechanical features, it is hoped that a purchaser will be able to specify and receive silencers which meet all the requirements of his plant. A detailed and realistic specification from the purchaser of his precise requirements should be of mutual benefit to both the manufacturer and the purchaser.

This guide deals only with the situation where the installation of a silencer is found to be the most suitable means of noise reduction. But it may not be the only option, and consideration should be given to other possibilities; for example, using acoustic insulation, or choosing alternative equipment which emits less noise (such as valves with low-noise trims or fans with lower tip speeds). The best choice will depend on economic and operational factors and it is not within the scope of this document to discuss how this should be made.

However, it is worth emphasising the importance of making this choice at the design stage so that space and installation requirements are considered in the layout; later decisions can be much more expensive and, possibly, less effective.

2. SCOPE

This document is intended as a guide to the selection of silencers which are appropriate for use with various noise sources. It is aimed at the practising engineer with a limited knowledge of acoustics to assist in the specification of the most suitable silencer for a particular purpose and to assess its operation when it is installed. In addition it should assist him in reviewing differing proposals submitted by vendors. However, the experienced acoustic engineer may also find it useful as an aide-memoire.

The guide places considerable emphasis on the mechanical aspects of silencers which have to be considered for various applications so that due consideration can be given to engineering design, operational aspects, safety, and cost.

3. TYPES OF SILENCERS

This section gives a general description of the various types of silencers which will be discussed in the following sections. It is intended to serve as a definition of the terms to be used and as an introduction to the engineer who is unfamiliar with the principles on which silencers operate.

3.1 Reactive Silencers

A reactive silencer consists of one or more chambers which give changes in volume and restrictions in the duct so that there is a change in the acoustic impedance of the total system of source and silencer. This is analogous to an electrical circuit and an appropriate change in impedance can reduce the sound power generated. But, in some cases, an incorrect design may even increase the sound power output of the total system (for example, when resonance occurs).

The behaviour of a reactive silencer depends very much on the relationship between the dimensions of the chambers and the wavelengths of the noise, so it is strongly frequency dependent; a single chamber, for example, is only effective over a narrow range of frequencies. To extend the range of frequencies the silencer may therefore be designed with several chambers of different dimensions. The relationship between frequency and dimension means that, for silencers of practical dimensions, reactive silencers are most effective for reducing low-frequency noise. Their narrow frequency range can sometimes be useful when the noise has distinct components (from, say, a reciprocating machine) or when it contains pulsations.

(See Fig. 1.)

3.2 Absorptive Silencers

Absorptive silencers depend on the sound energy being absorbed in layers of fibrous or porous materials. The fraction of the sound energy absorbed by the material generally increases with frequency so that absorptive silencers are less effective at low frequencies and become more efficient as the frequency increases.

They are therefore effective over a wide range of frequencies; the low-frequency behaviour of the absorptive material can be enhanced by a careful choice of the material thickness and the separation of the absorptive layers. So absorptive silencers vary in design from a simple duct with an internal lining of fibrous or porous material to a multiple sandwich of alternate absorptive layers and open spaces for the passage of gases (often called 'splitter silencers').

When good low-frequency performance is required (for example, in silencing gas-turbine exhausts) and an absorptive silencer is the only practical option, it may be necessary to use thick layers of absorptive filling with wide spacings, and this can lead to a silencer with large dimensions.

The absorption of noise depends on the sound waves passing through the material and being converted to heat energy by friction so it is important that the material should permit the passage of the sound waves. Glass fibre, mineral wool and open-cell plastic foams are commonly used, depending on the operating environment of the silencer.

High-pressure gases cause a considerable reduction in the performance of absorptive silencers. So when an in-line silencer is used in a high-pressure system it is important to appreciate that its quoted performance is likely to refer to low-pressure applications and may not give a true indication of its actual performance. (See Fig. 2.)

3.3 Reactive/Absorptive Combinations

Reactive and absorptive silencers have complementary properties in terms of their behaviour with frequency; the former are most effective at low frequencies and the latter at high frequencies. By combining these properties a silencer can be designed to extend the frequency range in which it is effective.

The simplest type of combination is the plenum chamber, which is basically a box in which the flowing gas enters and leaves on opposite sides so that it undergoes a change of direction. The frequency range of its reactive properties as a chamber can be extended by lining the interior walls with an absorptive material. Other combinations consist of reactive and absorptive sections being placed in series in the silencer (the more expensive car silencers use this principle, for example). (See Fig. 3.)

3.4 Helmholtz Resonators

A Helmholtz resonator differs from the silencers described above in that it is installed as a closed side arm to the duct and there is no net flow of gas through it. Its essential features are a narrow passage leading into a large cavity and the relative dimensions of these determine a resonant frequency at which the silencer will reduce the overall sound energy. The resonant response of the cavity reduces sound energy in a narrow band of frequencies only.

Because of the narrow frequency range over which it is effective, the Helmholtz resonator has a limited application for most industrial purposes, although it may be useful in cases where there is a prominent single tone to be silenced. (See Fig. 4.)

3.5 Diffuser Silencers

These depend on the absorption of sound energy by friction losses as the gas flow passes through a labyrinth of passages in a porous material. The energy loss is similar in principle to that in absorptive materials but the difference is that the gases flow through the material rather than over it.

The absorptive material may vary from a packing such as Raschig rings or steel wool to a sintered-metal plug, depending on the volume flow of the gas and the allowable back pressure of the silencer. (See Fig. 5.)

3.6 Multiple-Orifice Silencers

These silencers consist of many orifices which convert the gas stream into a number of jets of small diameter. The first effect of this is to change the quality of the noise so that the maximum of its spectrum shifts to higher frequencies; this renders it more amenable to absorption in an absorptive silencer section or to increased attenuation in the air as the noise propagates into the environment. A secondary effect is to reduce the total acoustic power of the source due to interaction between closely-packed jets.

Multiple-orifice silencers may be installed on their own or - more commonly - in combination with a following absorptive section. The increase in the frequency of the noise then leads to increased noise absorption in this section and to higher noise attenuation through the pipe walls and any piping insulation. (See Fig. 6.)

3.7 Active Noise Control (Anti-Noise)

An active noise-control device consists of an electronic system which reduces the noise radiated from the source by the process of wave cancellation. It usually includes detectors, such as microphones or accelerometers, a signal processing system with filtering and amplification, and cancelling sources, which are generally loudspeakers. These radiate noise equal in power but opposite in phase to the source noise. The device is mainly effective for low-frequency applications and it can be used instead of other types of silencers or in conjunction with them. However, it is not generally regarded as a silencer and does not come within the scope of this document.

4. SILENCER APPLICATIONS

4.1 Venting

Vents may be divided into two broad categories in terms of both plant operation and noise emission.

The first category includes vents which are used intermittently or rarely; for example emergency vents, or blow-down vents which are only used during start-up or shut-down operations. In most cases the aim is to vent the gases or vapours as quickly as possible; flow velocities are therefore high and the emergency valves or bursting discs offer the minimum resistance to the flow. The main source of noise is usually the high-velocity jet emerging from the vent tip.

The second category includes vents associated with pressure let-down systems or pressure-control systems, which may operate continuously or frequently. With these, the main source of noise is more likely to be the pressure-control valve: the gas velocity at the vent tip may be relatively low and the jet noise is insignificant compared with the valve noise emerging from the vent tip.

The differences between these categories may require a different approach to the noise reduction. In the first case, where jet noise at the vent is the main problem, the most likely solution for excess noise would be a silencer at the vent tip. In the second case the preferred solution may be an in-line silencer downstream of the pressure-control valve to reduce not only the noise issuing from the vent tip but also the break-out of noise from the vent pipe itself. It is also possible that the difference in the frequency of operation may lead to different noise limits for the vents; higher noise levels may be acceptable for emergency vents than for vents in continuous operation.

These two categories are dealt with separately below because of their distinctive requirements, but it must be appreciated that there is considerable overlap between them and the noise control for each individual case must be based on its particular requirements.

4.1.1 Continuous Venting

In the design of a new plant or the diagnosis of a noise problem in an existing plant, attention must be concentrated on determining the contribution of the pressure-control valve to the noise emitted by the vent, and any contribution from the vent pipe itself. This will indicate the most suitable position for the silencers; whether near to the valve or at the vent tip.

It will also indicate whether the silencer could be used as part of the pressure-reduction system or to change the frequency of the noise (suggesting the use, for example, of multiple-orifice plates).

The following aspects should be considered in the selection of the silencer:

- i) Pressure difference limits across silencer (whether maximum or minimum).
- ii) Pressure-vessel code requirements.
- iii) Silencer weight and any requirement for additional supporting structure.
- iv) Available space in pipework (for in-line silencer).
- v) Access for inspection and maintenance.
- vi) Rain water drainage.
- vii) Effect of operating temperature on silencer materials.
- viii) Erosion of absorptive layers due to high gas velocities.
- ix) Corrosion of internal parts due to the process gas or vapour.
- x) Environmental corrosion.
- xi) Possible blockage of orifices or absorptive materials by particles in the gas or vapour.
- xii) Possible minimum exit velocity at vent for environmental dispersion.
- xiii) Noise regeneration at the silencer exit due to high gas velocity.

