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"The EC Nozzle Transfer Package: A Flow Standard for High-Pressure Gas"

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The EC Nozzle Transfer Package: A flow standard for high-pressure gas

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SUMMARY

In order to provide a method by which test installations for high pressure gas meters within the EC can be assessed and checked, the Community Bureau of Reference (BCR) funded the construction of a transfer standard flow metering package. This nozzle transfer package (NTP) is a construction of six sonic nozzles. They are arranged such that the gas can flow through any one of the nozzles or through any combination of them.

Calibration of the NTP was performed by four laboratories for single nozzles, nozzle pairs, nozzle triplets, and all six nozzles. The calibration results were intercompared and analysed by means of a least squares technique.

The major conclusions which arise from this study, is that the NTP is well suited to serve as a transfer standard for high-pressure test facilities. The coefficients of the calibration curves of the NTP differ significantly from the values based on the ISO draft international standard[1]. Compared to this standard the uncertainty of the predictions has improved.

1. INTRODUCTION

In order to provide a method by which test installations for high pressure gas meters within the EC can be assessed and checked, the Community Bureau of Reference (BCR) funded the construction of a transfer standard flow metering package. After a first calibration this package should serve as the High Pressure Gas Flow Standard within the EC, that could subsequently be made available to all test installations that show interest.
In order to achieve a stable transfer standard it was decided to use sonic nozzles as flow standards. The nozzle transfer package (NTP) was designed by the N.V. Nederlandse Gasunie. It incorporates six nominally identical toroidal inlet critical flow venturi nozzles. They are arranged such that the gas can flow through any one of the nozzles or through any combination of them. The geometry of the nozzles is as specified in the ISO draft document on these devices[1]. They are sized as to give a volume flow rate of 400 m^3/h at line conditions.
The six nozzles were manufactured by the National Engineering Laboratory in Scotland.

BCR decided that the first calibration of the NTP should be carried out by those laboratories that took part in an earlier intercomparison campaign[2]. These are:
- the high pressure testfacility of the National Engineering Laboratory at East Kilbride, Scotland;
- the high pressure test facility of Gaz de France at Alfortville, France;
- the high pressure test facilities of the N.V. Nederlandse Gasunie at the locations Groningen and Westerbork in the Netherlands.
- the high pressure test facility of the Netherlands Measurements Institute at Bergum, The Netherlands.

The calibration of the NTP took place in the period of December 1984 till February 1987. The NTP is now available to other laboratories for testing.

2. DESCRIPTION OF THE NOZZLE TRANSFER PACKAGE

The NTP consists of six toroidal inlet sonic nozzles of the shape indicated in fig. 1. The nozzles are installed in parallel pipes positioned in a circle, connecting the inlet plenum to the outlet collecting chamber. Each pipe is provided with a flow straightenar at the inlet.
The nozzles can be moved axially against seats on the bottom of the outlet collecting chamber to shut off the flow of gas. The movement is induced by applying the pressure of the gas to one of the sides of the nozzle. In fig. 2 a scheme of the assembly is shown with the nozzle in pipe A open and the one in pipe B closed. Leakage along the nozzles or past the seats can be detected by small bleed valves.
The gas pressure can be measured on a pressure tapping provided with each of the inlet pipes.
The gas temperature is measured by means of Pt100 resistance thermometers that are placed in each pipe. Also in the inlet plenum chamber two Pt100's are placed. The pipe Pt100's and one of those at the inlet are installed directly in the gas flow. The second inlet one is placed in a pocket to allow checking without depressurizing the NTP.
The entire assembly is built according to the demands set in the ISO draft document[1].

3. CALIBRATION PROGRAMME AND TEST CONDITIONS

The laboratories agreed on a calibration programme that differed for each of the laboratories. Each laboratory reported to the EC on its results[3,4,5]. A review of the programme is given in table 1.
Typical properties of the natural gas used by Gaz de France and Gasunie / Netherlands Measurements Institute (NMi) are listed in table 2.

Table 1: Nozzle calibrations performed by different laboratories. All pressures mentioned are absolute pressures in bar.

		NEL	Gaz de France	Gasunie / NMi
single	pressure	5, 15, 25, 35	10, 20, 30, 40	11, 21, 31, 36, 61
	geometry	1-6	1-6	1-6
pairs	pressure	5, 10, 15	10, 20, 30, 40	11, 21, 31, 36, 61
	geometry	1+2, 1+3, 1+4	1+3, 2+5, 2+6	1+2, 1+3, 1+4
triplets	pressure	5, 10	10, 20, 30, 36	11, 21, 31, 36, 61
	geometry	1+2+5, 1+3+5	2+4+6, 3+4+6	1+2+3, 1+3+5
all six	pressure			11, 21, 31, 36, 61
	geometry			1+2+3+4+5+6
test gas		air (10-20°C)	natural gas	natural gas

Table 2: Typical properties of natural gas used for calibrations by Gas de France and Gasunie / NMi.

