DEVELOPMENT OF A MODEL TO PREDICT THE NOISE EMISSION OF GAS STATIONS IN THE NETHERLANDS

Riezebos, H.J., Gasunie Research, The Netherlands
Mulder, J.P., Gasunie Research
Pluymen, J., Gasunie Research
Boot,O., Gasunie Research
Mooij, C., Gastransport Services
Procee S., Gastransport Services

1. INTRODUCTION

Environmental noise emission is turning out to be more and more a topic of growing importance in the transportation and distribution of gas. Being a prudent operator Gastransport Services (the transportation part of Gasunie) defines targets with respect to noise emission. Gas stations are subject to a number of legislatory obligations. Noise emission is an important aspect of these demands. In the past there was no overall check on whether Gastransport Services as a prudent operator was fulfilling these demands. Rather in case of complaints a sound measurement at a particular station was issued to check whether the noise emission was within the legislatory boundaries and –if necessary- the required actions were taken to lower the noise emission. Recently –based on international environmental agreements- it was issued that an overall check on environmental noise problems should take place in order to have fixed them by the year 2010 at the latest.
With this goal in mind a project started to evaluate the current noise emission characteristics of all gas stations in the Netherlands. The focus of this paper is on the 750 gas city gate stations, where the gas is handed over to the gas distribution companies. Instead of costly measurements at more than 750 of these stations in the Netherlands a model has been developed to predict the noise emission.

1.1 A gas city gate station in the Netherlands

A gas city gate station in the Netherlands is usually situated in buildings inside rural areas. An example of such a building is given in figure 1a. The function of the station is to reduce the pressure, usually from the regional pressure (<~41 bara) down to the delivery pressure (9 bara). At the delivery pressure the temperature and gas volume flow is measured accurately since it is transferred to a gas distribution company.
The station has a gas control and delivery room consisting of a number of measurement and control runs (see figure 1b). Inside each run first the gas is filtered and then heated to prevent gas temperatures below 0 degrees Celsius to occur after the gas expansion at the regulator. Usually after making a U-turn the next section is the measurement section. It starts with a flow conditioner to quickly dampen out all swirl effects from the U-turn, which could affect a proper flow measurement. For the flow measurement mostly turbine meters are in use.
Noise emission is directly related to pressure drop, thus with respect to the emission of noise it is no surprise, that the most important component in the station is the pressure regulator. Concerning these regulators a vast variety of different types is present in the Netherlands. In the more than 2500 measurement runs more than 200 different types of valves with respect to manufacturer, type, nominal diameter and pressure class are mounted.

(1a) (1b)

Figure 1 Example of a gas city gate station (a) with inside the building in the control room a set of measurement and control runs (b)

1.2 The scope of the project

In the first stage of the project in 2001-2002 a parameter study has been performed to evaluate which parameters are essential to be able to make a reliable prediction of the noise emission.

After having completed this in the next stage the validity of the model is checked on the basis of its efficiency and discriminating power. This is done by evaluating the model on 50 randomly selected gas city gate stations in the period December 2002 – March 2003.

The discriminating power is needed to assign city gate stations into the categories “no problem” , which means that the station is up-to-date concerning noise-emission and ”problem”, which means that measures have to be taken in order to fulfil the legislatory obligations with respect to noise emission.

In this paper we will first describe the model and its parameters in section 2. Subsequently results of the verification measurements are given in section 3. The first model results are given in section 4.

2. DESCRIPTION OF THE MODEL

The main source of noise in a pressure reduction station is the noise of the valve or regulator. Bearing this aspect in mind, a model for the noise emission of a gas city gate station towards the emission points consists of four parts:

1. source model for the regulator noise
2. diffusion model for noise in the gas control room
3. calculation of noise reduction through the walls, doors and openings
4. calculation of the noise propagation towards the immission point

2.1 Model for the regulator noise

There are several national and international standards, describing the noise of regulators.

Using the national standard NEN 1059 -which is a general standard describing the demands with respect to gas pressure reduction and measurement stations- we can find a description how to calculate the noise levels depending on flow and pressure drop. However, since no discrimination

between several types of regulators and working areas is made this standard can not be taken as being representative for our noise emission model.
Another international standard is the IEC 534-8-3 “control valve aerodynamic noise – prediction method” [1].
The IEC standard uses the mechanical stream power as a basis for the noise prediction. Furthermore it determines the acoustic efficiency by using valve dependent parameters, like the valve style parameter and the pressure recovery factor F_L. It is well known, that the acoustic efficiency very much depends on the pressure ratio x. For conventional regulators having no noise suppressing devices this ratio determines Mach ratio M_j i.e. the speed of the gas inside the throat of the valve vs. the sound speed in the gas. If the speed of gas reaches the sound speed the acoustic efficiency η is high, but rather constant. In the IEC model this has been expressed as follows:

$$\eta = 1*10^{-4} * M_j^{\;6.6F_L^2} \approx 1*10^{-4} \qquad (1)$$

since M_j = 1.
In most of the cases we study conventional regulators without specific sound attenuation construction in the critical speed regime. In these cases the constant acoustic efficiency implies, that only the mass flow $\boldsymbol{q}$ (in kg/sec or normal m^3/hr) is governing the sound power L_w of the regulator noise.