The following types of silencer may be suitable for this duty:

- i) Absorptive.
- ii) Multiple-orifice.
- iii) Multiple-orifice/absorptive combinations.
- iv) Diffusers (for example, Raschid-ring or metal-wool packings).

4.1.2 Infrequent or Emergency Venting

For this type of duty the preferred position for the silencer is most likely to be on the vent tip and there will be a greater emphasis on minimising its restriction to the gas or vapour flow.

The contribution of valve noise must be investigated but may prove to be a secondary consideration. The intermittent use may also lead to greater condensation problems in the silencer.

The aspects listed in 4.1.1 should be considered, with increased emphasis on the following:

- i) Pressure difference limits across silencer (maximum allowable for required volume flowrate). For emergency vents it may not be permitted to install any device which could restrict flow, and this may limit the possible installation of a silencer.
- ii) Silencer weight and any requirement for additional supporting structure.
- iii) Access for inspection and maintenance.
- iv) Rainwater and condensate drainage.
- v) Effect of operating temperature on silencer materials.
- vi) Erosion of absorptive layers due to high gas velocities.
- vii) Corrosion of internal parts due to process gas or vapour, or to condensed liquids.
- viii) Environmental corrosion.
- ix) Noise regeneration at silencer exit due to high gas velocity (in particular, sonic velocities should be avoided).

The following type of silencer may be suitable for this duty:

- i) Absorptive.
- ii) Multiple orifice.
- iii) Multiple orifice/absorptive combinations.

4.2 Flares

4.2.1 Elevated Flares

With most flares there are two main sources of noise: The combustion noise from the flame and the jet noise from the steam or the high-pressure driving gas used for drawing in combustion air. Any reduction of the combustion noise will be as a result of a change in the combustion process and is beyond the scope of silencers. But silencers may be used to control the jet noise from the steam or high-pressure gas issuing from the slot of a Coanda-type flare. This noise will be mainly high frequency and the silencer will consist of some combination of screening and acoustic absorption, its shape and size will depend on the type of flare tip.

However, in general, there is only a limited application for reducing flare noise by silencers.

The following aspects should be considered in reviewing a proposed design of silencer:

- i) Weight of screen and any additional supporting structure.

- ii) Wind loading on screen.
- iii) Corrosion.
- iv) Effect of high temperature on material (steel and absorption elements).
- v) Possible modification by the screen of the flow of combustion air to the flame.
- vi) Acoustic effectiveness of the screen (the need for full-scale noise tests should be considered).

4.2.2 Ground Flares

With flares of this type the combustion normally occurs within walls, open at the top. Noise is emitted from the open top and from the combustion-air inlets in the walls. With the exception of small flares it is not practical to reduce the noise from the open top, but silencers may be fitted to the air inlets. These would be of the absorptive type and the following aspects must be considered:

- i) Adequate flow of combustion air.
- ii) Pressure drop across the silencer.
- iii) Corrosion.

4.3 Gas Turbines

There are three main aspects to consider when dealing with noise from gas turbines.

- a) The high-pitched noise from the combustion air intake.
- b) Broad-band noise radiated by the machinery casing.
- c) The low-pitched exhaust rumble from the power turbine.

Suppressing the noise from the gas-generator will require some form of enclosure. This will introduce ventilation/cooling requirements and these may also require silencers (see section 4.6). Other ancillary equipment (eg oil coolers) may need some silencing. Very substantial silencers will normally be required both for the gas-generator air intake and the power-turbine exhaust.

4.3.1 Gas-Generator Intake

The intake silencer will be located between the air filtration housing and the plenum chamber and might be arranged horizontally or vertically, depending on the overall design. The main points to consider in relation to the silencer are:

- i) Pressure-drop limitations to avoid power loss.

- ii) Machinery manufacturer's recommended layout (eg minimum distance from silencer to plenum chamber on gas-generator intake) and velocity limitations.
- iii) Construction must avoid rivets or other fastenings which may become detached in air flow.
- iv) Adequate packing and protection of absorptive filling to avoid severe settling or erosion.
- v) Breakout from the silencer casing must be controlled, particularly if the intake is outside the main enclosure.
- vi) The use of vibration breaks between the silencer housing and the inlet plenum to reduce flanking noise.

The most suitable silencer will be an absorptive type in the form of a splitter silencer. It may consist of one large set of splitters or two smaller sets which are offset to avoid a line of sight between the splitters. The silencer must be designed to reduce the high-frequency tones due to the blade-passing frequencies of the compressor.

4.3.2 Power-Turbine Exhaust

A large silencer will be essential if any significant reduction in the low-frequency rumble is required. This may be positioned horizontally or vertically, depending on the overall design. The size of the installation (particularly for large gas-turbines), and the temperature, volume, and velocity of the exhaust gases will impose severe requirements on the design of the silencer.

The following aspects should be considered in the selection of a silencer:

- i) Temperature
 - The effect on the silencer materials (consider the use of suitable steel and of ceramic fibres see Section 5.3).
 - The effect of thermal expansion on the silencer and on transition pieces to the machine.
- ii) Access for inspection and maintenance (provision of hatches).
- iii) Provision for replacement of absorptive elements and other internal components.
- iv) Lifting lugs for removal of large components.
- v) Erosion of the absorptive elements due to the high gas velocities (consider the use of stainless steel mesh and perforated plate to protect infill).

- vi) Corrosion of the internal parts due to the exhaust gas, to rainwater and to condensation during shutdowns.
- vii) External corrosion due to the environment.
- viii) Avoiding settlement of the absorptive material (e.g. by the use of division plates in the absorptive elements).
- ix) The minimum of joints for long silencers built in sections (suitable design to avoid blown joints).
- x) The minimising of turbulence in the flow through the silencer.
- xi) Noise regeneration at the silencer exit due to high gas velocity.

The appropriate silencer for this duty will be the absorptive type. The preferred design would be for an acoustically-lined cylindrical silencer with a central absorbing pod. Rectangular splitter silencers should only be accepted if the vendor can offer a robust and proven design.

It is of great importance that the silencer is designed in conjunction with the power-turbine exhaust volute to ensure that there is a smooth transition in the gas flow to the silencer. If necessary, flow-straightening elements may be required to give an even velocity profile at the entrance to the silencer. It is also necessary to avoid sudden changes in the cross-sectional flow area.

Active noise control has been used experimentally to reduce the low-frequency noise from the exhaust and has given promising results. It may be considered in some cases as an addition to the absorptive silencer.

4.4 Internal-Combustion Engines

The main source of noise which calls for a silencer is the exhaust and the predominant noise from this is low frequency with a specific component due to the firing rate of the cylinders. Exhaust silencers are usually supplied with the engine and are a familiar feature of road vehicles.

A fixed internal-combustion engine in a plant may be required to meet work-area or neighbourhood limits and a special silencer will then be required. The following aspects should be considered in its selection.

- i) Temperature
 - Its effects on the corrosion of the materials and the life of the silencer.
 - Thermal cycles and corrosion due to condensation.
- ii) Pressure-drop limitations to avoid power loss.

The most commonly used silencers consist of one or more reactive chambers designed so that they give the maximum insertion loss in a band of frequencies containing the firing frequencies for expected operating speeds. High-quality silencers may also contain an absorptive section.

4.5 Compressors and Blowers

4.5.1 Axial and Centrifugal Compressors

In general, these machines generate noise which is radiated mainly from the associated piping rather than from the casing, due to the relative thickness of the casing compared with the pipe walls. The noise tends to be greater in the discharge piping compared with the suction side so the silencer is usually required on the discharge side only; but some machines will require both suction and discharge silencers. There is often a pronounced tonal noise due to the blade-passing frequency of the rotor and stator blades and extra noise reduction will be required in the relevant octave bands (see Section 6.1.5).

The following aspects should be considered in the choice of silencer:

- i) Pressure-drop limitations across the silencer.
- ii) Pressure-vessel code requirements.
- iii) Weight limitations for large silencers on offshore platforms.
- iv) Space allocation in the piping system.
- v) Indication of flow direction.
- vi) Inspection procedures: Silencers incorporated in high-pressure systems can only be inspected during planned shutdowns and the inspection procedure needs to be carefully planned.
- vii) Integrity (see Section 5.10)
 - To avoid damage to the machine or downstream equipment.
 - To ensure a long operating life in silencers which cannot readily be replaced.
- viii) Noise testing: Periodic testing is recommended to check the silencer performance in view of the possible infrequency of visual inspections.
- ix) Narrow-band noise.
- x) Pressure effects on the acoustic properties of the filling.

The predominant noise from these machines is in the mid-frequency range (500 Hz to 2kHz) so the most suitable silencers are the absorptive type.

In view of the difficulty of inspection and replacement of in-line silencers in high-pressure piping systems, consideration should be given to putting acoustic insulation on the pipes as an alternative to using a silencer.