	Gaz de France	Gasunie / NMi
gas composition (mol %)		
N_2	0,93	14,0
CH_4	97	81,4
CO_2	0,06	1,0
C_2H_6	0,69	2,9
C_3H_8	0,23	0,41
C_4H_{10} (I)	0,09	0,08
C_4H_{10} (N)	0,07	0,02
molar weight	16,40	18,65
normal density (kg/m^3) (0°C, 1,01325 bar)	0,725 - 0,738	0,774
temperature (°C)	18 - 21	
Groningen		20,0 ± 0,5
Bergum (NMi)		20 - 27
Westerbork		7 - 10

4. TEST FACILITIES

The test facilities at each of the laboratories have been described in detail at numerous occasions before. Below reference is made to those descriptions. Only the most essential features of each of the facilities are given here.

4.1 The test installation of NEL, East Kilbride

The test facility of the National Engineering Laboratory in East Kilbride, Scotland, is shown schematically in fig. 3. The NEL facility is a primary device based on a gravimetric method combined with a secondary facility. It is operated with air.

The basic operation of the test facility is as follows.
A compressor feeds the air into a 12 m^3 storage volume through a plant that dries the air and eliminates oil vapour and dust. From the container a loop system with a volume of 6 m^3 is filled with air at a pressure of 65 bar. When the temperature in the ring conduit is stabilized the valve X is opened. The air, the pressure of which is kept at the desired value by the adjustable pressure controller, flows first of all through a sonic nozzle that serves as a standard and that adjusts to a certain mass flow rate according to the inlet pressure and temperature.
From the nozzle the compressed air flows through a switching device either into a high pressure spherical vessel (diameter 1,5 m) that can be weighed on a scale or into the test line where the flow meter to be calibrated, in this case the NTP, is installed. Downstream of the test line the air flows through a silencer into the open air. Various valves make an adjustment possible of the pressure in the test line. When the valve X is opened to start the measuring process, the loop system is connected at the same time with the storage container. Thus the air with known temperature that flows from the loop to standard nozzles is replaced by air from the storage container. This air cools off due to pressure reduction, but the temperature in the test line is not influenced by this as long as there is still warmed air between the inflowing air from the storage container and the outlet of the loop.

Direct calibration of the NTP installed in the test line on the other side of the diverter is not possible. Either a secondary calibration can be made using one of the calibrated standard nozzles to determine the flow rate or an indirect connection to the gravimetric rig can be made. In the latter case the mass flow rate through a meter on test is not calculated from temperature and pressure data but can be determined from an immediately following gravimetric test. In this case the standard nozzle only serves as a controlling device for the flow rate. A requirement for this method therefore is that the mass flow adjustment during the gravimetric test remains virtually constant.

4.2 Test facilities of Gaz de France, Alfortville, France

Gaz de France has two test facilities, a primary one and a secondary one shown in fig. 4. Both operate on high pressure natural gas. Sonic nozzles serve as standards in the secondary installation, that were calibrated in the primary one.

The secondary installation was used for the calibration of the NTP. As standards seven sonic nozzles with different sizes are installed. They have nominal volume flow rates of 1,5, 5, 10, 20, 40, 100 and 200 m^3/h. Through combinations of nozzles a whole range of flow rates can be selected.

The test facility is in the open air. To guarantee good temperature conditions the essential parts of the installation are thermally insulated. The secondary facility alows for testing of nozzles and gas meters up to pressures of 41 bar and flow rates up to 2,6 kg/s.
The nozzles used in the secondary installation are traceable to the primary test facility based on a volumetric method.

4.3 Gasunie test facilities at Groningen and Westerbork, The Netherlands

A scheme of the installation in Groningen, situated at the Research Laboratory of the N.V. Nederlandse Gasunie is shown in fig. 5. The natural gas enters the installation at a pressure of 40 bar. It leaves the installation usually at a pressure of 8 bar and then flows into the piping system of the municipal gas distribution company. The installation consists of two parts. Part A is called the "primary high pressure standard installation". It consists of 10 CVM meters with a capacity of 400 m^3/h each. This part is used mainly for the calibration of meters to be used as standards in other installations. These meters, installed at position D, can be tested up to 40 bar. The maximum operating pressures of the CVM's is 8 bar. Part B is used for routine verifications.
For the calibration of the NTP the CVM meters were used as standards and thus the NTP was installed at position D.

The installation of the Bernoulli Laboratory in Westerbork is constructed as a bypass around a valve in a main transmission line. A schematic drawing is given in fig. 6. After the gas has passed the test installation it returns to the same transmission line. Due to that no pressure regulation is possible. Both the standard meters and the meters to be tested operate at a pressure of about 60 bar.
The standard meters, 10 turbine meters with a capacity of 4000 m^3/h each, are installed in a building. The meter to be tested is installed in the open air. The outside pipe is insulated and partly roofed in to avoid direct radiation of the sun.

Through a system of transfer standard meters the high pressure standard meters in all Gasunie test facilities are traceable to the primary flow standard of the Netherlands Measurements Institute in Dordrecht.

