# FLOWMETRING AND ACOUSTIC STUDY OF A GAS FLOWRATE LIMITER

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## Abstract:

The CRIGEN had realized a wide experimental study on gas flowrate limiter used on compact meter station for measuring gas flow at variable pressure. This device is used to control and limit, for a specified pressure, the flowrate of the meter station. It is a perforated plate with a constant holes size. Each hole is functioning as a sonic nozzle. The number and size of the hole are defined by the meter station maximal flowrate.

This paper shows that the flowrate limiter geometry (the hole size, the ratio plate thickness/hole size and the number of holes) can be changed without affecting the meter station characteristics: flowrate range, residual pressure loss. In the other hand the noise produced by this device can be decreased by reducing the hole size.

## Introduction

The CRIGEN collaborates closely with GRTgaz (the French gas transmission company) with the aim of optimizing and securing its network.

This paper is presenting an experimental study of the flowrate limiter (a perforated plate) used on a compact and variable pressure metering station (figure 1).
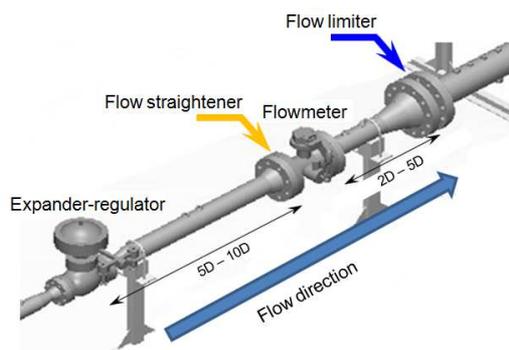


**FIG. 1 –** Scheme of a compact meter station for measuring gas flow at variable pressure

This paper consists of three parts:

- The first part summarizes a bibliographical study on limiter. This confirms the formula used for the sizing of the compact meter station flowrate. Also, it shows that the flowrate limiter geometry (the hole size, the ratio plate thickness/hole size and the number of holes) can be changed (increased/decreased) without affecting the meter

station characteristics: flowrate range, residual pressure loss.

- Then three geometries with different hole sizes had been tested on the CRIGEN benches. In the second part are exposed the experimental flowrate results of these flowrate limiters. Experimental results show clearly that, for a ratio "plate thickness/hole size" included between 2.5 and 8 and for a constant upstream pressure, the limiter geometry has no impact on the meter flowrate. This confirms the bibliographical study results.

- The third part of this paper is dedicated to the noise measurement for different upstream pressure and with the different flowrate limiters. These tests prove that the more the size of holes is small and the more the noise decreases.

## State of art on flowrate limiter

A compact variable-pressure gas metering station is composed by succession of components: an expander-regulator, then a flow straightened, then a flowmeter and finally a flowrate limiter (figure 1).

It is used to keep a high pressure at the flowmeter to increase the flowrate range of the metering station. This device is a perforated plate with a defined number $N_{Holes}$ of calibrated holes (figure 2) of a diameter "d". Holes are organized to guarantee a better homogeneity of the flow downstream. The ratio of the total holes section "$A_{Holes}$" ($A_{Holes}=N_{Holes} \times \frac{\pi d^2}{4}$) and the internal pipe section "S": $\beta = \frac{A_{Holes}}{S} \ll 1$. Holes are often realized without particular machining (no chamfer). The thickness of the performed plate "e" has to guarantee it mechanical resistance because of the important pressure differential on both sides of the plate. The ratio $\frac{e}{d} \gg 1$.
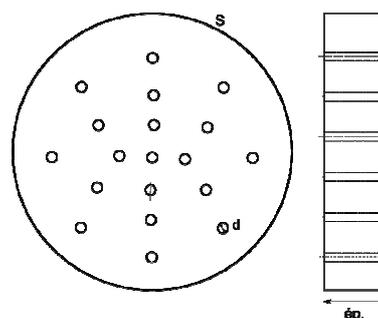


**FIG. 2 –** An example of a flowrate limiter. DN100 – $Q_{max}$=5000 Nm$^3$/h (19 holes of $\varnothing$5mm – e = 25mm)

According to the physics, a flowrate limiter behaves as a set of parallel ultrasonic nozzles. This provided that the ratio of the downstream and upstream $\frac{P_{DS}}{P_{US}} < 0,5$ [1] ("DS": downstream, "US": upstream). The total flowrate passing through the limiter is the sum of all the flowrates of each ultrasonic hole. Then, the total mass flowrate $Q_M$ is given by the same formula as for the ultrasonic nozzle:

$$Q_M = C_d^* \cdot A_{Holes} \cdot \left[ \frac{2\gamma}{\gamma - 1} \cdot P_{US} \cdot \rho_{US} \cdot P^{\frac{2}{\gamma}} \cdot \frac{1 - P^{\frac{\gamma - 1}{\gamma}}}{1 - \beta^2 \cdot P^{\frac{2}{\gamma}}} \right]^{\frac{1}{2}}$$