4.5.2 Reciprocating Compressors

The predominant noise from these machines is low-frequency and is often characterised by noise corresponding with the cylinder frequency. With air compressors drawing air from the atmosphere the inlet is the main source of noise, but piping noise on the discharge side may also be a problem; silencers may therefore be required on the suction and discharge sides.

The requirements for silencers are similar to those given in Section 4.5.1 for axial and centrifugal compressors. Because of the low frequencies the silencers are usually reactive and may be referred to as pulsation dampeners.

4.5.3 Screw Compressors and Blowers

The characteristic feature of compressors of this type is the emission of a pronounced tonal noise, corresponding to the lobe or screw-passing frequency of the machine. This is mainly radiated by the piping so that suction and discharge silencers may be required; but there may also be significant radiation from the casing. The requirements for the silencers are similar to those given in Section 4.5.1 for axial and centrifugal compressors. However, particular attention must be paid to the transmission of structure-borne noise from this type of compressor; this may flank the silencer and may extend to all associated steelwork, including lubricating oil pipes.

The silencer specification must allow the special reduction for narrow-band noise (see Section 6.1.5) and, where possible, vibration isolation should be put in the piping and machine mounting (see Section 5.11).

4.5.4 Fans

Fans (other than those for ventilation) may be used to provide combustion air for forced-draught burners, cooling air, or to remove flue gases in stacks. Fans for forced-draught burners are frequently fitted with silencers; usually these are on the suction side, but they may occasionally be fitted to the discharge side when there is a risk of noise breakout from the ducting. The noise from fans is generally broad-band but there may be tonal components due to blade passing effects, particularly with centrifugal fans.

The following aspects should be considered in the selection of silencers:

- i) Pressure difference across the silencer.
- ii) Adequate flow of combustion air.
- iii) Space allocation.

- iv) Vibration isolation from fan (e.g. by the use of a flexible section in ducting).
- v) Noise from motor driver.

Absorptive silencers are used for this purpose. However, in many cases it may be worth considering the selection of a low-noise fan.

4.6 Ventilation

Ventilation may be required for various purposes in industrial plants; they include, the provision of fresh air for people, the removal of excess heat from machinery, the removal of flammable vapours, and the removal of dust or undesirable fumes. The ventilation system may be noisy in itself (due to air-flow or fan noise), or it may allow the transmission of noise from one space to another. It is then necessary to use silencers to control the noise.

4.6.1 Natural Ventilation

The movement of air is produced by temperature differences or by the wind. Usually there is little pressure difference to provide the air flow and flow velocities are low.

The main aspects to be considered in the selection of silencer are:

- i) Minimal resistance to air flow.
- ii) Required volume-flow rate (cross sectional area of silencer).

Two types of silencer are commonly used for this application:

- i) A lined duct with bends so that there is no line of sight between its ends. The lining is a sound-absorbing material. This type of silencer may be applied to ventilation for small spaces, such as acoustic or weather enclosures for machines.
- ii) Acoustic louvres. These are similar to normal ventilating louvres but the vanes or aerofoils are perforated and filled with sound-absorbing material. They are most suited to ventilation for large spaces such as buildings since they tend to be bulky, but they can be mounted in groups to offer a large open area for air flow.

4.6.2 Forced Ventilation

The air movement is produced by fans or blowers and these may be the main source of noise in the system, so a careful selection of the driving unit is the first stage of noise control; noise may also be generated by turbulence in the air flow at bends or at grilles. These aspects require careful design of the system which is outside the scope of this document. Silencers may be used to reduce the fan or blower noise (see 4.5.4) or they may be used to reduce the noise within the ducting.

The following aspects should be considered in the selection of ducting silencers:

- i) Pressure-difference limits across silencer.
- ii) Size compatibility with ducting and available space.
- iii) Corrosion.
- iv) Attenuation of pure tones from fans/blowers.
- v) British Standard method of test for attenuation.
- vi) Structure-borne noise (use of flexible connections).
- vii) Noise break-out from silencer casing.
- viii) Noise from motor driver.

4.7 Heat-Exchanger Fans

Fans are widely used in industry for delivering cooling air to heat exchangers; they may be in water-cooling towers or in fin-tube heat exchangers for cooling petroleum and chemical products. The fans may be of large diameter and may be installed in banks of heat exchangers. When this is the case, the size of the installation and the large volume of air being moved precludes the use of silencers and noise reduction has to be obtained by selecting low-noise fans and motor drivers. However, with small installations it may be possible to use silencers to reduce excess noise; usually these will have to be on both the inlet and the discharge of the cooling-air system.

The following aspects should be considered in the selection of silencers:

- i) Adequate air flow.
- ii) Draining.
- iii) Saturation of absorptive filling with wet-cooling towers (an impermeable membrane may be used).
- iv) Corrosion.
- v) Narrow-band noise.
- vi) Noise from motor driver.

Absorptive silencers are used for this purpose.

4.8 Combustion Plant

The source of the noise in furnaces, boilers and incinerators with natural-draught ventilation is the combustion process and this is mainly emitted through the air registers.

With forced-draught furnaces and boilers, the fans and their drivers may be an additional and significant source of noise; they may be forced-draught or induced-draught. Noise radiated from the walls and ducting is outside the scope of this document.

4.8.1 Natural-Draft Combustion Plant

There are two approaches to the reduction of burner noise:

- i) Silencers on the air registers of individual groups of burners.
- ii) Plenum chambers around groups of burners.

With regard to the use of silencers on individual burners, the following aspects must be considered:

- i) Adequate flow of combustion air.
- ii) Pressure-drop limits across the silencer.
- iii) Access to burners for adjustment (for example the provision of hatches).
- iv) Adequate access to the burner area, and escape in the case of flame-back, (for example, adequate headroom for floor-fired heaters).
- v) Rerouting of fuel and steam pipes (particularly with regard to access).
- vi) Prevention of oil spills into the acoustic absorbent to avoid wicking effects (for example, the provision of non-absorbing drip trays).
- vii) Vibration isolation of the silencer from the plant.

With regard to the use of plenum chambers, particularly those formed by acoustic walls around the entire burner area of floor-fired units, the following additional aspects should be considered:

- viii) Observation windows to view flames during burner adjustments.
- ix) Adequate, clearly-marked doors for emergency escape.
- x) Adequate wall mass for the reduction of low-frequency noise.

4.8.2 Forced-Draft Combustion Plant

The fan noise may be reduced by a change of fan type, but this is outside the scope of this document. Otherwise it will be reduced by the use of absorptive splitter silencers and the following aspects must be considered:

- i) Adequate flow of combustion air.

- ii) Pressure drop across silencer (consider the effect on fan performance).
- iii) Noise from motor driver (see 4.9).
- iv) Noise from fan belts (particularly toothed belts).

4.9 Electric motors

The silencing of electric motors is a well-established practice and most vendors can provide several versions of a particular type of motor in order to meet particular requirements for noise emission. In purchasing new motors, it is therefore essential to provide a detailed specification of these noise requirements, so that the silencing features are incorporated in the construction; for example, it may be possible to purchase a smaller fan, or to use a uni-directional fan when the direction of rotation is known.

Where reduction is required for existing motors, however, it will be necessary to apply some form of external silencing of the emitted noise.

The main noise source in an air-cooled electric motor is the cooling fan and when this is excessive it will require a silencer. Noise may also be radiated from the casing of both air-cooled and water-cooled motors and this would normally be reduced by using an acoustic enclosure over the motor; this is outside the scope of this guide. The noise from cooling fans is broad-band in character but there may be narrow-band components due to blade-passing frequencies from the fan or rotor/stator passing frequencies from within the motor. It is worth reviewing the possibility of using uni-directional fans to reduce the noise. But when this solution is not practicable, or not sufficient, it will be necessary to use a silencer. Sometimes it may be sufficient just to install a silencer in the air inlet to the fan, but in many cases a silencer will be required for the cooling air discharge. With CACA motors (cooling air, cooling air), these silencers will be separate items, but with TEFC motors (Totally Enclosed Fan Cooled), where the cooling air blows down the outside of the fins on the casing, there may be a single silencer over inlet and discharge.

The following aspects should be considered in the selection of a silencer:

- i) Volume flow for adequate cooling.
- ii) Ensuring that cooling air is directed along the casing (TEFC motors).
- iii) Space allocation in plant.
- iv) Narrow-band noise.

Absorptive silencers are used for this purpose.

5. MECHANICAL CONSIDERATIONS

5.1 Corrosion

Corrosion has to be considered for both the external and internal components of the silencer and all the materials have to be specially selected or be protected from any corrosive attack they may experience.

Externally, the main problem is usually atmospheric corrosion, mainly of steelwork, and this may be reduced by the use of stainless steel or, where this is uneconomical and mild steel is used, by specifying a galvanised coating or an appropriate painting schedule.

Internally the problem is to ensure that the materials are compatible with the fluid - and with each other. High humidity, high temperatures and traces of acidic substances in the fluid are common causes of corrosion of the internal components, but acidic condensation may also be a significant cause in silencers which are subjected to thermal cycles. Protection by painting is usually inadequate because it can be damaged during the fabrication of the silencer, and consideration should be given to the use of stainless steel, galvanised steel, or to an adequate corrosion allowance for the expected life of the silencer.