4.4 The Bergum test facility of the Netherlands Measurements Institute

A schematic drawing of the Bergum installation is given in fig. 7. The installation was built in parallel to a gas line that feeds an electric power plant. The gas enters the station at a pressure of 60 bar and leaves with a pressure of 8 bar. The installation is equipped with 4 turbine standard meters with a capacity of 4000 m^3/h each, a turbine standard with a capacity of 1000 m^3/h, a turbine standard with 400 m^3/h capacity and a CVM standard with a capacity of 100 m^3/h. At the entrance of the installation, the gas passes through a filter and then through a heat exchanger to compensate for the temperature drop due to the pressure reduction furtheron in the installation. The maximum operating pressure of the test installation is 50 bar. The meters to be tested and the standards operate at the same pressure. The flow is controlled at the outlet of the installation. For very low flow rates a set of three sonic nozzles is used to avoid disturbances in the flow due to downstream pressure variations.
Also the Bergum standard meters are traceable to the primary flow standard of the Netherlands Measurements Institute in Dordrecht.

4.5 Uncertainties

In table 3 the systematic, random and total uncertainties in the results of each of the test installations are listed. The systematic uncertainty is due to the test installation. The random uncertainties are based on the random variations in the parameters that add to the final result.
The figures based on a 95% confidence level, are estimated from statements of the participating laboratories.

Table 3: Systematic, random and total uncertainties estimated for the different test facilities based on a 95% confidence level.

	pressure (bar)	uncertainty (%) systematic	random	total
NEL	5 - 35	0,35	0,16	0,38
Gaz de France	10 - 40	0,30	0,07	0,32
Gasunie				
Groningen	11	0,17	0,18	0,25
	21	0,17	0,21	0,27
	31	0,17	0,24	0,28
	36	0,17	0,26	0,29
Westerbork	60	0,27	0,30	0,40
NMi Bergum	11	0,22	0,19	0,29
	21	0,22	0,22	0,30
	31	0,22	0,25	0,31
	36	0,22	0,27	0,32

5. RESULTS

5.1 Reynolds number

To be able to intercompare the results found they are tabulated as function of the Reynolds number Re, with respect to the nozzle throat d. Re can be calculated from the mass flow rate Q_m and the dynamic viscosity μ of the medium used according to

$$Re = 4\ Q_m\ /\ (\pi\ d\ \mu). \qquad (1)$$

For the calculation of the viscosity NEL has used a polynomial equation based on the upstream temperature and density[4].
Gaz de France, Gasunie and Netherlands Measurements Institute used the Herning-Zipperrer formula for μ as can be found in ref. 6.

<u>Note</u>: Henceforward the Re-number will be given in units of 10^6 for ease of handling.

5.2 C_* calculation

As basis for the calculation of C_d from the experimental results the C_* calculation according to Johnson was taken. This method is presented in the draft ISO standard[1]. It was realized that this method of calculation is not perfect and is even out of the application range for the type of gas used in the Netherlands.
The new calculation method (AGA-8) according to Starling et al.[9] might produce better results, but since that is a complicated calculation method not yet available to every laboratory at the time of the calibration, use of the Johnson method was favoured.

5.3 Single nozzles

In figs. 8(a-f) the results for C_d as function of Re are shown for each of the single nozzles. The results obtained in 1985 by Gasunie and Netherlands Measurements Institute are combined.
Comparing the standard deviation with the reported random uncertainty the values for the NEL results correspond of course since the standard deviation was the basis for the random uncertainty quotation. The Gaz de France results are also in line with their estimated random uncertainty. The Gasunie results reproduce much better than could be expected on the basis of the estimated random uncertainty. This can be explained by the fact that in the uncertainty estimate the largest part (0,16%) came from the uncertainty in the molar mass of the gas calculated from the gas composition. If the gas composition is more stable than expected also the random variation caused by it is small. Subtracting this part from the random uncertainty figure leads to an uncertainty close to the actually found random variations in C_d.

From the results of the nozzle calibrations within the package the following features attract attention:

- All three laboratories have found C_d values that differ significantly from those predicted by the ISO-draft. This is illustrated by fig. 8(g).
- The slopes found are larger than the ISO-prediction.
- The results from Gaz de France are for all nozzles 0,1% to 0,2% lower than those from NEL and Gasunie.
- The results from the Bergum facility lie in the order of 0,10% higher than those obtained from the Groningen facility. This is more than expected from the calibration and intercomparison data from both installations obtained with transfer standard meters.
- The Bergum (NMi) and Westerbork (Gasunie) data coincide within the experimental uncertainty. It is remarkable that the results of C_d at Re = 24 are larger than unity, which is in contradiction with the theoretical background of the sonic nozzle behaviour. However, the C_d values are in line with the extrapolation of the results found at the lower Re values.
- Comparison of the Gasunie results in 1985 and 1987 show a systematic decrease of the latter. This decrease is on the edge of statistical relevance.

5.4 Nozzle combinations

Aim of the testing of nozzle combinations was to find out whether the nozzle performance was influenced by parallel use. Based on the theory of critical flow no mutual influence is expected.
Using the mass flow formula the expected C_d value for the nozzle combination can be calculated. However, Gaz de France has reported that the temperatures

of each of the nozzles was within 0,1 K from the mean temperature which is negligible in the calculation of C_*. NEL and Gasunie have not reported on temperature differences, so it is assumed that the differences can be neglected. Thus only the nozzle diameters influence the average C_d of a combination of nozzles, and it can be calculated using the nozzle throat areas as weighting factors. However, since the nozzle diameters are almost equal the weighted mean calculation does not differ significantly from a simple mean, so that

$$C_d(exp) = (C_{d1} + C_{d2} + ...)/n. \qquad (2)$$

Nozzle combinations should be compared to the single nozzles results under the same conditions, i.e. each laboratory has to be considered separately. The differences found for each laboratory can than be brought together.
As already indicated the various laboratories took different combinations. The following combinations can be compared as they involve the same geometrical position.