$\Rightarrow$ **Eq. X**: $\frac{Q_M}{A_{Holes}} = C_d^* \times Constant \times (\rho_{US} \times P_{US})^{1/2}$

with:

- $C_d^*$: critical flowrate coefficient,
- $\gamma$: specific heat ratio $C_P/C_V$,
- $\rho_{US}$: upstream gas density,
- P: constant given by the equation below.

$$2 - (\gamma + 1) \cdot P^{\frac{\gamma - 1}{\gamma}} + \beta^2 \cdot (\gamma - 1) P^{\frac{\gamma + 1}{\gamma}} = 0$$

According to the works of BRAIN and al. [1], for non machining holes plate in an ultrasonic mode, there are three ultrasonic regimes (figure3). Each of these regimes has its own critical flowrate coefficient $C_d^*$ (figure 4):

- <u>Case 1</u>: Separated flow: $0 < \frac{e}{d} < \delta$ with $\delta \approx 0.5$,
- <u>Case 2</u>: Marginally reattached flow: $\delta < \frac{e}{d} < \varepsilon$ with $\varepsilon \approx 7$,
- <u>Case 3</u>: Fully Reattached flow: $\frac{e}{d} > \varepsilon$

The same paper gives, also, some experimental results of critical flowrate coefficient collected from literature (figure 5)
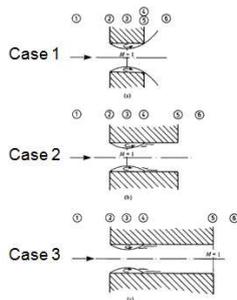


**FIG. 3** – Basic flow patterns when the flow first approaches the choked condition. **a)** Marginally reattached flow. **b)** Fully reattached flow. **c)** Fully reattached flow.
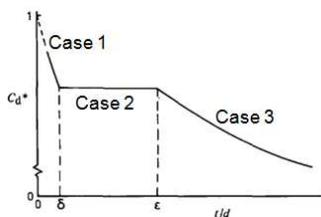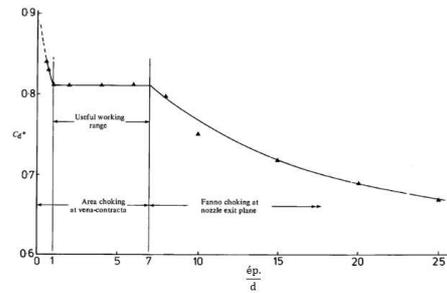


**FIG. 4** – Predicted trend of $C_d^*$ with e/d.



**FIG. 5** – Graph showing the relationship between critical discharge coefficient, Cd*, and the ratio e/d [1, 2, 3, 4, 5, 6, 7]

The figure 5 shows that for the case 2, the critical discharge coefficient is constant, about 0.84. Also, that $\delta \approx 1$ and $\varepsilon \approx 7$.

Then, for a constant holes section $A_{Holes}$ and plate thickness e, the holes diameter can be changed as long as $1 < \frac{e}{d} < 7$.

For this study, 3 different limiters had been designed:

- Limiter N°1: DN100, e = 25mm equipped with 19 holes of diameters 5mm $\Rightarrow \frac{e}{d} = 5$ and $Q_{V-max}$ ($P_{US}$=19 bar) = 5230 Nm³/h (figure 6-a).

- Limiter N°2: DN100, e = 25mm equipped with 53 holes of diameters 5mm $\Rightarrow \frac{e}{d} = 8.33$ and $Q_{V-max}$ ($P_{US}$=19 bar) = 5250 Nm³/h (figure 6-a).

- Limiter N°3: DN100, e = 25mm equipped with 5 holes of diameters 10mm $\Rightarrow \frac{e}{d} = 2.5$ and $Q_{V-max}$ ($P_{US}$=19 bar) = 5505 Nm³/h (figure 6-c).