$$L_w = 10*\log(q) + c_1 \qquad (2)$$

For silent noise regulators having a special design instead of pressure reduction in one step it effectively comes down to a reduction of the pressure in many steps. Thus we are not dealing with the simple relation as given in equation (2), but rather it will be a relation:

$$L_w = 10*\log(q^m) + 10*\log(x^n) + c_{xq} \approx 10*\log(q^m) + c_2 \quad \text{with m>1} \qquad (3)$$

The last equality is most of the times valid since x is usually quite constant (pressure reduction from 41 to 9 bara). Usually the IEC standard sound power is the one, which can be measured in a non-reverberant room surrounding the near vicinity of the regulator. For our model on the other hand we are facing a few complicating factors:

1. The whole downstream piping can be considered as noise emitting. It is our experience that even 15D or more downstream of the regulator the noise levels measured at the pipe wall after the U-turn in the measurement section are still comparable to the one close to the regulator.
2. It is a fact, that the regulators are usually operating inside a gas delivery building inside a gas room, which certainly is not a non-reverberant room.
3. There are almost 190 different types of regulators considering the valve-diameter-pipe schedule combinations present in the total number of about 1200 delivery stations. The valves are from 11 different valve manufacturers.

So to gain an model accuracy of 2-3 dB we adapted the following working schedule for the regulator noise:

- We check within an overall inventarisation the actual sound emitting level $L_{p(1,1)}$ i.e. the sound pressure level at 1 meter downstream of the regulator and 1 meter from the heart of the downstream piping.
- We look into our database of historical sound measurements on city gate stations with similar type of regulators to find and compare the pattern of noise emission as a function of gas flow, using the general equation (eq. (3)). Each set of data are analysed to obtain a low and a high value for c denoting the band width of the noise levels. The high value of c will be used for a pessimistic estimate to determine the stations of which we can be sure that we can fulfil the legislatory obligations. The low value of c will be used for an optimistic estimate to determine the stations, of which we can be sure that adaptations have to be done to the station to fulfil the legislatory obligations.
- For the model we use predicted flow values in a situation, which can be considered to be the maximum representative operational condition at which the (legislatory) noise emission obligations need to be fulfilled. We will address this question further in section 4.2.

For a number of regulator types we show the sound emission as a function of flow in figures 2a-2c. The IEC 534-8 trends are also given.

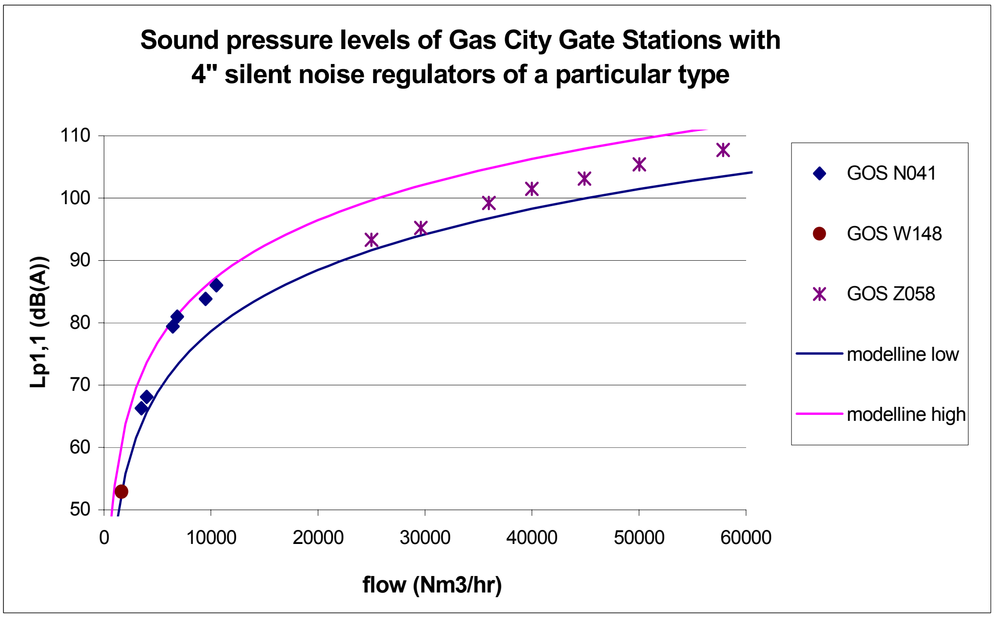

Figure 2a   Flow dependency of sound pressure levels $L_{p(1,1)}$ for city gate stations having particular silent noise regulators.