Gasunie	Gaz de France	NEL
1 + 2	-	1 + 2
1 + 3	1 + 3 / 2 + 6	1 + 3
1 + 4	2 + 5	1 + 4
1 + 3 + 5	2 + 4 + 6	1 + 3 + 5
1 + 2 + 3	-	-
-	3 + 4 + 6	-
-	-	1 + 2 + 5
1 - 6	-	-

The results of the nozzle pairs, nozzle triplets and all six nozzles are shown in figs. 9, 10 and 11, respectively.
The nozzle triplets for which no corresponding geometries were available, are combined in fig. 10(b).

6. ANALYSIS

Some systematic differences can be observed between the various laboratories and some unexplained features have been spotted in the data. They tend to stay within the uncertainties for the measurement results and thus it is considered justified to analyse the results in relation to one another. A set of equations for C_d is developed with uncertainty limits that can serve as the basic calibration results of the NTP.
From the results of the statistical analysis it should also become clear if there are any significant differences between the various geometries.

6.1 Least squares analysis

The data for single nozzles, nozzle pairs, and nozzle triplets were fitted with the relationship:

$$C_d = a + b\,Re^{-\frac{1}{2}}, \qquad (3)$$

in which a and b are the calibration coefficients. A linear least squares technique with weighed data was applied as described in ref. 7. The weighing factors were proportional to $1/s^2(C_d)$.
The uncertainty with 95% confidence level of the discharge coefficient predicted by the fit will will be refered to as $s_{95}(C_d)$.
Details of the followed procedure are explained in ref. 10.

6.2 Results

The results of the fits of the single nozzle data are shown in table 4 and fig. 8(a-f). In table 4 the fits of the single nozzle data are shown together with the fit of all single nozzle data, the mean calibration coefficients obtained from the six fits of the single nozzles, and the proposed ISO-values of ref. 1.
From table 4 it appears that the calibration coefficients of the separate nozzles and the mean calibration coefficients agree within their mutual uncertainty bounds. The fits of the separate nozzles agree within uncertainty bounds with the fit of all single nozzle data. Moreover, it appears that the values of the coefficients a and b obtained from the fits differ significantly from the values stated in the ISO draft international standard[1].
As can be found from the last column in table 4, the uncertainty of the discharge coefficient predicted by the fits with 95% confidence is 0,3% which is better than the literature value of 0,5%.
These results also mean that the calibration coefficients obtained from all single nozzle data give a correct description of the results found at each of the nozzles separately.
In all fits of table 4 only one outlier was found: in the fit of all single nozzle data. Due to the high number of data it was not necessary to remove this outlier.
For each of the nozzles the graphical representation of the measurements is depicted in fig. 8(a-f). The measurements are indicated by symbols and the fit is represented by the solid line. The accuracy of the fit based on the standard deviations of the coefficients a and b is indicated by the dashed lines which mark the 95% confidence interval of the fit. The procedure for obtaining this confidence interval is explained in ref. 8. Note that the shown confidence interval in fig. 8 does not indicate the uncertainty of a discharge coefficient predicted by the fit.
The fit for all single nozzle data is shown in fig. 8(g) together with the result following from the ISO values. Again the difference is very clear.

The results of the fits of the nozzle pairs and nozzle triplets are also shown in table 4. The fitted curves and the measurements are depicted in figs. 9 and 10. In table 4 the calibration coefficients for the different nozzle combinations are compared with the equal weight averages of the calibration coefficients of the corresponding single nozzles. In the cases of opposite nozzle pairs and nozzle triplets these calibration coefficients agree within their mutual uncertainty bounds. This agreement is also found for the calibration coefficients of all single nozzle data and the results of the opposite nozzle pairs and nozzle triplets.
When the nozzle pairs do not consist of two opposite nozzles the agreement is less good. The reason for this is not known but the flow geometry may have some effect. The uncertainty with 95% confidence of the predicted discharge coefficients C_d is 0,2% for nozzle pairs and 0,4% for nozzle triplets.

Table 4: Results from the least squares fit of the calibration data of the NTP.