**a)**



**b)**

**c)**



**FIG. 6 – a)** Flowrate limiter N°1, **b)** Flowrate limiter N°2, **c)** Flowrate limiter N°3.

## Natural gas setup (GDF SUEZ – CRIGEN)

For the experimental tests, a natural gas flow metering test facilities "PLAT" had been used (figure 7). It is a part of GDF SUEZ Research Division. It is supplied with natural gas from GRTgaz transmission network. The gas is filtered and its temperature controlled.

The test method is based upon the assessment of the mass flow rate using Venturi nozzles operated in sonic conditions. The mass flow through the set of nozzles in use is determined from the upstream stagnation pressure and the upstream density. The flow coefficients of each nozzle are determined beforehand by an individual calibration on the French primary bench "PISC" (CESAME-EXADEBIT). This mass flow indicated by the tested device is determined from the pressure and temperature measured at its location, the raw flow indicated by it and the density measured upstream of the nozzles (equation below). Real gas effects are taken into account by applying compressibility factor corrections for the thermodynamic conditions at the measurements locations. These various measurements and calculations allow a comparison between the reference and the tested device mass flows, thus, to determine the device deviation.

$$Q_m = A \cdot C_d \cdot C^* \cdot \frac{P_0}{\sqrt{r \cdot T_0}}$$

Where:
- Po, To: the gas absolute stagnation pressure and temperature,
- A: the cross section of the nozzle,
- $C_d$: discharge coefficient (ISO 9300),
- $C^*$: critical flow function (ISO 9300),
- r: ratio of the Universal gas constant on the molar mass.

This bench is working at the conditions below:

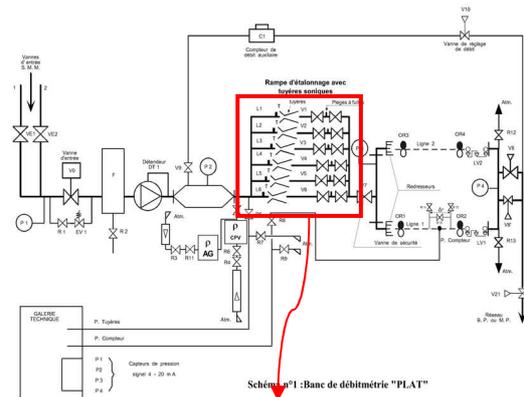| Flowrate Q [SQMPH] | $10 \rightarrow 11000$ |
|---|---|
| Pipe diameters | DN50 $\rightarrow$ DN200. |
| P [bar] | 1.0 bar $\rightarrow$ 50 bar |
| Error | ±0.32% |



**FIG. 7 –** Scheme of the GDF SUEZ natural gas flowmetering bench "PLAT"

## Experimental results

For these tests, flowrate limiters had been considered as a classic flowmeter. The flowrate passing through has been measured with the flowrate reference of the bench (the sonic nozzles). To confirm the **Eq. X** and the fact that the critical discharge coefficient is constant for $\delta < \frac{e}{d} < \varepsilon$, the flowrate is compared to the upstream pressure $P_{US}$. For the noise analyzes, an anechoic case (1m x 1m x 1m) had been used around the limiter. The noise had been measured with a calibrated high sensitivity sonometer.

With the aim of comparing the three limiters, on the figures 8 and 9, are plotted, respectively, the mass flowrates through the three tested limiters according to the upstream pressure $P_{US}$ and the ratio $\frac{Q_M}{A_{Holes}}$ according to the upstream ratio $(\rho_{US} \times P_{US})^{1/2}$ (**Eq. X**). From these two graphs, it is easy to notice that the three limiters have an identical behavior and their curves merge. And for given $P_{US}$ the shift of the mass flowrate is about 0.35%. In the other hand, the figure 9 shows that the measured mass flowrate of these limiters fit perfectly on a straight line according to the $(\rho_{US} \times P_{US})^{1/2}$. Exactly as predicted by **Eq. X**.

These results confirm the theoretical behaviour exposed on the state of art and:

- the critical discharge coefficient is constant perfectly stable as long as $\delta < \frac{e}{d} < \varepsilon$,
- $\delta \approx 1$,
- But, $\varepsilon$ seems to be higher than 7.