When stainless steel and aluminium are used, consideration should be given to possible chloride attack, either from the fluid or from mineral wool when it is used as the absorptive filling. It is therefore advisable to specify a maximum chloride content in the mineral wool. There may also be a limit on the alkalinity of materials in contact with aluminium.

5.2 Erosion

Where gases pass through the silencer with high velocity there is a risk of erosion of the internal components. If the gases contain particles, such as catalyst fines or coal dust, this may lead to pitting and holing of the steel components. But, more generally the problem is one of erosion of the absorptive filling. This reduces the efficiency of the silencer and the fibres carried away in the gas stream may contaminate the process operations of the plant.

One solution is to restrict the velocity of the gases, particularly in localised areas with flow restrictions. However, this usually means increasing the cross-sectional area in the flow sections and leads to an increase in the size of the silencer, with a consequent increase in cost and weight.

An alternative to restricting the gas velocity is to provide protection for the absorptive filling and the extent of the protection will depend on the velocity of the gas.

For velocities below 15 m/s the filling can be protected by a layer of woven glass cloth on the surface exposed to the gas. For velocities below 30 m/s the filling may be protected by a layer of woven glass cloth and a layer of perforated metal on the gas side.

For velocities above 30 m/s it is advisable to insert a layer of wire mesh between the glass cloth and the perforated plate.

In situations where the absorptive filling is exposed to high-velocity gases it is advisable to specify long-strand fibres for the filling; the longer they are the less likely they are to be eroded.

5.3 Materials for the Absorptive Filling

The following materials are commonly used for absorptive filling:

- a) glass fibre (maximum operating temperature: 530°C)
- b) mineral wool (" " " 950°C)
- c) ceramic fibre (" " " 1260°C)
- d) stainless-steel wool

Open-cell plastic foam may be used for some applications, but its use should be specifically approved by the purchaser. There may also be a limited application for stainless-steel mesh where temperature, erosion or corrosion conditions are too severe to use the above materials.

The temperature of operation is usually the first consideration in the choice of a suitable absorptive filling and its maximum operating temperature should be reviewed in relation to this. Although the materials listed under (a) - (c) are fairly inert, their compatibility with the process gas or vapour must be examined; for example, high-temperature steam may severely limit the effective life of glass fibre and mineral wool.

For high-temperature applications it may be necessary to limit the resin content; and, when used with stainless steel, to limit the chloride content (see Section 5.1).

5.4 Draining

Where there is a possibility of vapours condensing in the silencer or of rainwater entering it, a suitable drain should be provided. The most vulnerable part is the inside of the outer shell, which may be colder than the inside of the silencer if it is operating with a hot gas and it is important that the drain should be able to empty this part. Flammable condensates should be drained to a closed system.

5.5 Impermeable Membrane

Where there is a possibility of flammable liquids splashing into the absorptive filling, it will be necessary to put a thin plastic membrane between the filling and the perforated plate to reduce the risk of a wicking effect and consequent fire. This may also be needed to prevent the filling being clogged by solids.

The membrane must be thin if it is not to impair the acoustic properties of the silencer and consequently it is liable to mechanical damage; it will also have a limited temperature range of operation. Impermeable membranes are more commonly used with acoustic enclosures and in the acoustic treatment of rooms (often, for reasons of hygiene) and there are well-established techniques for applying them as a protection for the absorptive layer. However, it is rare for them to be used in silencers and the purchaser would have to make a specific requirement for one if he saw a need for it.

5.6 Pressure Drop

The insertion of a silencer into a flow system may cause an additional impedance to the gas or vapour flow and the purchaser must specify the maximum allowable pressure difference across the silencer for its particular duty. This must take into account the flow rate, temperature and dynamic viscosity of the fluid in question. The vendor should quote the expected pressure difference and should indicate the calculation or measurement procedures on which his data are based.

5.7 Installation

Silencers are bulky in relation to the piping systems in which they are placed. This means that, in the design stage of a plant, an early decision must be made to use a silencer for a particular application so that adequate space for it can be allocated in the plant layout. Large industrial silencers can also be heavy and may need special supporting structure which will have to be considered at an early stage in the design; for structures such as offshore platforms, where weight is an important factor, the weight of a large industrial silencer may make a significant contribution to the total weight of the structure. Its erection may also require the use of special cranes.

Even at the other end of the scale where small silencers are used (say, for the exhausts of pneumatic tools) it will be necessary to allow for their size and weight.

These considerations apply equally to the installation of silencers for noise control in existing plants and the additional stresses in the structures must be taken into account.

The direction of flow is important and must be clearly marked on the silencer to ensure that it is correctly installed.

5.8 Inspection and Maintenance

Once installed, silencers tend to be forgotten and it is assumed that they will maintain their acoustic performance indefinitely. But there may be a gradual deterioration of the internal components causing a slow decrease in the noise reduction, which may not be noticed until there is a complaint or a noise survey of the installation. Frequently, it is not easy to inspect the inside of a silencer; it may be a welded construction, it may be inaccessible (say, high up on a vent), or it may be in a pressurised system.

Nevertheless it is important to establish a programme of regular inspection and maintenance. The frequency of inspection will depend on the severity of the duty of the silencer; where there is a risk of erosion of the filling due to high-velocity gas, or of clogging by particles, or of destruction of the filling by chemical action, a frequent inspection will be necessary.

It will be necessary to consider whether the silencer can be removed as a whole or whether the internal components, such as the absorption pods, can be removed separately; or, with large silencers, whether access to the interior can be obtained through manholes.

The inspection of the filling is not easy because it is usually retained by welded perforated plate (and possibly glass cloth or an impermeable membrane) and an appropriate procedure will have to be agreed with the vendor, either at site or in the vendor's factory. The repair procedure will also have to be considered; whether by replacement of the silencer or replacement of components. Timing will be an important factor, particularly if the replacements can only be carried out during plant shutdowns.

5.9 Temperature Effects

The first obvious effect of using a silencer with high-temperature gases is on the choice of materials, which must be suitable for the operating temperature. Some typical maximum operating temperatures for the absorptive filling are given in 5.3 and the lower operating temperature of glass fibres should be noted; it means that glass cloth cannot be used to prevent erosion of the filling at operating temperatures higher than this.

A second effect is thermal expansion and this must be allowed for in the design of the silencer.

But a further effect, which is sometimes overlooked in the design of the silencer, is the increase in the speed of sound of the gas. In absorptive silencers this influences the acoustic properties of the filling and the optimum spacings between the absorptive elements. In reactive silencers it will change the resonant frequencies of the chambers so that the maximum noise reduction no longer matches the dominant frequencies of the source. Thus, a standard silencer whose design is based on the speed of sound in the gas at ambient temperature may no longer be effective for higher temperatures. (It may be noted that, if its design has been optimised for air, it may not be suitable for other gases with a different velocity of sound, whether at ambient or higher temperatures.)

In general, therefore, silencers for use with hot gases need to be specially designed; both in terms of materials and their acoustic performance.

5.10 Integrity

When a silencer is installed on the suction side of a compressor special attention must be paid to its integrity of construction to ensure that materials are not sucked into the machine or other downstream components. It is recommended that no rivets should be used in its construction. Erosion protection of the absorptive filling is also an important aspect.

5.11 Vibration Isolation

Pipes which are rigidly attached to rotating machines such as compressors may transmit a large amount of structure-borne noise along their walls; it may be a significant proportion of the noise from the machine. This structure-borne noise will be passed on to the walls of the silencer and their greater area may lead to an increase in the noise radiated to the air compared with the original pipe.

Whenever possible therefore a vibration isolator should be inserted between the machine and the silencer. This could be in the form of a section of rubber or plastic piping, or a thick flange gasket with vibration isolated bolts. However, this can only be used in low-pressure systems.

With piping that has to conform to pressure codes, this may not be acceptable and it may be necessary to apply acoustic insulation to the walls of the silencer. This however will not prevent the further transmission of structure-borne noise along the pipe and in some cases it may be worth considering vibration damping of the walls of the silencer by surrounding them with a sand box or a similar arrangement.

6. ACOUSTIC REQUIREMENTS

6.1 Specification

6.1.1 General

The purchaser should specify the acoustic performance of the silencer in one of the following forms, and how it should be measured:

- a) The dynamic insertion loss.
- b) The sound-power level of the discharge from the silencer.
- c) The sound-pressure level at a specified position near the silencer.

In all cases he should specify his requirements in octave bands from 63 Hz to 4 kHz, and in some cases at 31 Hz and or 8 kHz. The vendor should quote the performance of the silencer in the same terms and should include the effect of regenerated noise in his data.

The parameter selected for specifying the acoustic performance should be based on the method by which the silencer will ultimately be tested in operation.

6.1.2 Dynamic Insertion Loss

This refers to the effective noise reduction of the silencer with the gas flowing through it and would include the effect of noise regenerated by the gas flow. To specify this parameter, the purchaser would need to know the noise from the source and the reduction required to meet some work-area or neighbourhood criterion.

