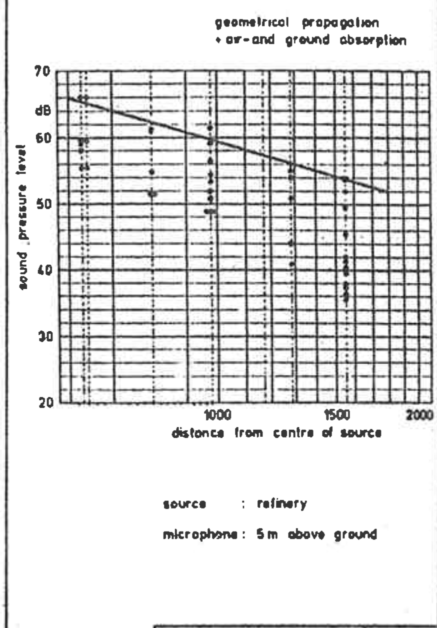
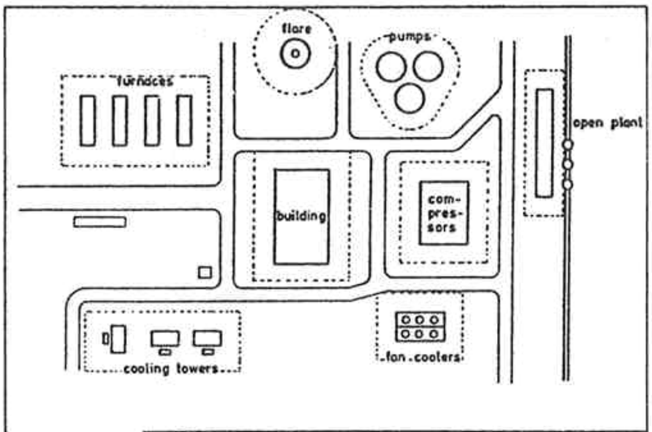
From this it can be concluded that such individual immission measurements are of very limited value indeed.
Only if taken over a longer period of time, or if done under specified climatic conditions they can serve as a meaningfull comparison with set community noise limits. And this remains the only purpose which immission measurements really can serve. They are in general not suitable to quantitatively determine which individual sources within the plant contributes to the noise level measured outside.
To answer this question the following method for the identification of the contributing noise sources can be used.



IMMISSION MEASUREMENTS Fig. 1

Figure 2 shows the plan of a hypothetical plant which contains many different noise sources.
The first aim is, to determine the sound power output, or the emission, of these sources.



PLANT WITH NOISE GROUPS Fig. 2

To do this systematically and with a minimum of measurements, the plant will be subdivided into severall noise groups, around which a closed measuring surface can be put in such a way that the noise levels on that surface are as constant as practically possible.
The noise power level can than easily be determined in the well known way

$$L_p = \overline{L} + 10 \log F + K \qquad (1)$$

L_p = sound power level

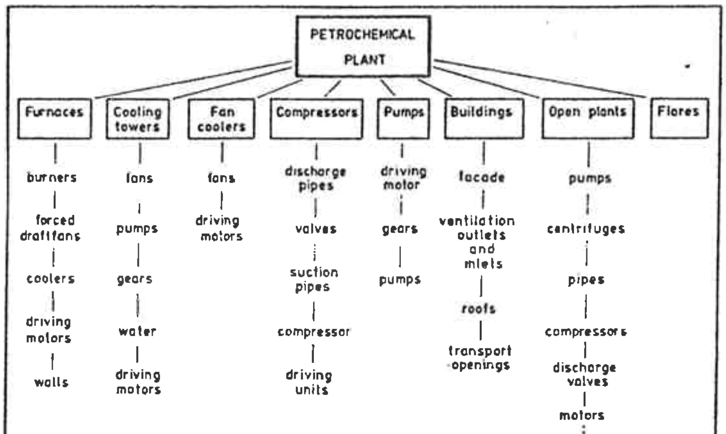
$\overline{L}$ = the mean sound pressure level on the measuring surface F

F = measuring surface

K = correction factor, usually between + 1 and - 6 dB.