1) Single nozzles in the package

Nozzle	N	a s(a)	b s(b)	s95(Cd)
1	19	1.0032 (12)	-20.8 (4.1)	0.0029
2	18	1.0037 (10)	-18.6 (3.2)	0.0028
3	18	1.0032 (9)	-18.1 (2.5)	0.0027
4	18	1.0019 (13)	-15.2 (4.2)	0.0036
5	18	1.0018 (12)	-14.8 (3.9)	0.0032
6	18	1.0027 (12)	-17.5 (4.0)	0.0033
all data	109	1.0026 (5)	-16.8 (1.4)	0.0029
1-6		1.0028 (11)	-17.5 (3.7)	
ISO		0.9935	- 1.525	0.005

2) Nozzle pairs

Nozzle	N	a s(a)	b s(b)	s95(Cd)
1+2	8	1.0033 (5)	-13.8 (1.6)	0.0013
1,2		1.0035 (11)	-19.7 (3.7)	
1+3,2+6	16	1.0009 (10)	-12.3 (3.0)	0.0024
1,2,3,6		1.0032 (11)	-18.8 (3.5)	
1+4,2+5	12	1.0022 (10)	-14.7 (3.3)	0.0021
1,2,4,5		1.0027 (12)	-17.4 (3.9)	

3) Nozzle triplets

Nozzle	N	a s(a)	b s(b)	s95(Cd)
1+3+5, 2+4+6	10	1.0023 (20)	-16.7 (6.7)	0.0039
1-6		1.0028 (11)	-17.5 (3.7)	
3+4+6, 1+2+5, 1+2+3	10	1.0026 (18)	-17.2 (5.1)	0.0042
1-6		1.0028 (11)	-17.5 (3.7)	

4) All six nozzles

Nozzle	N	a s(a)	b s(b)	s95(Cd)
1+2+3+ 4+5+6	6	1.0030 (5)	-10.9 (1.2)	0.0006
1-6		1.0028 (11)	-17.5 (3.7)	

The fit of the Gasunie results for all six nozzles is shown in fig. 11. The calibration coefficients are listed in the lower part of table 4. The value of a agrees with the mean value of the six nozzle calibrations. The value of b deviates significantly from the mean value of the six nozzle calibrations. A remarkable result is that the uncertainty with 95% confidence in the predicted discharge coefficients (0,07%) is much smaller than the results of previous calibrations. The reason for this low uncertainty is that there are calibration differences between the different laboratories. Therefore, the results of a separate laboratory will be much more consistent than the cumulated results of the three laboratories.

7. CONCLUSIONS

From the present analysis the following conclusions can be drawn.

The calibration curve obtained from all single nozzle data gives a correct description of the observed discharge coefficients in experiments with single nozzles, pairs of opposite nozzles, and nozzle triplets.

The uncertainty in the discharge coefficients predicted with this calibration curve is 0,3% at a 95% confidence level. This uncertainty is exclusive of the specified systematic uncertainties of the laboratories. The reported values of the systematic uncertainties are all about 0,3%. Root square summation of the two types of uncertainties leads to a total uncertainty of 0,4%.

The calibration coefficients resulting from experiments described in this report differ significantly from the values stated in the ISO draft international standard[1]. The uncertainty of the predictions has improved compared to ref. 1.

In view of the fact that the three laboratories used significantly different gases, operated on different principles and have quite distinct traceability paths, the overall level of agreement from the calibrations of the Nozzle Transfer Package is encouraging.

Within the uncertainty limits specified the results from the least squares analysis can be used to calculate mass flow rates through the NTP. This means that the Nozzle Transfer Package is practically available for laboratories which want to use the NTP for testing and calibration puposes.

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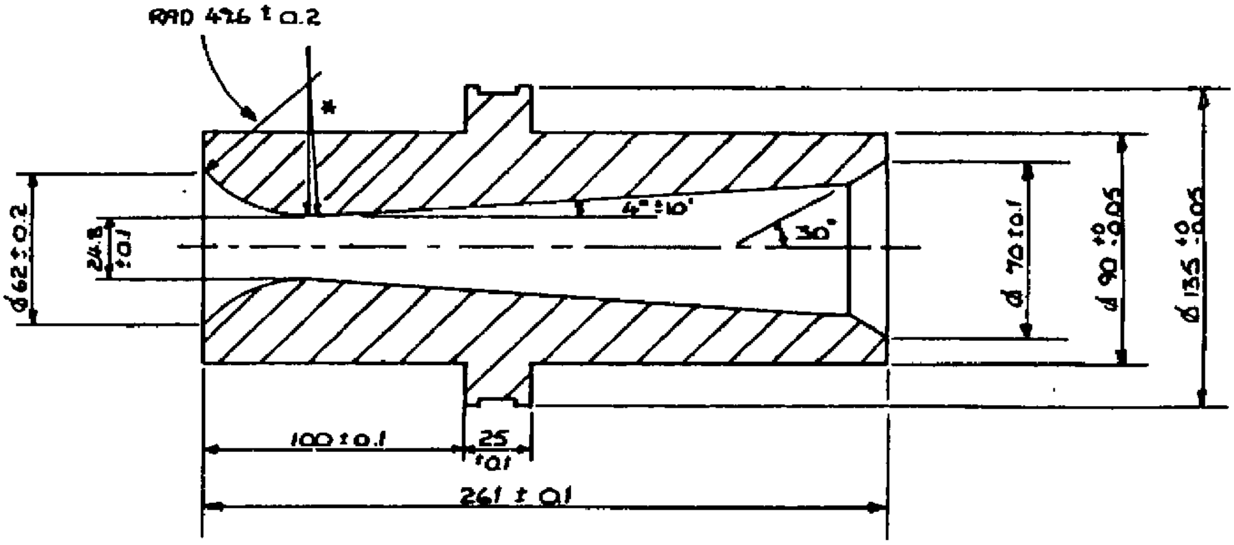


Figure 1: Leading dimensions of the toroidal inlet critical flow venturi nozzles. The inlet radius extends 4° beyond the throat to become tangent to the conical diffuser (*). All dimensions are in mm, the material is SS316. Full details can be obtained from the NEL drawing no. A3-A/19956.