For an open system such as a vent he would measure or calculate the sound-power level of the unsilenced vent and compare this with the sound-power level required to meet the criterion. The difference between them defines the required dynamic insertion loss of the silencer.

For a closed system he would need to know the internal sound-power level of the noise source (say, a valve, compressor or orifice plate) and how this relates to the noise radiated externally from the piping. There are no standard procedures available for doing this at present (although some are being developed) so this technique is unlikely to be widely used for the time being.

6.1.3 Sound-Power Level

In specifying the sound-power level of the discharge from the silencer, the purchaser is passing to the vendor the responsibility of estimating the noise generation due to the gas flow. This will depend on the relative expertise of the two parties.

There are various procedures for calculating the noise due to gases discharging from open pipes, some sophisticated and some simple, and the choice will depend on the particular circumstances.

Many vendors use procedures which they consider suitable and the purchaser must satisfy himself that the procedure used is acceptable to him.

6.1.4 Sound-Pressure Level

The purchaser may define the required sound-pressure level at a specified position or the required reduction of the sound-pressure level at that position from a specified level.

In the first case, this leaves the vendor with the responsibility of making the necessary acoustic calculations - and this must be acceptable to the purchaser. In the second case (probably the more likely possibility of the two) the vendor must relate the known characteristics of his silencer with its effect on the other acoustic properties of the system; in a closed system for example, with the effect on structure-borne noise and the relation with the frequency in characteristics of the pipe walls. The simple use of dynamic insertion loss may not be sufficient for this purpose. For an open system such as a vent he would have to consider the propagation path to the specified position.

6.1.5 Narrow-Band (Tonal) Noise

When the source noise contains narrow-band components it will be necessary to reduce them to a level where they are masked by broad-band noise from other sources. It is possible to make a detailed study of the noise spectrum by narrow-band analysis; but for most purposes it is sufficient to make a subjective judgement by ear of the presence of a narrow-band component, and whether it is a dominant feature of the source noise. The octave band in which it occurs may be indicated by a peak in the spectrum or it could be determined by comparison with a source of known frequency; with rotating equipment it may be calculated from the blade-passing frequency of the rotor.

Ref. 1 gives recommendations for the amount by which the narrow-band noise must be reduced to be masked by broad-band background noise; it depends on the frequency of the component and whether the reduction is required for work-area or neighbourhood noise. The reduction refers to the octave band in which the narrow-band noise occurs and therefore defines the insertion loss of the silencer in that band; it means that an absorptive silencer will have too great an insertion loss in the neighbouring bands since its characteristics do not give band-pass effects.

6.1.6 Details to be agreed between Purchaser and Vendor

The following details should be agreed with the purchaser:

- a) The pipe size and the type of connection required on the silencer inlet; also, any forces due to attached piping and reactive forces due to the piping.

- b) The flow conditions, including:
 - i) Gas or vapour and its molecular weight
 - ii) Type of valve, its size and characteristics (for example, C_v/C_g)
 - iii) Pressure and temperature upstream and downstream of valve
 - iv) Maximum mass-flow rate
 - v) Maximum pressure at the silencer inlet
 - vi) Pressure drop across the silencer
 - vii) Maximum velocity in absorption section of silencer.
- c) The acoustic performance.
- d) The appropriate pressure code (if applicable) and the design pressure.
- e) The position and type of drain connections.
- f) Drawings showing the general dimensions, detailed arrangement of the internal fittings, materials of construction and surface treatment.
- g) The position and style of the identification marks and indication of flow direction.
- h) Operating environment (climate, design wind speed).

6.2 Testing

It is not easy to test a silencer in an operating plant, particularly to obtain results which would be accurate enough for contractual disputes. Frequently this is due to the interference of background noise from other equipment; but, often, it is difficult to obtain comparative measurements of the noise source before and after the silencer is added. Generally, if the area-noise criterion (work area or neighbourhood levels) is met after installing the silencer, the purchaser will be satisfied and will not be concerned with whether the silencer has performed in accordance with the vendor's claims. The problem arises when the criterion is not met and it is necessary to prove that the silencer performance has not met the specification.

6.2.1 Dynamic Insertion Loss

To determine the dynamic insertion loss of the silencer it will be necessary to make equivalent measurements with and without the silencer in position. These should be measurements of sound-power level or sound-pressure level at the outlet from the system.

It will not normally be possible therefore to make accurate determinations of the insertion loss of in-line silencers because the measurements would have to be made outside the piping system and would be influenced by the acoustic characteristics of the pipe walls (transmission loss and structure-borne noise).

6.2.2 Sound-Power Level

The sound-power level of the source and silencer should be measured by one of the procedures given in EEMUA Publication No.140 (Ref. 1). For vent and exhaust silencers it will usually be most suitable to use the small-source method; sound-pressure level measurements would then be made on a hemispherical or spherical measurement surface whose radius is large compared with the source dimensions.

Silencers in ventilation systems should be tested according to BS 4718. In-line silencers in piping systems should be tested by the procedures in Ref. 1. This will mean determining the radiated sound-power level of the pipe downstream of the silencer, either by acoustic or by vibration measurements.

Large silencers for fans or gas-turbine inlets may be tested with the large-source method of Ref. 1.

6.2.3 Sound-Pressure Level

In principle it is straightforward to measure the sound-pressure level at a specified position near the silencer and to compare it with a criterion or with the sound-pressure level without the silencer. However, the measurements suffer the same problems as the methods discussed above; they may be affected by background noise; and it may be difficult to reproduce the same operating and background conditions with and without the silencer. But for many purposes this may be the most useful and direct test of the silencer; for example, for small silencers on tools and vehicles, or where the source noise dominates the background.

7. REFERENCES

Noise procedure specification (Revision 2). EEMUA Publication No.140 (First published as OCMA specification No. NWG-1, March 1980).

GLOSSARY OF ACOUSTIC TERMS

A.1 The Decibel

Several important acoustic quantities are measured in terms of decibels. The decibel is ten times the logarithm of the physical quantity divided by a reference value. The International Standards Organisation (ISO) has defined the appropriate reference values for the acoustic quantities in common use. Any physical quantity measured in decibels is referred to as a "level". Examples are sound-pressure level and sound-power level.

A.2 Sound-Pressure Level

This is an indication of the loudness of a noise and is the quantity measured by sound-level (or "noise") meters. As its name implies, it is measured in decibels and it is ten times the logarithm of the mean-square of the pressure variations (above and below the ambient pressure) which form the sound energy. It is defined as:

$$L_p = 10 \log_{10} (p^2/p_o^2) \quad (\text{dB})$$

where,

p is the instantaneous pressure variation from the ambient pressure (measured in Pa or N/m^2)

p^2 is the mean-square pressure variation

p_o is the reference quantity of 20×10^{-6} Pa

A.3 Sound-Power Level

This is the measure of the acoustic power (in watts) emitted by a noise source. The relevant decibel term is ten times the acoustic power of the source divided by the reference quantity. It is defined as:

$$L_w = 10 \log_{10} W/W_o \quad (\text{dB})$$

where,

W is the acoustic power of the source (in watts)

W_o is the reference quantity of 10^{-12} W

This term is usually numerically larger than the sound-pressure level and must not be confused with it because it is also measured in decibels. It is analogous to the power of, say, an electric-light bulb, whereas the sound-pressure level would be analogous to the brightness of light as seen by the eye. The acoustic sound power of a source is a relatively small quantity and may be in the range of 10^{-6} to 10^{-9} of the mechanical power of a piece of equipment.

APPENDIX A

A.4 Frequency

The frequency of a sound is a measure of its "pitch". It is now measured in hertz (Hz), which replaces the older term, cycles per second (cps). High frequencies of audible sounds are measured in kilohertz (kHz).

A.5 Broad-Band Noise

Most industrial noises consist of a continuous spectrum of frequencies, analogous to white light, and this is referred to as "broad-band noise". In nature, this is typified by the noise from a waterfall which contains a mixture of sounds ranging continuously in frequency from a roar to a hiss.

A.6 Octave Bands

In order to obtain a rough spectrum of the "character" of a noise it is common practice to measure the noise energy separately in various frequency bands. These bands have been defined internationally by the ISO and consist of a series of adjacent bands whose centre frequencies double in value from one to another. The most commonly used bands have centre frequencies of 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. For special purposes, measurements can be made in other octave bands, such as 31.5Hz and 16000Hz.

A.7 Narrow-Band or Tonal Noise

The sound emitted by a musical instrument consists of a series of discrete tones (the fundamental note plus harmonics) and their frequencies are well defined. Some industrial equipment can emit musical notes (in addition to broad-band noise) and this is referred to as "tonal noise". More often, the frequencies are not as uniquely defined as in musical instruments and consist of a narrow range of frequencies, referred to as "narrow-band noise". The two terms are often used interchangeably to describe a noise where tones stand out above the broad-band noise.

MODEL DATA SHEET FOR SPECIFYING A SILENCER

Specification for Purchase of a Silencer (Delete items which are inapplicable)

PART 1 INFORMATION FROM PURCHASERNOTES **A : Equipment to be Silenced**

Plant:

- (1) Type of Equipment:
Item No:
Type of Silencer Required:

(2) B : Acoustic Data

Noise Type: Continuous/Intermittent
If intermittent, Duration..... hours.
Frequency of occurrence.... times/day/week/month.