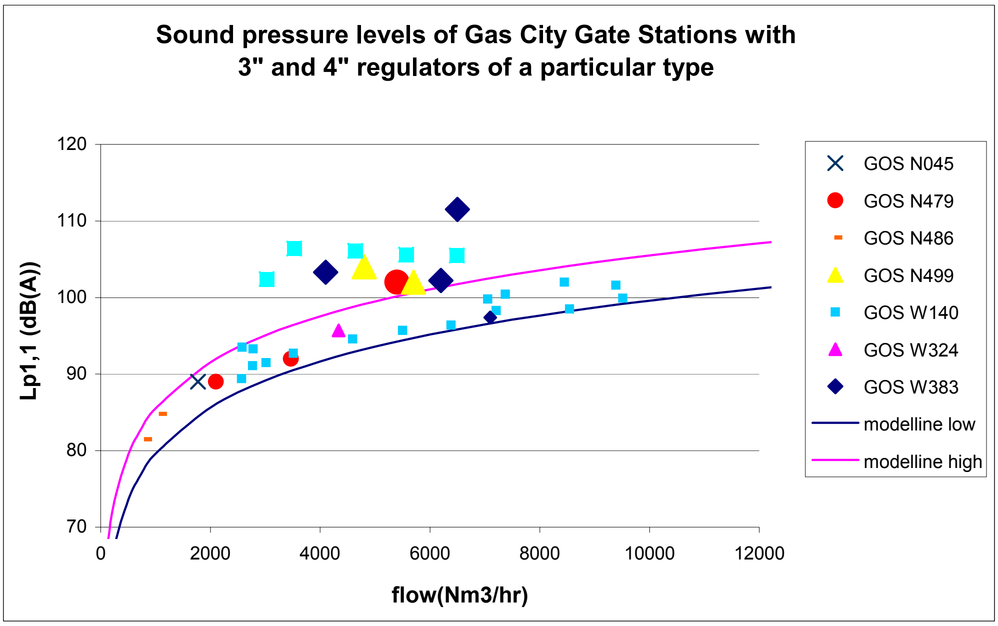

Figure 2b   Flow dependency of sound pressure levels $L_{p(1,1)}$ for city gate stations having particular pressure regulators. The thick marked data points indicate increased soundlevels due to severe acoustic resonances inide the regulator (whistling).The whistling effects have not been taken into account determining the model lines.

2.2 Model for the gas room acoustics

As the regulator is the source of noise in the gas room, the emission of noise is mainly situated in the downstream pipework. In this model step we determine the sound levels on the inside of the gas room based on the given value of sound pressure at a distance of 1 meter downstream of the regulator and 1 meter from the hart of the pipework.

Important issues are the total sound power and the reflection characteristics of the walls, ceiling and floor in the gas room.

With respect to the first issue sound pressure measurements have been performed over the whole downstream piping. Concerning the second issue we have performed reverberation time measurements to determine the reflection/absorption characteristics of the walls. With Sabine's law we can determine the absorption surface A (in m^2) of the walls, floor and ceiling of the room with volume V (in m^3), based upon the measured reverberation time T_{60}.

$$T_{60} = \frac{V}{6A} \quad \text{(in seconds)} \qquad (4)$$

T_{60} is defined as the time required to decrease the sound level in the room by an amount of 60 dB after the sound source inside the room has been switched off.

The absorption surface A is defined as

$$A = \sum_{W} \alpha_W S_W \equiv \overline{\alpha} \sum_{W} S_W = \overline{\alpha} O \qquad (5)$$

with

- O being the total surface of the walls, floor and ceiling of the room
- S_w being the total surface of wall W
- α_w being the absorption coefficient of the material of wall W
- $\overline{\alpha}$ being the average absorption coefficient in the gas room

Why do we need the total absorption surface A? Well, if there is a source of sound L_w in the room, we get the following scheme for the sound pressure $L_{p,r}$ at a distance of r from the source:

$$L_{p,r} = L_w + 10\log\left(\frac{\varphi}{4\pi r^2} + \frac{4}{A}\right) \qquad (6)$$

φ is de direction factor of the source; for a sound source close to a concrete floor we take φ =2. In the graph below we show the sound pressure distribution inside the room as a function of distance from the source. We assume a fictious source with a sound power of 100 dB (r. $1*10^{-12}$ W).