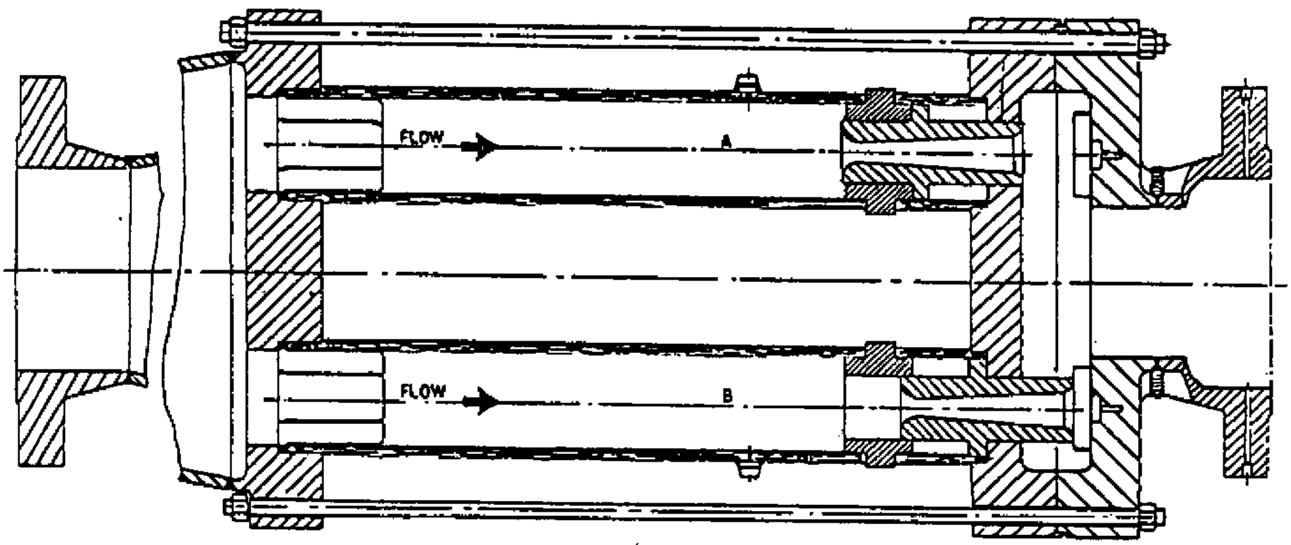


Figure 2: Schematic set-up of the Nozzle Transfer Package. At A a nozzle is shown in the open position, at B in the closed position.

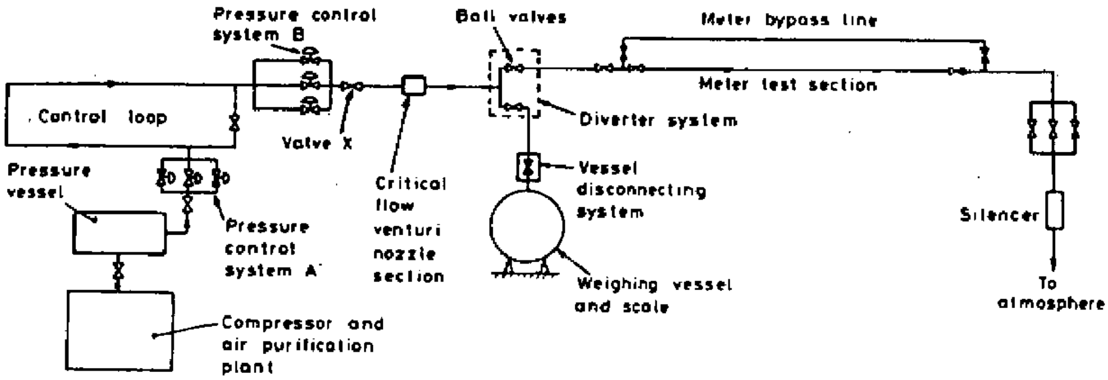


Figure 3: High pressure testinstallation at NEL, East Kilbride, Scotland.