The value of K becomes negative if the microphone picks up sound wave components other than normal to the measuring surface. This is the so called projection error.
The practical poblem with the application of eq (1) is always how to select a suitable measuring surface F so that K approaches zero, or assumes a known value, and that the number of relevant measuring points becomes a minimum.
Returning to figure 2: in general each of these noise groups contains a number of individual noise sources, but a noise group can also consist of only one major noise source.

Figure 3 gives a schematic example for a practicable system of noise groups with their individual noise sources from the petro-chemical industry.

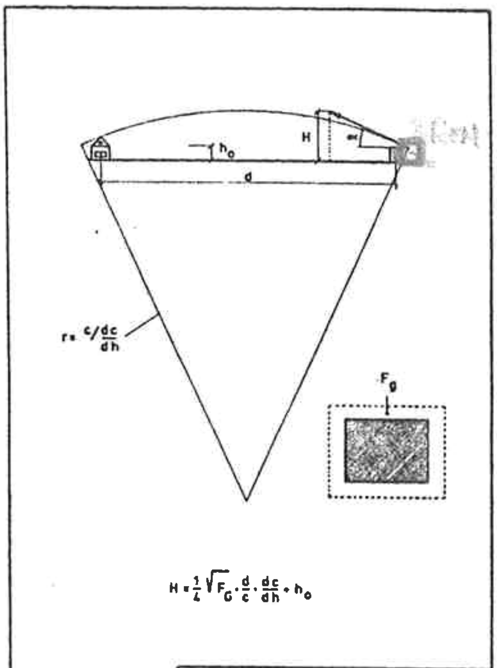


NOISE GROUPING Fig. 3

The measurement procedure then starts with the determination of the noise power output from each group by applying equation(1).
The groups differ greatly from each other in area and height of their principle noise sources, and the selection of suitable microphone positions to measure the sound pressure level $\bar{L}$ will vary accordingly.
The required height of the microphone position above groundlevel can be determined with the help of the schematic sketch of figure 4.

The noise group be relatively large in plane and consists of many incoherent sources.
The propagation of sound be downwind with positive wind gradient. The area deliniated by the microphone positions be F_g.
The mean height of the principal noise sources within the group is h_o.
The distance between the centre of the group and the measuring point in the community is d.
Then the microphone height H can be calculated as follows:

$$H = \frac{1}{4} F_g \frac{d}{c} \frac{dc}{dh} + h_o . \qquad (2).$$



REQUIRED MICROPHONE HIGHT | Fig. 4

For most practical applications the radius of the downwards bent sound ray is approximately equal to 5 km and with the distance (d) equal to 2 km, one obtains for the relevant emssion angle

$$\alpha \sim 20^{\circ}.$$

The required microphone height above h_o will only be dependent on F_g and can easily amount up to more than 10 mtr.
It will, therefore, be advisable to measure as close around the source as possible.
A further practical restriction, apart from the required microphone height, is the influence of other noise sources in other groups or from traffic near the plant.
The measurements will, therefore, nearly always have to be done by using a highly directional microphone.

After having determined the sound pressure level $\overline{L}$ in eq (1), with the help of the measurements described above, the measuring surface F has to be known.
It can be assumed to be the hemisphere above the source with the base area F_g.

$$\text{Then } r^2 = F_g \text{ and } F = 2\,\pi\, r^2, \text{ so that } F = 2\,F_G.$$

In order to obtain the sound power level (L_p in eq 1) the correction K has still to be determined.
This will be done with the help of figure 5.