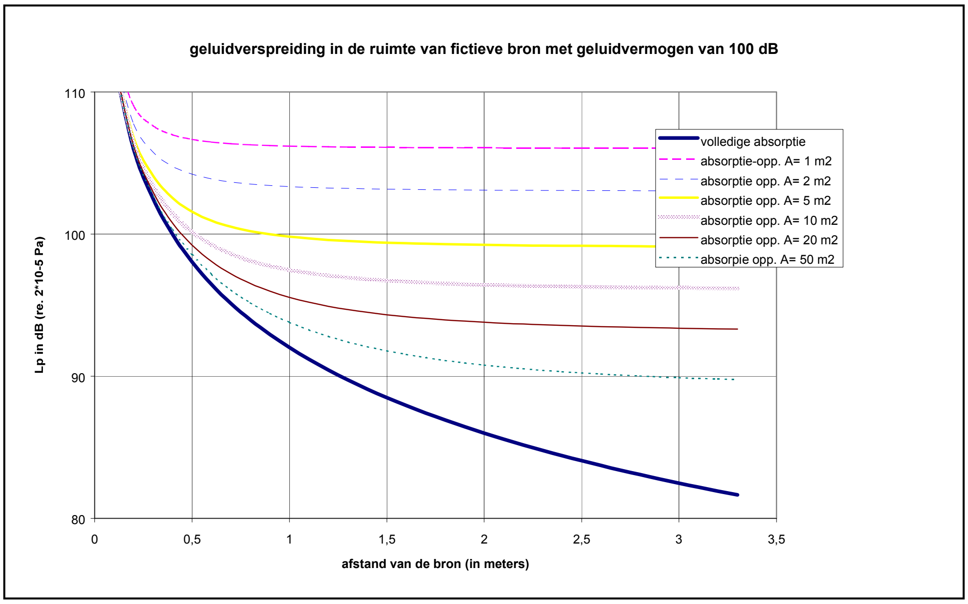

Figure 3 Influence of the absorption surface A on the room acoustics

From figure 3 we can conclude, that in high reflecting rooms with a small absorption surface A already at a small distance from the source (say 1 m) we measure sound pressure levels, comparable to the levels, which are present in the whole gas room.

2.3 Sound reduction of walls, doors and ventilation openings

The construction of the buildings of the city gate stations has been reasonably standard. So we can make use of the standard rules in building acoustics concerning the acoustic attenuation of all types of materials. In practice there will be deviations from the standard theoretical values due to sound leakage through cracks and holes in the structure e.g. in the doors and ventilation openings.
For the model we assume a fixed sound attenuation Δ in the range 500 Hz – 8 kHz dependent on the type of construction

$$\begin{aligned} \tilde{L}_{p,brick,outside} &= \tilde{L}_{p,wall,inside} - \Delta_{brick} \\ \tilde{L}_{p,ventilation,outside} &= \tilde{L}_{p,wall,inside} - \Delta_{ventilation} \\ \tilde{L}_{p,door,outside} &= \tilde{L}_{p,wall,inside} - \Delta_{door} \end{aligned} \qquad (7)$$

For the bricks we make use of the standard theoretical values used in building acoustic calculations. For the doors and ventilation there are two possible ways to determine the attenuation values Δ:

1. on the basis of a classification based on material properties, which can be visually inspected.
2. on the basis of a measured attenuation

The first method gives an increase in efficiency for the model, since the inventarisation of model parameters takes less time. The second option takes more time, but will give an increase in model accuracy and hence in discriminating power.

2.4 Sound propagation towards immission point

In the next step, a calculation needs to be performed for the propagation of sound towards the immission point.
In the previous section the sound pressure levels on the outside of the city gate stations were calculated. First step is to calculate the sound power level on each wall. We therefore make use of the “Lp + 10*log (S)” rule to calculate the sound power values on the outside of each wall x, making use of the three different components as mentioned in (7):

$$\begin{aligned} L_{W,brick}, x &= \tilde{L}_{p,brick,outside} + 10 * \log(S_{brick,x}) \\ L_{W,door}, x &= \tilde{L}_{p,door,outside} + 10 * \log(S_{door,x}) \\ L_{W,ventilation}, x &= \tilde{L}_{p,ventilation,outside} + 10 * \log(S_{ventilation,x}) \end{aligned} \qquad (8)$$

To determine the total sound power level $W_{tot,x}$ on the wall we can add all three sound power levels

$$W_{tot,x} = W_{brick,x} + W_{door,x} + W_{ventilation,x} \qquad (9)$$

or adding the logarithmic values

$$L_{W,tot,x} = 10\log(\sum_i 10^{\frac{L_{W,I,x}}{10}}) \qquad (10)$$

with the summation i over the three aspects (door, brick and ventilation).
Having determined the total sound power of each wall of the building we are able to calculate the total sound pressure at a certain immission point, e.g. the nearest house or building.
In this respect it is important to know the orientation of the immission point with respect to the city gate station.

The orientation sensitivity is based upon the rules as specified by the Dutch specification with respect to performing measurements and calculations of industry noise levels [3].

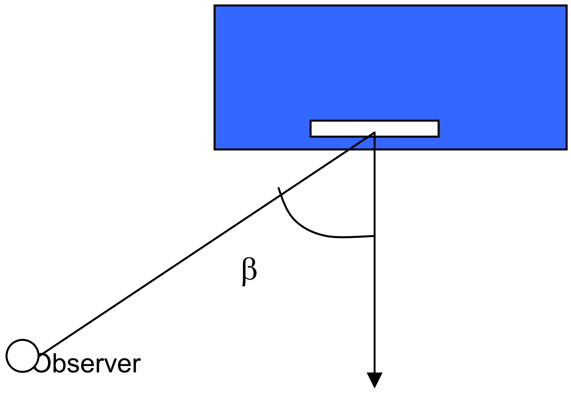

Figure 4 Importance of orientation of observer

For an observer positioned at a distance r and an angle β of wall x the partial sound pressure can be written as

$$L_{p,r,x} = L_{w,tot,x} - 10\log(4\pi r^2) + D_i - \sum D \qquad (11)$$

D_i denotes the geometrical correction specified in the specification [3] as:

- β between 0 and 85 degrees (+ direction) : D_i= + 3 dB
- β between 85 and 115 degrees (0 direction) : D_i= - 2 dB
- β between 115 and 180 degrees (- direction) : D_i= - 7 dB
- position in the "shadow" / backside of the wall: D_i= - 15 dB

The other correction terms are summarized in the correction ΣD. These are corrections either enhancing the observed sound pressure (in case of reflection terms (obstacles and/or bottom reflections) or attenuating the observed sound levels (due to dikes, buildings, vegetation, etc.). These special cases are specified in [3].