Noise Emission of Equipment

Octave-band centre frequency (Hz)	31.5	63	125	250	500	1K	2K	4K	8K
Unsilenced sound-power level (dB)									
Unsilenced sound-pressure level (dB)									

- (3) Measurement position:
- (4) Narrow-Band Noise (tick O.B.s)
- (5) **Required Acoustic Performance of Silencer**

Dynamic insertion loss (dB)
Silenced sound-power level (dB)
Silenced sound-pressure level (dB)

- (6) Measurement position:

C : Process Details

Gas/Vapour: Mol. Weight:
Mass flow rate: (kg/s)
Gas/Vapour Temperature: (°C)

Pressure difference limit across silencers: minimum: (bar)
maximum: (bar)

Inlet pressure to silencer (bar A)
Outlet pressure (bar A)

APPENDIX B

D : Constructional Requirements for Silencer (See Drawing No:....)

Operating environment (climate)

- Temperature range ($^{\circ}\text{C}$)
- Wind loading

Silencer to be installed in open/under cover, horizontal/vertical.

Materials of construction:

- casing
- absorptive filling
- impervious membrane

Painting schedule before delivery:

Details of installation:

- space available
- maximum weight (kg)
- inlet flange size/rating....mm/....BS/ANSI
- outlet flange size/rating....mm/....BS/ANSI
- stresses from adjacent pipe connections
- drain connections

Pressure-vessel code:

Design pressure: (bar A)

Design temperature range ($^{\circ}\text{C}$)

Position and style of identification marks

Access for inspection and maintenance

PART 2 INFORMATION TO BE SUPPLIED BY VENDOR

A : Design Details

Silencer type (absorptive/reactive/diffuser etc).

Drawing showing dimensions, arrangement of internals and drain connections and direction of flow.

Flange size/rating

Pressure rating (for pressure vessel)

Materials of construction:

- casing
- flanges
- absorptive filling
- impermeable membrane

Method of retention of absorptive filling

Method of securing internals (bolts/rivets/welding)

Supporting structure required

Foundation and holding-down requirements

Pressure difference at maximum flow rate

Maximum fluid velocity in absorptive section

Weight of complete unit

Maximum operating temperature

Surface protection at delivery

APPENDIX B

B : Acoustic Performance with the Process Fluid at Operating Temperature

Octave-Band Centre Frequency (Hz)	31.5	63	125	250	500	1K	2K	4K	8K
Dynamic insertion loss (dB)									
Silenced sound-power level (dB)									
Silenced sound-pressure level (dB)									

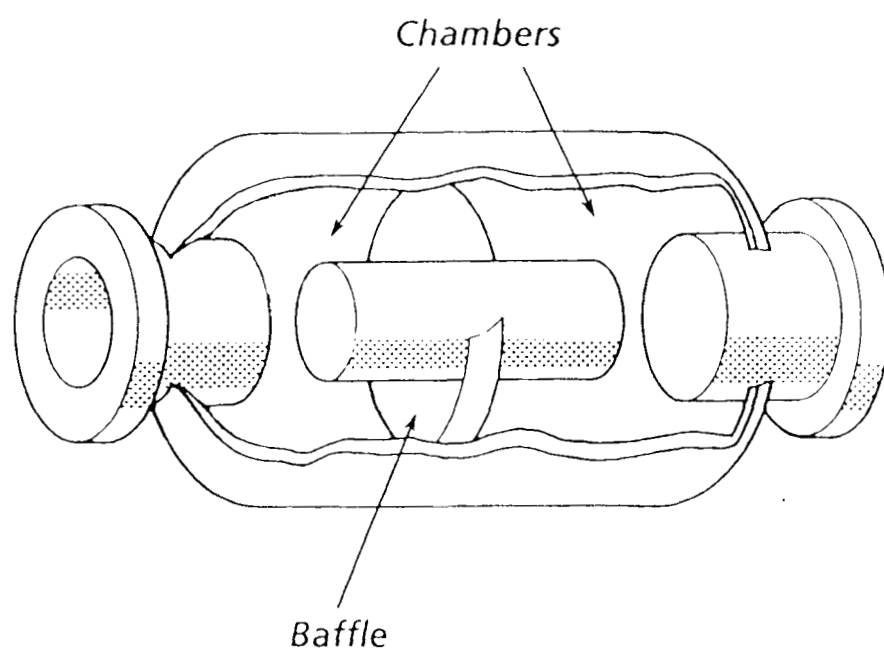
Measurement position

Description of the basis of the performance estimates
(calculations/measurements)

Other remarks on application of silencer

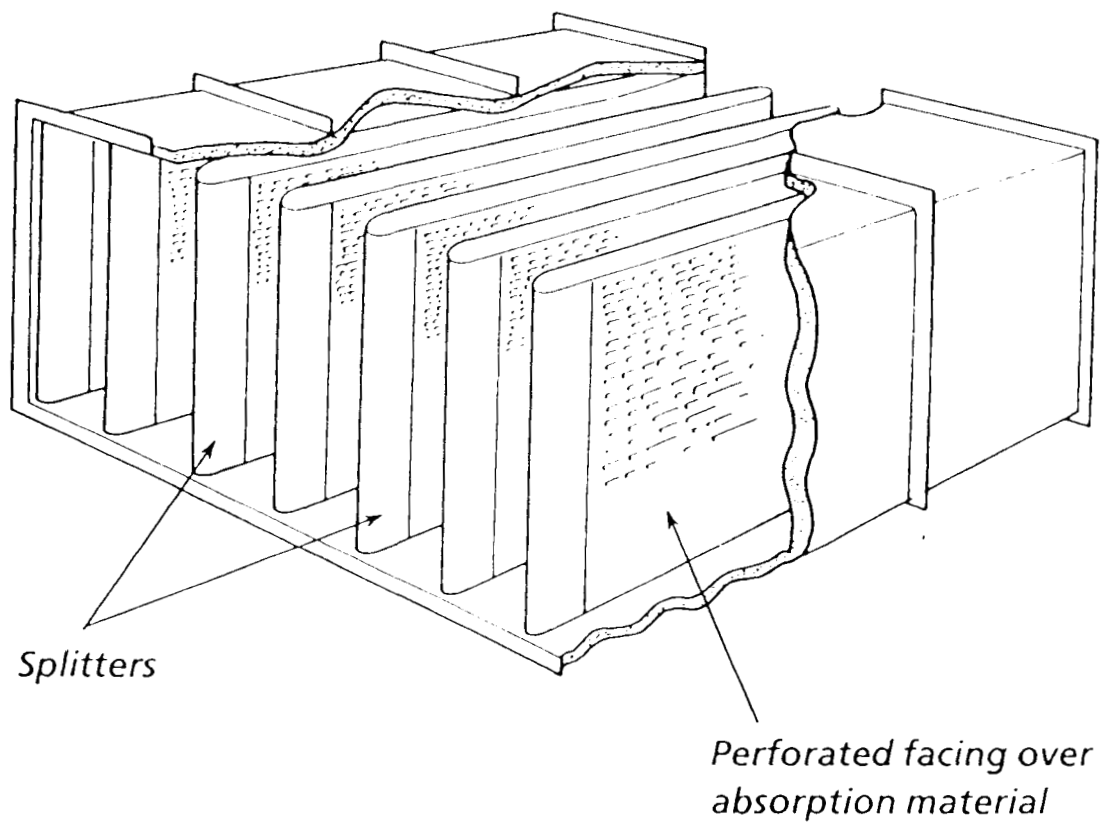
NOTES ON MODEL SPECIFICATION

- (1) Give details of type of valve/compressor etc. and any special characteristics, such as cylinder frequency in reciprocating machines.
- (2) A general indication of the application will be of use to the vendor, who may have specialised advice to offer.
- (3),(6) The measurement position for sound-pressure level measurements should be indicated on a dimensioned sketch.
- (4) Indicate the octave band or bands where narrow-band noise occurs.
- (5) The required acoustic performance should include any reductions to reduce narrow-band noise in the appropriate octave bands.