The examples a, b, c and d show some typical situations

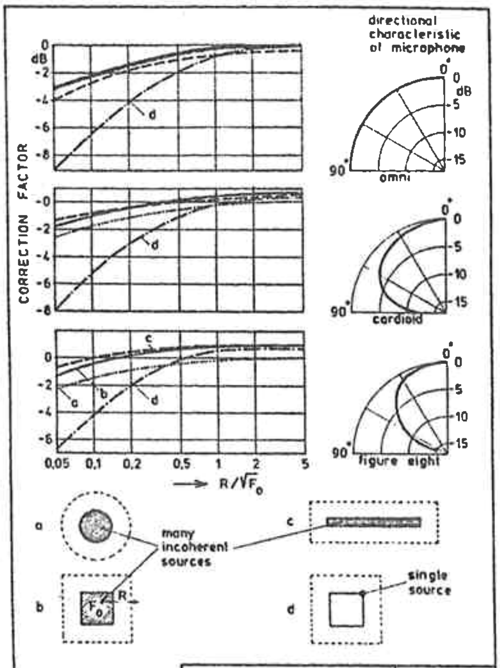
a) a circular array of incoherent noise sources,

b) a square array of incoherent noise sources,

c) a rectangular array of incoherent noise sources,

d) a single noise source at the corner of a square.

The distance of the microphone path around the boundary of the source be R. Then the correction factor K can be calculated for the different microphone characteristics.



CORRECTION OF ANGULAR ERRORS Fig 5

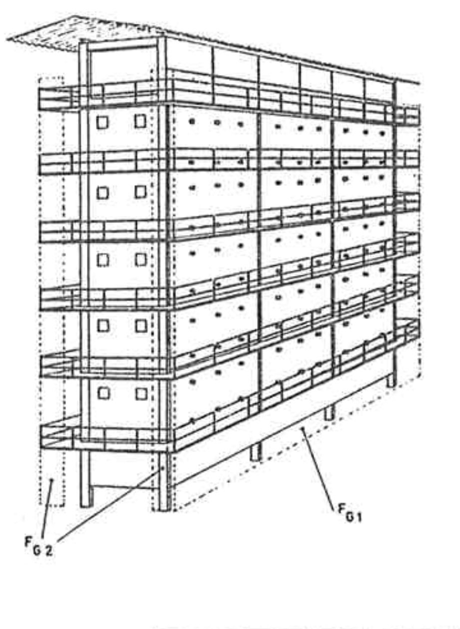
From the results it can be seen, that the situation d entails the greatest correction which typically amount to

$$+ 1,5 \text{ dB} < \Delta L_p < 3 \text{ dB}$$

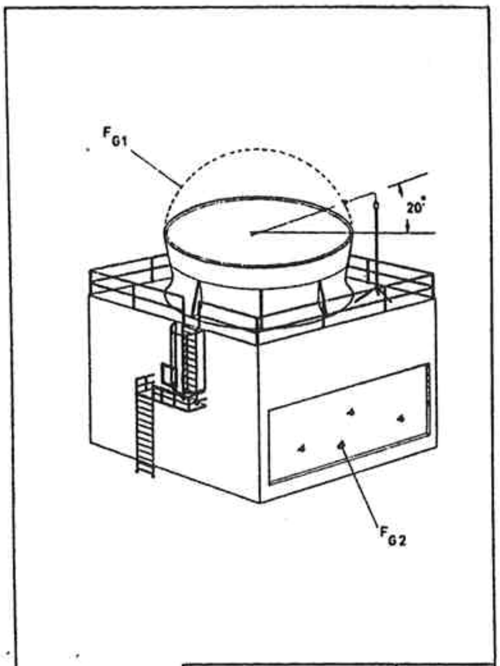
Thus, the emission level of large noise sources, mostly the noise groups, can be determined by measuring the sound pressure level on a prescribed path at a certain height, 10 to 20 m around the source, and by applying equation (1).
A comparison of the emission levels obtained for all noise groups will than reveal whether some of them can already at this stage be identified as "not contributing".
The remaining contributing groups have to be further analysed to identify the contributing individual noise sources within each group.
This will also be done with the help of eq. (1), but the choise of a suitable measuring surface F will be varying much dependent on the different types of individual noise sources.
By the help of a few examples we shall try to describe the possible choises of measuring surfaces.