The calculation of the critical discharge coefficient gives a value about 0.876±0.003, which is a little higher than 0.84 according to the works of BRAIN and al [1].
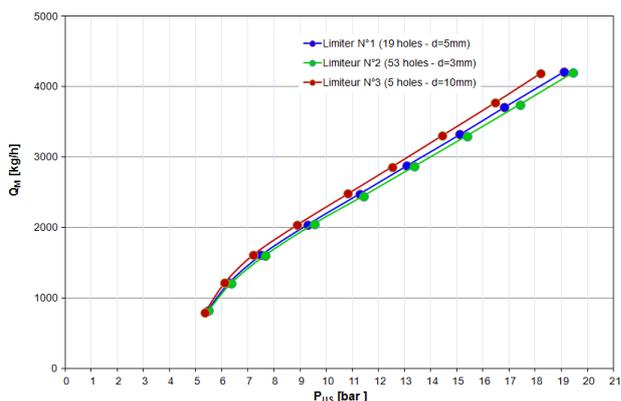
**FIG. 8** – The mass flowrate through the 3 limiter according to the upstream pressure $P_{US}$.
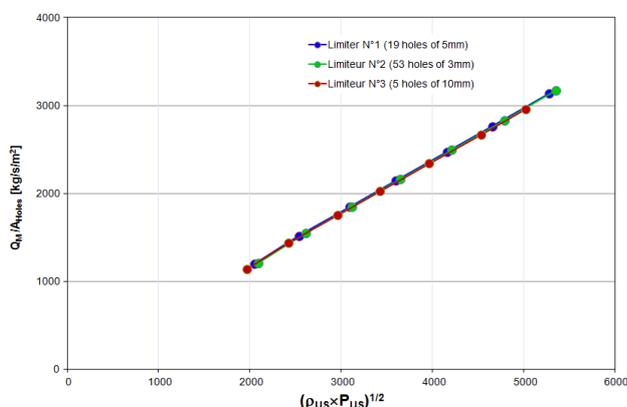


**FIG. 9** – The measured ratio $\frac{Q_M}{A_{Holes}}$ according to the upstream pressure $P_{US}$ and density $\rho_{US}$.

For the noise analyzes, on a single graph (figure 10), the measured acoustic power are compared for the three limiters according to the mass flowrate $Q_M$. From this figure, we notice that the acoustic power produced by the pressure loose and the gas passing through the small holes increases with the flowrate. This is due to the fact that, the more the flowrate increase the more is the pressure loose through the performed plate. Also, for $Q_M$=4200 kg/h, the acoustic energy reach for:

- the limiter N°1, the value of 84.4 dB(A),

- the limiter N°2, the value of reach 79.9 dB(A),

- the limiter N°3, the value of 91.6 dB(A).

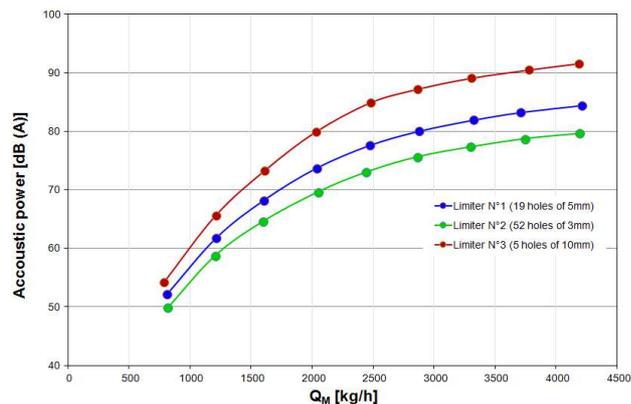Therefore, the limiter N°3 and N°2 are, respectively, the more and the less noisy.



**FIG. 10** – The acoustic power according to the mass florate $Q_M$ pressure $P_{US}$ and density $\rho_{US}$.

## Conclusions

To conclude, the bibliographical study exposed in this paper shows that:

- The critical discharge coefficient Cd* is constant as long as $\delta < \frac{e}{d} < \varepsilon$, the holes section $A_{Holes}$ and the plate thickness e are unchanged.
- The noise produced by the gas passing through the holes is higher when the holes are bigger.
- The produced noise is proportional to the gas flowrate.

Three different limiters had been tested. The first with $\frac{e}{d} = 5$. For the second, $\frac{e}{d} = 8.33$ and the for the third one $\frac{e}{d} = 2.5$.

The experimental results confirm all the theoretical behaviors:

- The critical discharge coefficient Cd* is perfectly constant for $2.5 < \frac{e}{d} < 8$. Therefore, the actual values of $\delta$ and $\varepsilon$ are, respectively, 2.5 and 8.
- The critical discharge coefficient Cd* value is equal to 0.87.
- The more the holes are bigger, the more is the produced noise.
- The produced noise is proportional to the gas flowrate.

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