3. MODEL VERIFICATION MEASUREMENTS

The model has been verified performing measurements in a number of city gate stations. In first instance measurements were performed to define the model. Later on the model steps were checked on a random selected group of 50 city gate stations.

Recapitulating the model steps:

1. source model for the regulator noise
2. diffusion model for noise in the gas control room
3. calculation of noise reduction through the brick walls, doors and openings
4. calculation of the noise propagation towards the immission point

the main issues in the verifications are model steps 1-3.

Step 4 is fully determined by the Dutch measurement specifications [3].

3.1 Verification of the model for regulator noise

Step 1 is the model input, which can only be checked by obtaining for each individual regulator a sufficient number of experimental data points with respect to the sound pressure at 1 meter downstream of the regulator and 1 meter distance from the heart of the pipe.

It might be of importance to the model to check how the noise emission takes place across the downstream piping.

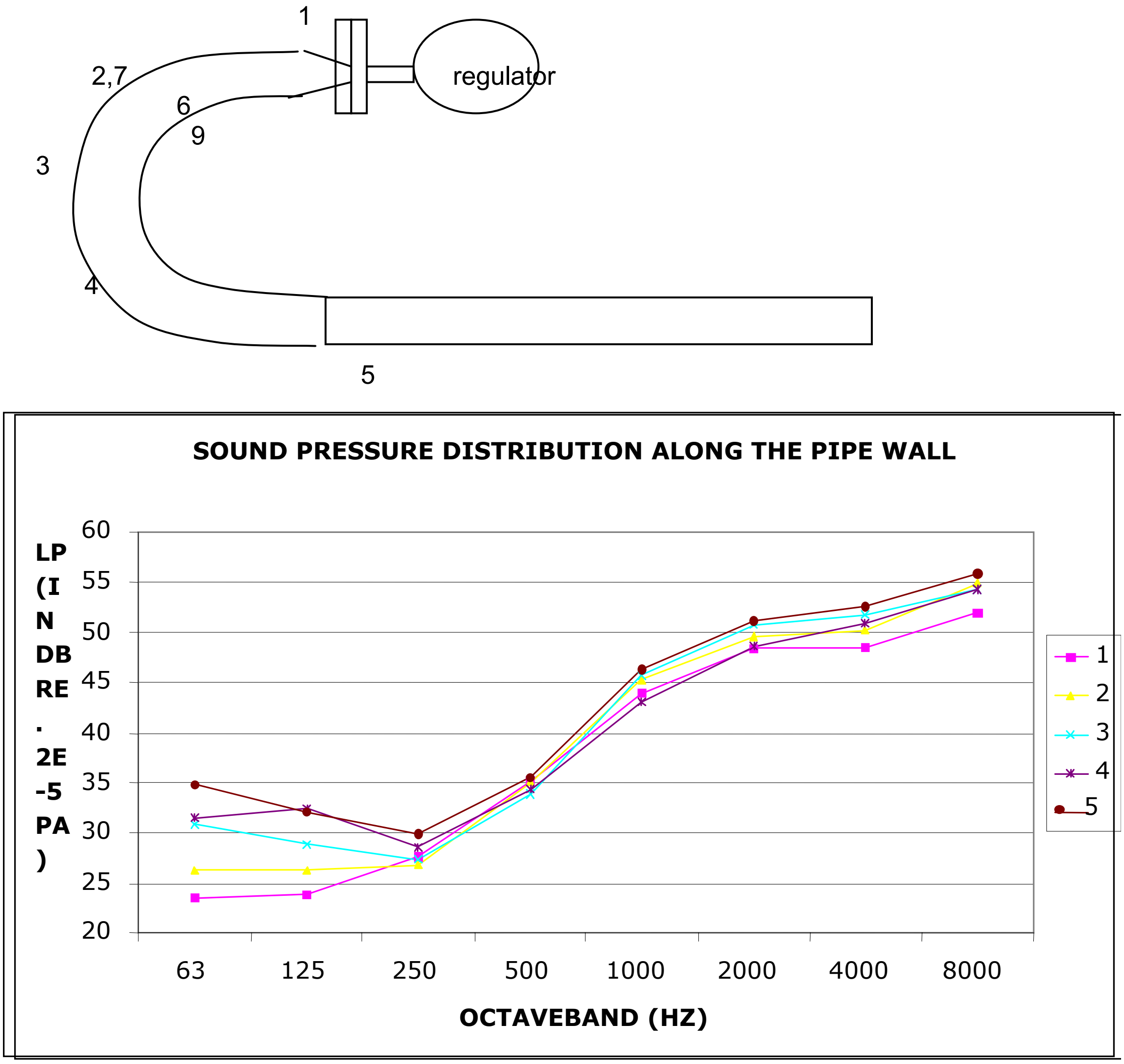

Figure 5 Example of how sound emission takes place across the whole downstream pipework; sound pressures measured at different positions across the downstream piping

However, a more thorough investigation to determine more exactly how noise will be emitted across the downstream piping turns out to be of little relevance in view of the results of the next step.
Further verification measurements at the 50 stations prove that it is in general for regulators which have no noise attenuation construction possible to determine the sound pressure levels $Lp_{1,1}$ at maximum representative conditions within an accuracy of +- 2 dB by extrapolating only one measured Lp value at certain conditions.