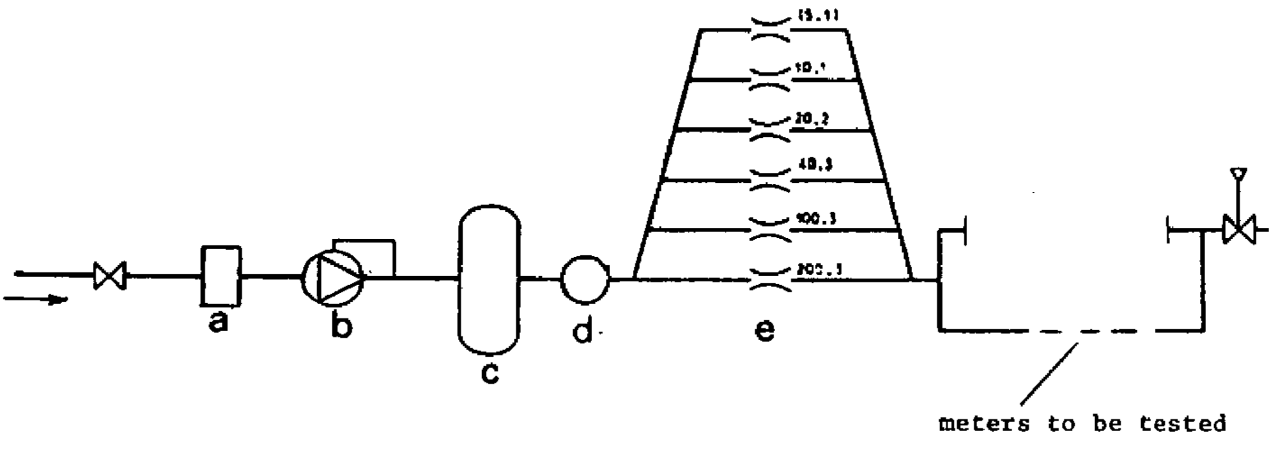


Figure 4: Secondary high pressure test installation of Gaz de France at Alfortville, France.
a = filter, b = pressure regulator, c = vessel, d = densitometer, e = sonic nozzle standards with indicated the nominal volume flow rates in m^3/h.

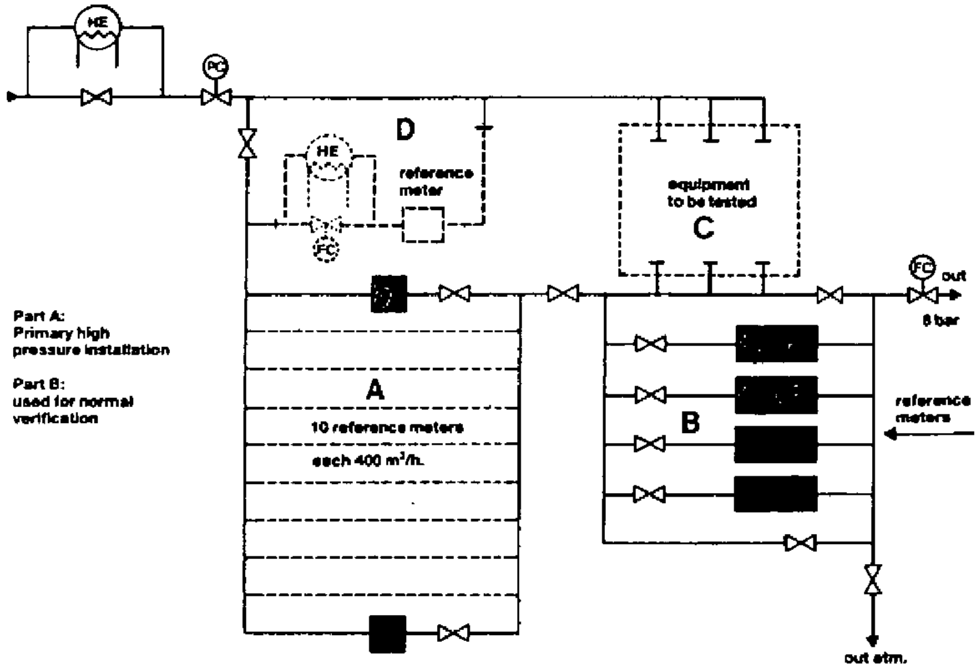


Figure 5: The high pressure test installation of Gasunie at Groningen, the Netherlands. Part A is the primary facility, part B the secondary facility. The NTP was installed at position D for calibration with the standards in part A as reference.
TC = temperature control, PC = pressure control, HE = heat exchanger, FC = flow control.