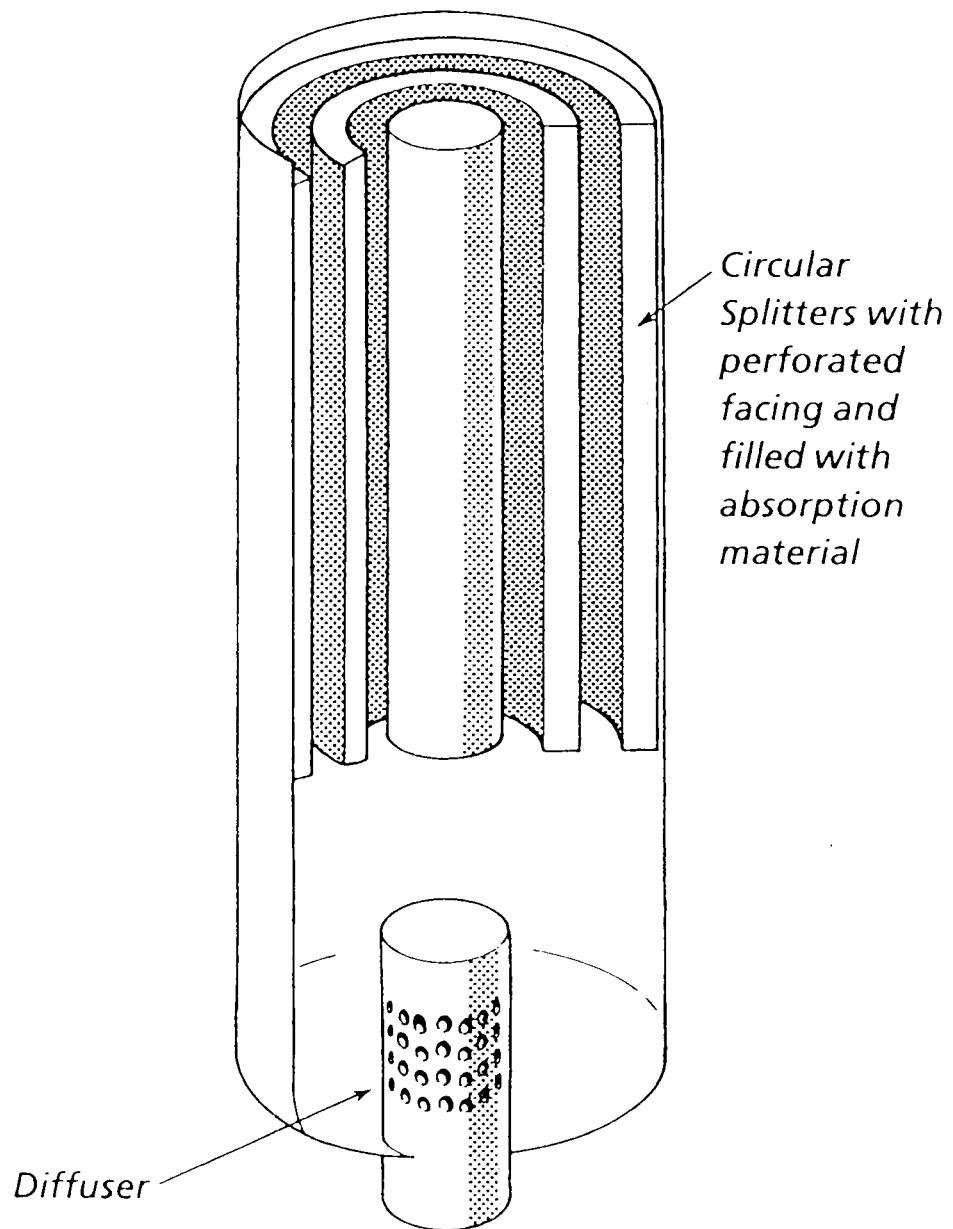
Reactive Silencer

Figure 1



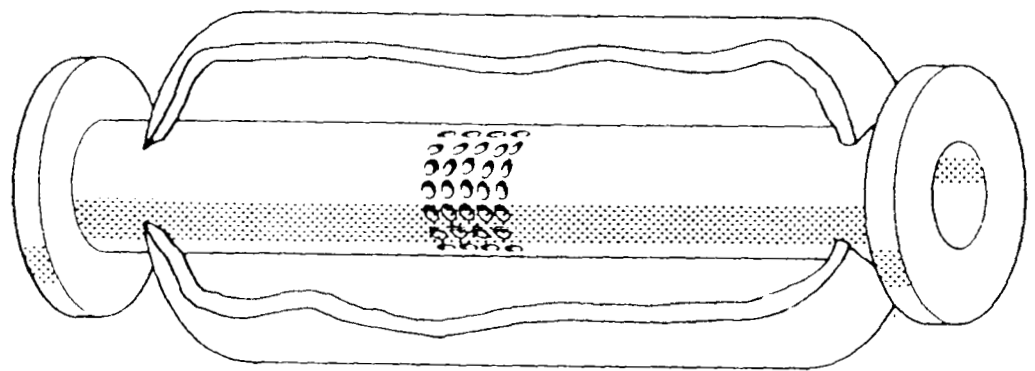
Rectangular Absorptive Silencer

Figure 2



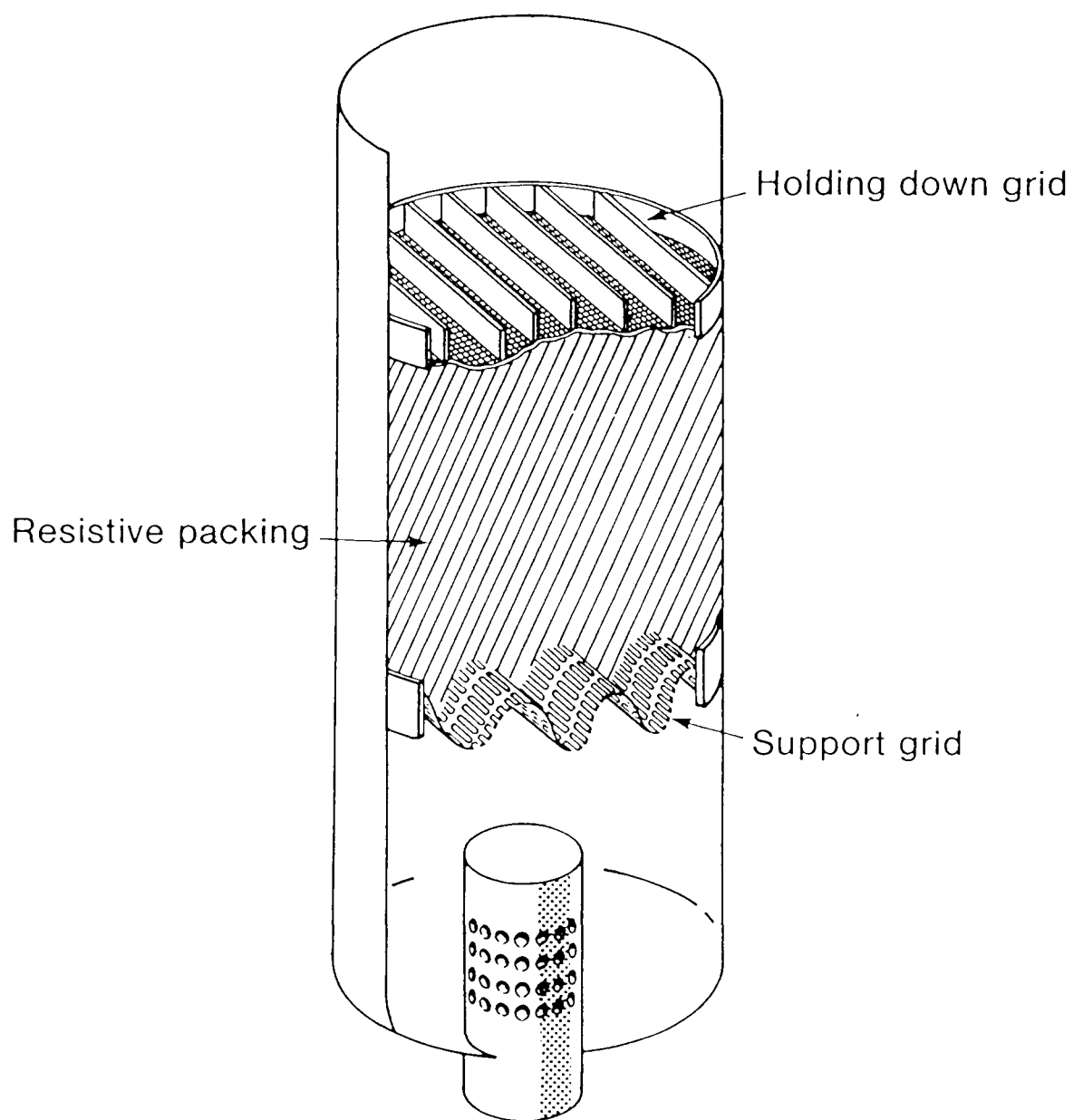
Combined Reactive and Absorptive Silencer