3.2 Verification of the diffusion model for noise in the gas control room
For the model how noise is spread in the control room we performed measurements of reverberation time as given in eq.(4) in a number of city gas stations. Furthermore this has been checked by performing sound pressure measurements all over the gas control room. Both set of data show, that gas control rooms built in the Netherlands in general have a rather high reverberation time T_{60} -thus a small absorption surface *A*. A typical result is shown below in figure 6.

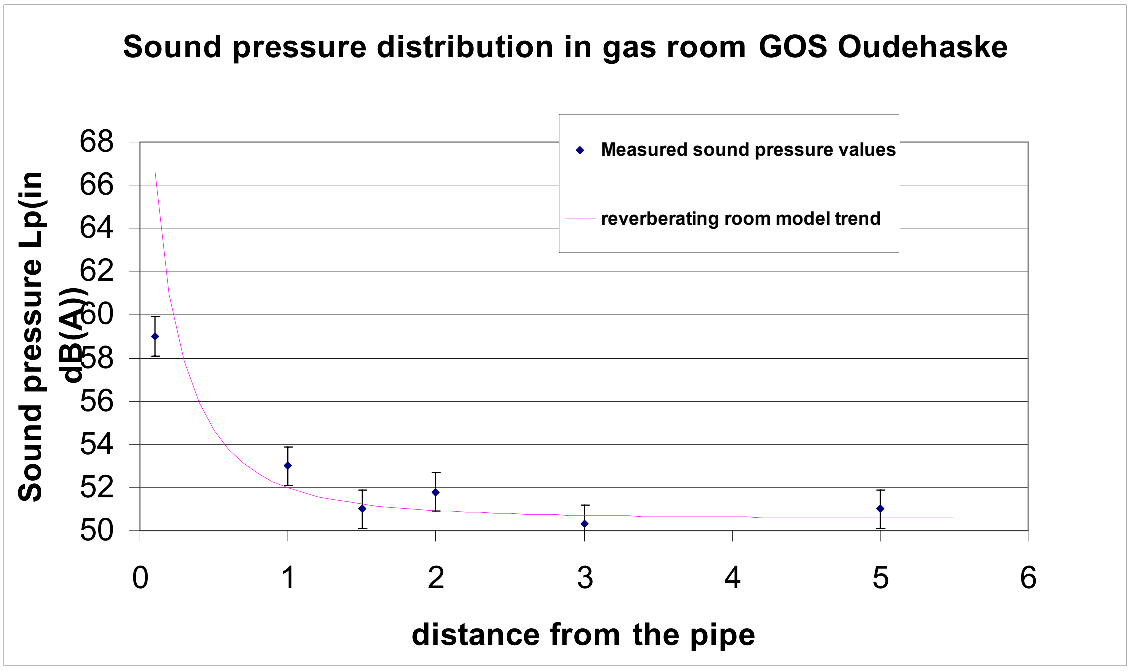

Figure 6 Sound pressure in the gas control room as a function of distance r (in meter) from the downstream piping. The trend line shows the expected line on the basis of the measured reverberation time

From figure 6 we can conclude, that the gas control rooms are so reverberant, that detailed information about the position of the observer with respect to the downstream piping is not very important. Wherever you measure inside such a room the sound levels are approximately the same (within the requested model accuracy of 3 dB). From the model point of view this implies that a simple correction from sound pressures determined at the (1,1) position towards the inside of the walls in the room is acceptable within the model accuracy.

3.3 Verification of the noise reduction through doors and ventilation openings
Instead of using the sound attenuation factors specified in building acoustic handbooks we verified the attenuation of doors and ventilation openings in practice. In practice large differences between theoretical and practical values can occur mainly due to unexpected sound leaks through cracks and holes.

The verification was performed by placing a large sound source inside the building and measuring the sound levels both on the inside and on the outside.
The measurements at 50 city gate stations show, that

- The ventilation is difficult to categorize, since the variation in different type is large. One class can be defined, namely the ventilation holes, for which no specific sound attenuation measures have been taken. It is clear, that to be able to perform an accurate prediction attenuation values need to be measured for each particular city gate station, since there is no classification possible, which can accurately (<~ 2 dB) describe the attenuation based upon visual characteristics.
- After visiting 50 stations we can categorize doors by using four different types This classification is based on properties, which can be visually inspected:
  - Multiplex doors
  - overlap doors
  - wooden doors
  - steel doors

  For each category the measurements were analysed. It appeared that the categories were well chosen. Only the category 'multiplex' is showing too much variation in the sound attenuation properties (> 4 dB). Dividing it into a category with and a category without chink cover we obtain two separate categories which have a smaller variation.
  The measured attenuation for all doors in the category 'wood is shown below:

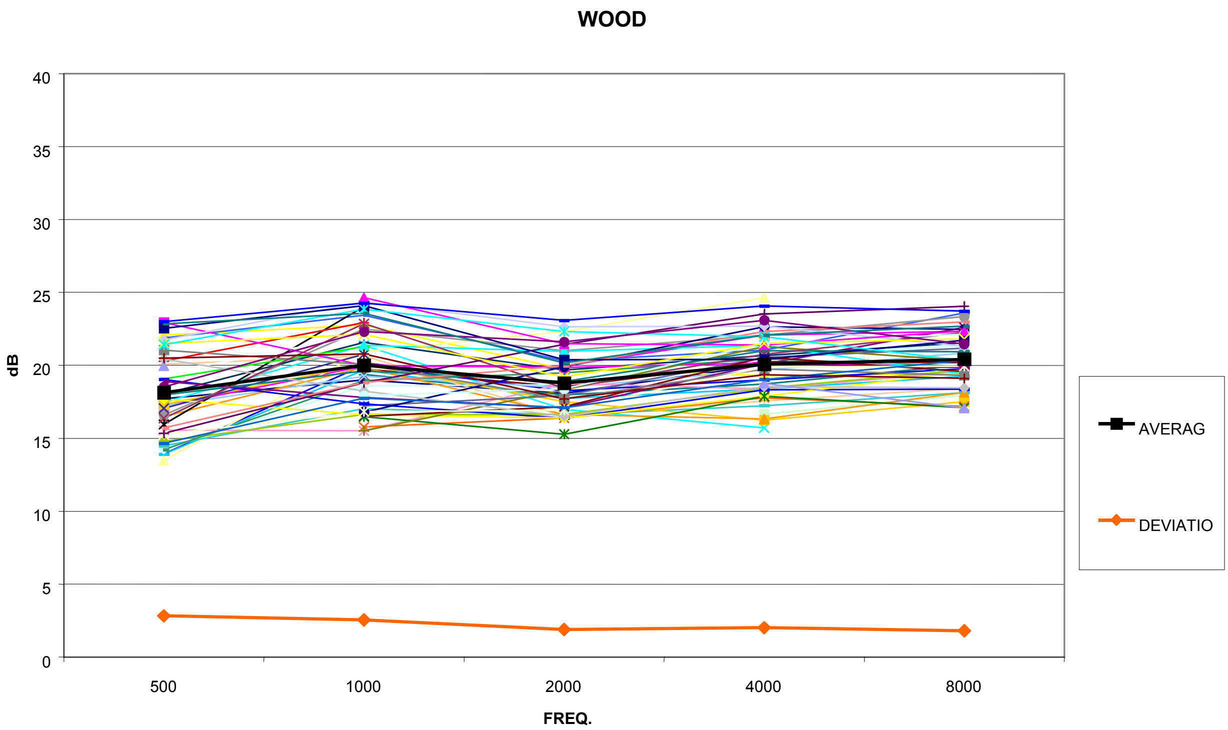

Figure 7 Sound attenuation factors of wooden doors in several city gate stations

The results of the model verification show that the sound attenuation of the doors can be modellized on the basis of the material properties, which can be visually inspected. The deviation σ is over the whole spectral range of the order of 2 dB.
For ventilation opening on the other hand inspection of the variation in attenuation factors shows, that no good classification can be obtained on the basis of visual inspection within the expected variation.

4. FIRST RESULTS

4.1 Inventarisation of model parameters

The necessary input parameters for the model of each city gate station are given in the table in appendix I. For an accurate model the quality of the input data is of crucial importance. Therefore we adapted the strategy to perform the inventarisation of the model parameters by a sound specialist. In a period of two months some 50 of the 750 randomly selected city gate stations were visited and the model parameters were gathered.

4.2 Determination of the maximum representative operational conditions

Planning models of Gasunie are able to describe the load (flow and pressures) of the city gate stations as a function of effective temperature T_{eff}. In this parameter the effects of daily average temperature T, wind speed w and solar radiation S are incorporated.

The legislatory sound emission boundaries differ at different daily periods, namely day period(D=7-19), evening(E=19-23) and night period(N=23-7).

Now we come to the questions which situation can be defined as being maximum representative. In the jurisprudential it is defined as a situation which –in exceptional circumstances- occurs not more than 12 times a year.

After ordering the historical meteorological data over the last 75 years in the Netherlands station "de Bilt" we have defined it as the situation which occurs 11 days or less in the 10% most severe winter periods. This turns out to be the situation at an effective temperature of –9 degrees Celsius as, can be seen in the table below.

Situation in average year		***Situation 10% coldest years***	
T-eff (degrees Celsius)	***# days <= T-eff***	***T-eff (degrees Celsius)***	***#days <= T-eff***
-4	14,6	-8	14,3
-5	10,0	-9	10,9
-6	8,1	-10	8,1
-7	6,0		
-8	4,3		
-9	3,0		

Table 1 Statistical information about number of days in Netherlands at which certain "effective" temperatures can occur

4.3 Efficiency of the model

To be able to make a good judgment about the efficiency of the model there are two parameters, which are important. First there is the discriminative power, i.e. the ability to be able to determine whether a city gate station either certainly fulfills or not fulfills the legislatory obligations. The problem is that there will be city gate stations, for which the model can not make a prediction accurate enough to determine whether it fulfills the requirements or not.