Figure 6 shows a furnace of which the sound power level can be obtained by putting up two measuring surfaces F_{g1} and F_{g2} at 1,50 m distance from the furnace walls.
Since only these parts of the furnace are responsible for the total sound emission no completely envelopping surface will be needed.

The mean sound pressure level $\overline{L}$ in eq (1) will then be obtained through a great number of measuring points over each of the surfaces F_{g1} and F_{g2} and the total sound power level by adding up the sound power levels L_{P1} and L_{P2} for F_{g1} and F_{g2} respectively.



MEASURING SURFACE OF FURNACE Fig. 6



MEASURING SURFACES OF COOLING TOWER | Fig. 7

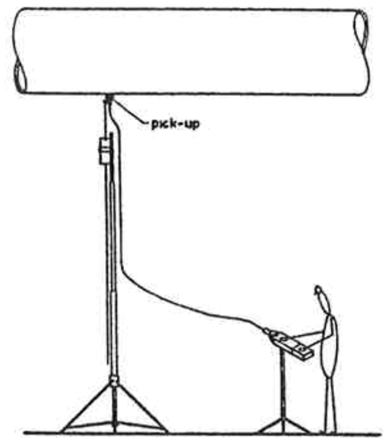
The next example is shown in figure 7, a cooling tower.
The noise emitting path is the air discharge on top of the tower and the suction side.
Around the discharge opening a hemisphere F_{g1} can be put, and a second measuring surface F_{g2} is taken over the whole area of the air intake opening.
For the determination of $\bar{L}$ over F_{g1} only one microphone position is needed as shown in the figure, because of the symmetry of the sound field around the vertical axis and because the emission remains constant over an angle of elevation from approximately 15° to 20° which is the relevant range that determines the immission level at a far distance.
At the suction side the mean sound pressure level has to be obtained by taking a number of individual measurements over the surface F_{g2}.

The sound power level will then again be calculated from eq (1), separately for both surfaces, because for each surface the influence of screening and scattering during propagation is different.

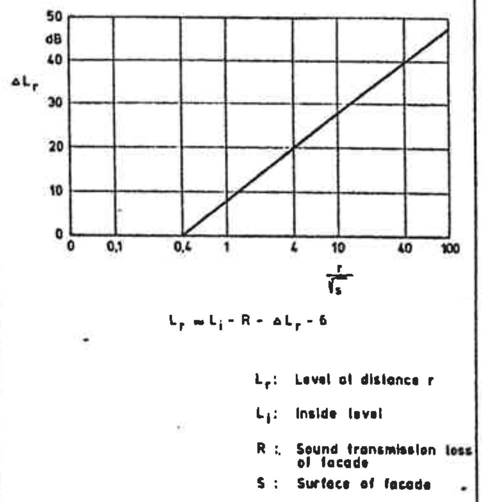
A quite different method has to be applied to determine the noise emission of pipes, because in most installations airborne noise measurements around a single pipe will not be possible due to interference from noise of other pipes close by.

A reliable method to eliminate such interference is to measure the vibration level of the pipe walls by means of a pick-up as shown in figure 8.

From the measured velocity level the radiated sound power can easily be calculated if the radiation factor of the pipe wall is known. The radiation factor approaches unity if the pipe walls are at least 6 mm thick and the frequency is higher than about 1000 Hz.
A typical A-weighted octave band spectrum of pipe noise shows a peak at about 2000 Hz and also the wall thickness of most pipes amounts to at least 6 mm.