Figure 3



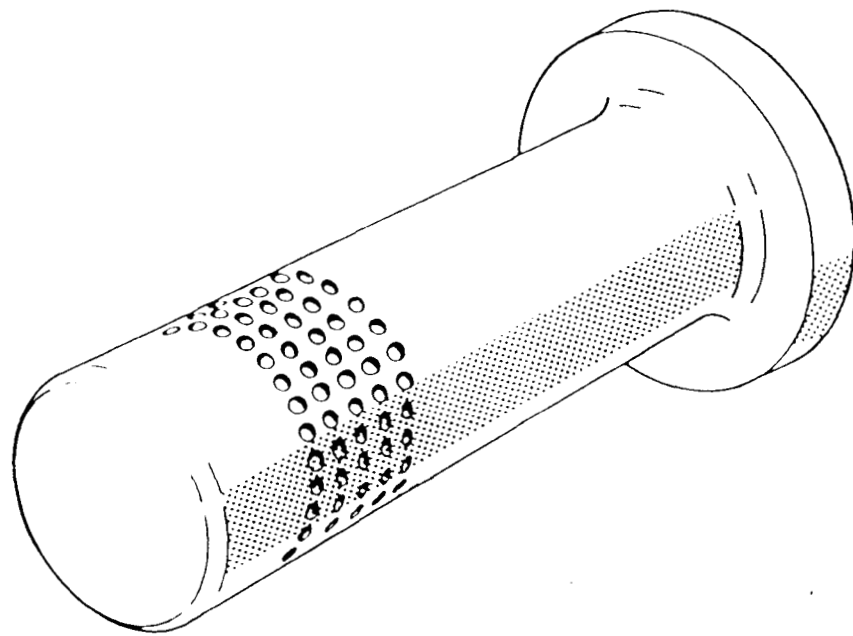
Form of Helmoltz Resonator

Figure 4



Diffuser Silencer

Figure 5



Multihole Silencer
(sometimes referred to as a Diffuser Silencer)

Figure 6

SUMMARY LIST OF CURRENT EEMUA PUBLICATIONS

Introductory Note

Publications are listed in numerical order under the following headings: Electrical, Instrumentation & Control, Mechanical Plant and Equipment, Offshore, Storage Tanks and Vessels, Noise, and General. (For further details see website www.eemua.co.uk/publications.)

An asterisk (*) indicates a publication in preparation

Amendments Where amendments have been issued, these are listed in bracketed italics after the title of the publication. It is intended that amendments be placed on the website www.eemua.co.uk/publications/amendments.

Publication No.

ELECTRICAL

- | | |
|----------|--|
| 132 : 88 | Specification for Three-phase Cage Induction Motors (<i>Amdt No 1, Mar 02</i>) |
| 133 : 88 | Specification for Underground Armoured Cable Protected against Solvent Penetration and Corrosive Attack |
| 181 : 95 | A Guide to Risk Based Assessments of In-situ Large Ex 'e' and Ex 'N' Machines |
| 186 : 97 | A Practitioner's Handbook—Electrical Installation, Inspection and Maintenance in Potentially Explosive Atmospheres (<i>Updated & reprinted 2002</i>) |
| 198* | Electromagnetic Compatibility A User Guide to Installations and Standards |

INSTRUMENTATION & CONTROL

- | | |
|-------------|--|
| 138 : 88 | Design and Installation of On-Line Analyser Systems |
| 138 S1 : 93 | Design and Installation of On-Line Analyser Systems: A Guide to Technical Enquiry and Bid Evaluation |
| 155 : 88 | Standard Test Method for Comparative Performance of Flammable Gas Detectors against Poisoning |
| 175 : 95 | Code of Practice for Calibration and Checking Process Analysers—Formerly IP Code of Practice 340 |
| 178 : 94 | A Design Guide for the Electrical Safety of Instruments, Instrument / Control Panels and Control Systems |
| 187 : 00 | Analyser Systems - A Guide to Maintenance Management |
| 189 : 97 | A Guide to Fieldbus Application for the Process Industry |
| 191 : 99 | Alarm Systems - A Guide to Design, Management and Procurement |

- 201: 02 Process Plant Control Desks Utilising Human-Computer Interfaces—A Guide to Design, Operational and Human Interface Issues

MECHANICAL PLANT AND EQUIPMENT

- 107 : 92 Recommendations for the Protection of Diesel Engines for Use in Zone 2 Hazardous Areas
- 143 : 85 Recommendations for Tube End Welding: Tubular Heat Transfer Equipment, Part 1 — Ferrous Materials (*No subsequent parts issued*)
- 151 : 87 Liquid Ring Vacuum Pumps and Compressors
- 153 : 96 EEMUA Supplement to ASME B31.3 —1996 Edition, Process Piping (*Amdts Dec 2000 & Feb 02*)
- 164 : 93 Seal-less Centrifugal Pumps: Class 1
- 167 : 91 Specification for Quality Levels for Carbon Steel Valve Castings
- 168 : 91 A Guide to the Pressure Testing of In-Service Pressurised Equipment
- 169 : 93 Specification for High Frequency Electric Welded Line Pipe (*Obsolescent*)
- 170 : 91 Specification for Production Testing of Valves—Part 1 Ball Valves (*Reprinted 2001 incorporating Amdt No 1 Apr 96 & other minor changes*)
- 171 : 94 Specification for Production Testing of Valves—Part 2 Plug Valves (*Errata & Amdt No 1 Apr 96*)
- 172 : 95 Specification for Production Testing of Valves — Part 3 Gate Valves (*Amdt No 1 Jan 96*)
- 173 : 95 Specification for Production Testing of Valves — Part 4 Butterfly and Globe Valves
- 179 : 96 A Working Guide for Carbon Steel Equipment in Wet H₂S Service (Developed largely from Oil Refinery experience)
- 182 : 95 Specification for Integral Block and Bleed Valve Manifolds for Direct Connection to Pipework (Incorporating Information Sheet No 20: Application Guidelines) (*Reprinted incorporating Amdt No 1 Nov 98*)
- 184 : 96 Guide to the Isolation of Pressure Relieving Devices
- 185 : 96 Guide for Hot Tapping on Piping and other Equipment (*Reprinted 2000 incorporating Amdt No 1 Dec 97*)
- 188 : 99 Guide for Establishing Operating Periods of Safety Valves
- 192 : 98 Guide for the Procurement of Valves for Low Temperature (Non-cryogenic) Service
- 196 : 99 Valve Purchasers' Guide to the European Pressure Equipment Directive (*Reprinted 2002 incorporating Amdts 1–3, Nov 00, Feb 02 & Aug 02, respectively*)

- 199 : 00 On-Line Leak Sealing of Piping - Guide to Safety Considerations
- 200 : 00 Guide to the Specification, Installation and Maintenance of Spring Supports for Piping
- 202 : 01 Guide to the Use of ISO 15649 and ANSI/ASME B31.3 for Piping in Europe in Compliance with the Pressure Equipment Directive (*Reprinted 2002 incorporating Amdt No 1 May 02*)

OFFSHORE

- 144 : 87 90/10 Copper Nickel Alloy Piping for Offshore Applications—Specification: Tubes Seamless and Welded
- 145 : 87 90/10 Copper Nickel Alloy Piping for Offshore Applications—Specification: Flanges Composite and Solid
- 146 : 87 90/10 Copper Nickel Alloy Piping for Offshore Applications—Specification: Fittings
- 158 : 94 Construction Specification for Fixed Offshore Structures in the North Sea (*Reprinted 2000 incorporating Amdts 1 (Rev'd) & 2, Apr 97, & 3 Sep 02, and other minor emendations*)
- 166 : 91 Specification for Line Pipe for Offshore Pipelines (Seamless or Submerged Arc Welded) (*Obsolescent*)
- 176 : 98 Specification for Structural Castings for Use Offshore
- 194 : 99 Guidelines for Materials Selection and Corrosion Control for Subsea Oil and Gas Production Equipment (*Under revision, 2003*)
- 197 : 99 Specification for the Fabrication of Non-Primary Structural Steelwork for Offshore Installations

STORAGE TANKS AND VESSELS

- 147 : 86 Recommendations for the Design and Construction of Refrigerated Liquefied Gas Storage Tanks
- 154 : 02 Guidance to Owners on Demolition of Vertical Cylindrical Steel Storage Tanks and Storage Spheres (2nd Edition)
- 159 : 03 Users' Guide to the Inspection, Maintenance and Repair of Aboveground Vertical Cylindrical Steel Storage Tanks (3rd Edition) (*In two volumes, completely revised and expanded*)
- 180 : 96 Guide for Designers and Users on Frangible Roof Joints for Fixed Roof Storage Tanks
- 183 : 99 Guide for the Prevention of Bottom Leakage from Vertical Cylindrical Steel Storage Tanks
- 190 : 00 Guide for the Design, Construction and Use of Mounded Horizontal Cylindrical Bulk Storage Vessels for Pressurised LPG at Ambient Temperatures

NOISE

- 104 : 85 Noise: A Guide to Information required from Equipment Vendors
- 140 : 85 Noise Procedure Specification
- 141 : 85 Guide to the Use of Noise Procedure Specification
- 161 : 88 Guide to the Selection and Assessment of Silencers and Acoustic Enclosures

GENERAL

- 101 : 94 Lifting Points—A Design Guide
- 105 : 02 Factory Stairways, Ladders and Handrails (Including Access Platforms and Ramps) New edition 2002
- 148 : 86 Reliability Specification—Model clauses for inclusion in purchasing specifications for equipment items and packages
- 149 : 97 Code of Practice for the Identification and Checking of Materials of Construction in Pressure Systems in Process Plants
- 193 : 99 EEMUA Recommendations for the Training, Development and Competency Assessment of Inspection Personnel
- 195 : 99 Compendium of EEMUA Information Sheets on Topics Related to Pressure Containing Equipment (*Amdt No 1 Jan 00*)