If there are m of these undefined stations from the total checked N, the model discriminative power P is determined as:

$$P = \frac{N - m}{N} \qquad (12)$$

Secondly the parameter to describe the model efficiency is the saved time with respect to performing a full environmental sound study. If the model inventarisation cost a working time T_{model} and a normal measurement takes a time T_{meas} the gain in efficiency E is defined as:

$$E = \frac{T_{meas}}{T_{model}} \quad (13)$$

The model approach is good as long as P*E is larger than 1, otherwise the traditional approach is the best.
For the first 50 city gate stations we have found that the discriminative power P will be at least 40% in combination with a efficiency gain E being about 8. This gives us the confidence, that the model is at least three times better in comparison with the traditional approach.
One other advantage of the model approach –besides its efficiency- is, that one is able to predict the effect of sound attenuation measures immediately.

5. SUMMARY AND CONCLUSIONS

A model has been developed to calculate the noise emission of more than 750 gas city gate stations in the Netherlands.
The main source of noise in a pressure reduction station is the noise of the valve or regulator. Bearing this aspect in mind, a model for the noise emission of a gas city gate station towards the emission points consists of four parts:

1. source model for the regulator noise
2. diffusion model for noise in the gas control room
3. calculation of noise reduction through the walls, doors and openings
4. calculation of the noise propagation towards the immission point

For the source model it is shown that in general for regulators which have no noise attenuation construction possible to determine the sound pressure levels $Lp_{1,1}$ at maximum representative conditions within an accuracy of +- 2 dB by extrapolating only one measured Lp value at certain conditions.
For the diffusion model we can conclude, that the gas control rooms are so reverberant, that detailed information about the position of the observer with respect to the downstream piping is not very important. From the model point of view this implies that a simple correction from sound pressures determined at the (1,1) position towards the inside of the walls in the room is acceptable within the model accuracy.
The attenuation of ventilation holes can not be categorized. Instead a sound attenuation measurement has to be taken. The attenuation of doors can be categorized on the basis of four categories.
The first results gives us the confidence, that the model is at least three times better in comparison with the traditional approach. Moreover using the model one is able to predict the effect of sound attenuation measures immediately.

6. REFERENCES

1 IEC 534-8-3 “Industrial control valves-noise considerations- control valve prediction method” 1st edition 1995-06

2 “Noise and Vibration control”. Leo L. Beranek, Rev. edition 1988 ISBN-0-9622072-0-9

3 Dutch authorities instruction for measurement and calculation of industry noise: “Handleiding Meten en Rekenen Industrielawaai”, 1999, ISBN 90442 02327 uitgave Ministerie van VROM Zoetermeer.

APPENDIX I LIST OF MODEL PARAMETERS

CITY GATE STATION INFO			
0.0	GOScode	Gasunie code of the station	-
0.1	GOSnaam	Name of the station	-
0.2	Gebied	Gasunie Area Code	-
0.3	Q-9	Mass flow through the station at maximum representative operational conditions Teff= –9 in 2002/2003	Nm3/hr
0.4	Q-9_2010	Mass flow through the station at maximum representative operational conditions Teff= –9 in 2010/2011	Nm3/hr
0.5	valve1 valve2 valve3	Total of valve manuf.-type-length-diameter of all runs in the city gate station(in order of delivery)	-
0.6	Length width height	Geometry data of the gas control room in the city gate station	m m m
ACTUAL OPERATIONAL DATA			
1.1	Q-actual	Actual flow value in city gate station	Nm3/hr
1.2(1000) 1.2(2000) 1.2(4000) 1.2(8000)	Lp1,1 –1000 Lp1,1 –2000 Lp1,1 –4000 Lp1,1 -8000	Actual sound pressure levels at position (1,1) of the delivery valve in 4 octave bands	dB(A)
1.3,1.4	Pin,pout	Inlet and outlet Pressures in station	bara
BUILDING CHARACTERISTICS			
2.1	S1door S1vent	Total surface of doors and ventilation openings at the first wall (wall 1)	m^2 m^2
2.2	S2door S2vent	Total surface of doors and ventilation openings at wall 2	m^2 m^2
2.3	S3door S3vent	Total surface of doors and ventilation openings at wall 3	m^2 m^2
2.4	Doortype Venttype	Type of door (w.r.o sound attenuation) Type of ventilation (w.r.o. sound attenuation)	- -
2.5	*Δ-door* *Δ-vent*	*Measured attenuation values (in 1000, 2000, 4000 and 8000 Hz octave bands)*	*dB*
IMMISSION POINT DATA			
3.1	R1,R2,R3	Distance of immision point with respect to wall 1, 2 and 3	m,m,m
3.2	O1,O2,O3	Orientation of the immision point with respect to wall 1, 2 and 3 respectively	(denoted with +, o,- of --)
3.3	*ΣΔcorr*	Possible corrections like attenuators (dikes, walls, etc) or reflectors	