VIBRATION MEASUREMENTS ON PIPES — Fig. 8



IMMISSION LEVEL OF RADIATING FACADES — Fig. 9

The next example deals with the noise emission of buildings. Here the same procedure can be followed as for the furnace, that is to say putting up measuring surfaces at close distance parallel to both façades.
An other method can be applied if the sound insulation of the façade is known. Then the noise level inside the building can be measured and one can calculate either the noise power transmitted through the façade or the noise level outside at a certain distance as shown in figure 9.

After having obtained the sound power level of each individual noise source, the sound pressure level L_r at a certain point in the neighbouring community, having the distance d from the sound source, can be calculated.
The calculation will be done with the help of the equation

$$L_r = L_p - 10\log 2\pi r^2 - A\,(f;r) - B\,(f).r - C\,(f;r) - D\,(r) \qquad (2)$$

wherein:

A: as a function of frequency and distance, describes the influence of screening due to obstacles on the way from the source to the receiver and of scattering and absorption within the noise group. This term can assume values between 0 and 20 dB.

B: as a function of frequency, describes the air absorption ranging from 0 to $2 \cdot 10^{-2}$ dB/m.

C: as a function from frequency and distance, describes the ground absorption, and depents on the height of the sound source above groundlevel, vegetation etc.

D: as a function of distance, describes the influence of wind- and temperature gradient.

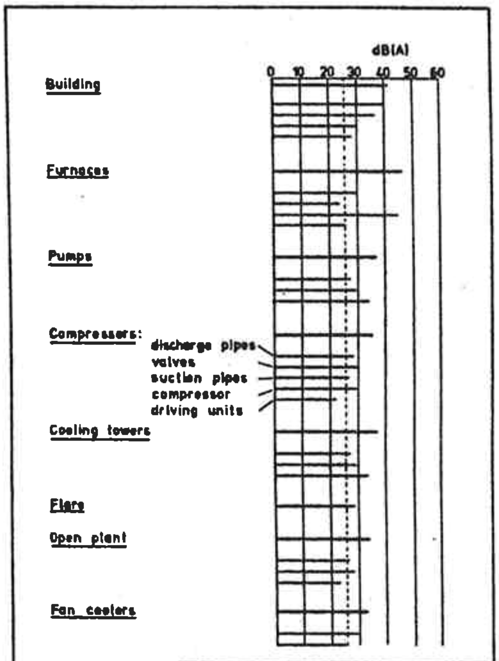
The sound pressure level L_r due to each individual source represents the clue for the identification of the contributing noise sources in the plant.
This is shown diagrammatically in figure 10.
Each noise source is represented by a line of which the length is proportional to the sound pressure level L_r.

The noise reduction, needed for each source to comply with a certain community level can be easily read off that diagramme.
This reduction will be

$$L = L_r - (L_c - 10\log n) \quad (3)$$

L_c = community noise limit

n = number of noise sources.

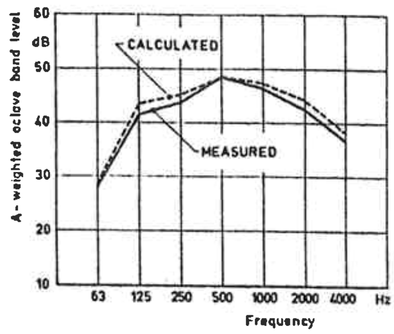


IMMISSION LEVELS OF CONTRIBUTING NOISE COURCES Fig.10

This completes the analysis of an existing noise problem and forms the first necessary step off towards solving it.

The same systematic approach can be used for the planning of new plants, with the only difference that the emission levels of the individual noise sources will be taken from the experience devided from results of measurements on many similar and already existing installations.

To conclude this paper, in figure 11 an indication will be given about the accuraty of the described method.



COMPARISON OF CALCULATED AND MEASURED IMMISSION LEVELS | Fig.11

This figure gives a comparison of the measured and the calculated immission level of an existing plant. The difference between measurements and calculations are for all octave bands smaller than 2,5 dB. The difference in A levels is typically smaller than 1,5 dB.

Acknowledgements

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