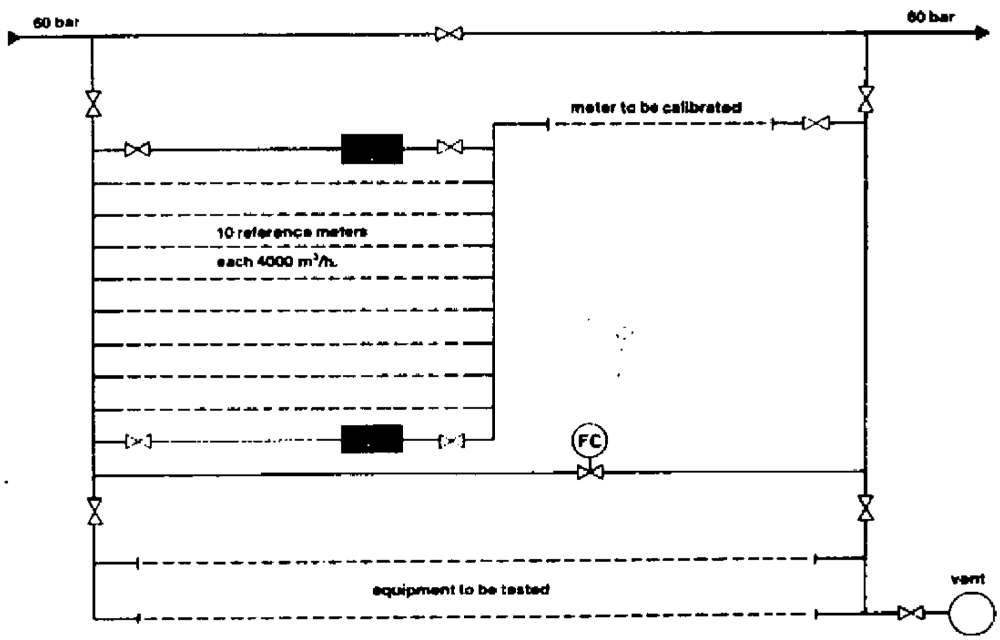


Figure 6: The high pressure test installation of Gasunie at Westerbork, the Netherlands.

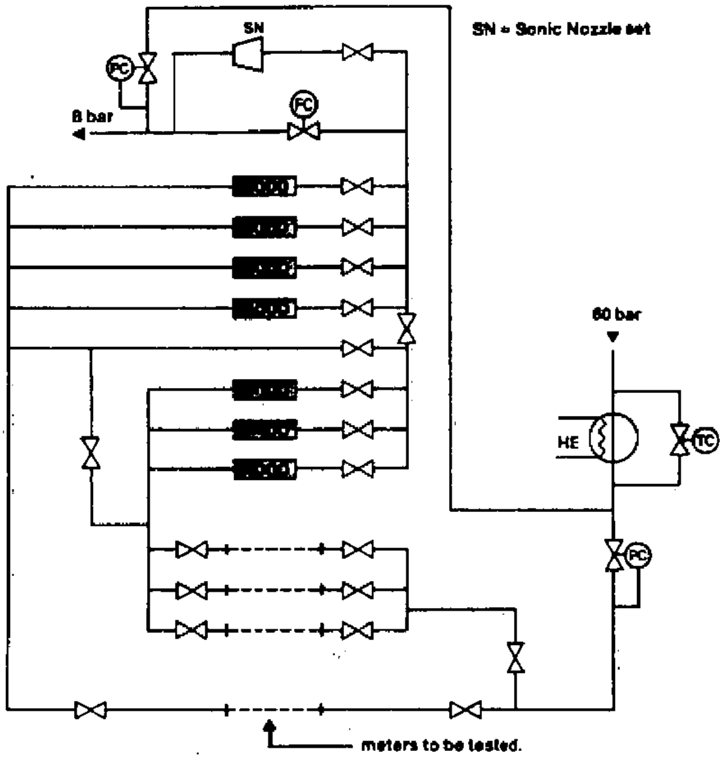
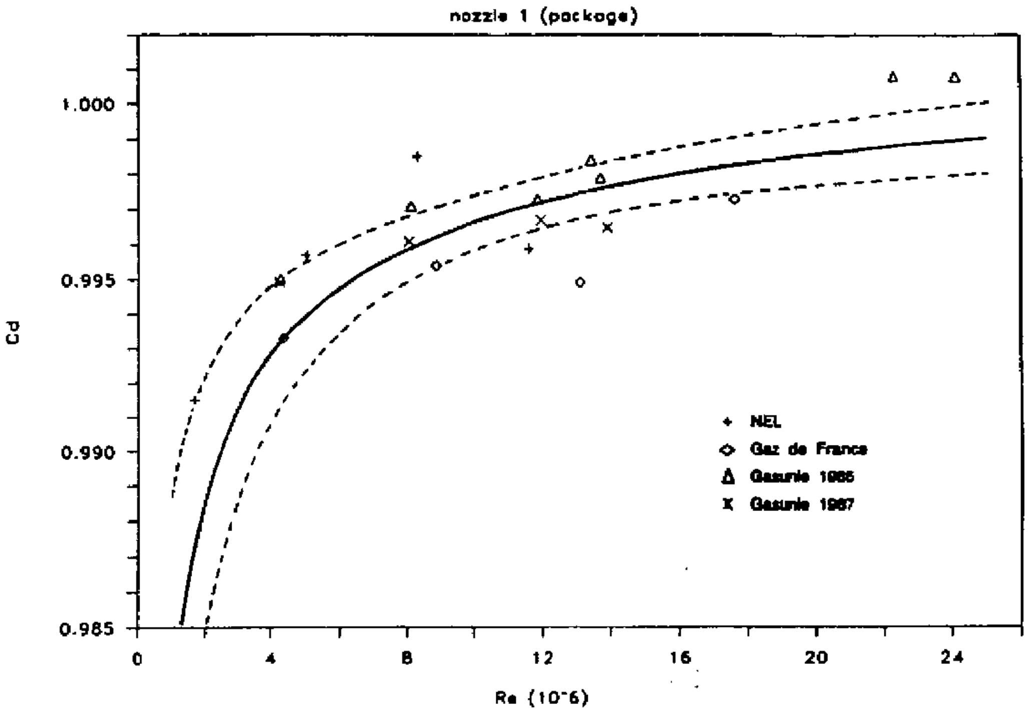


Figure 7: The high pressure test installation of the Netherlands Measurements Institute at Bergum, the Netherlands.



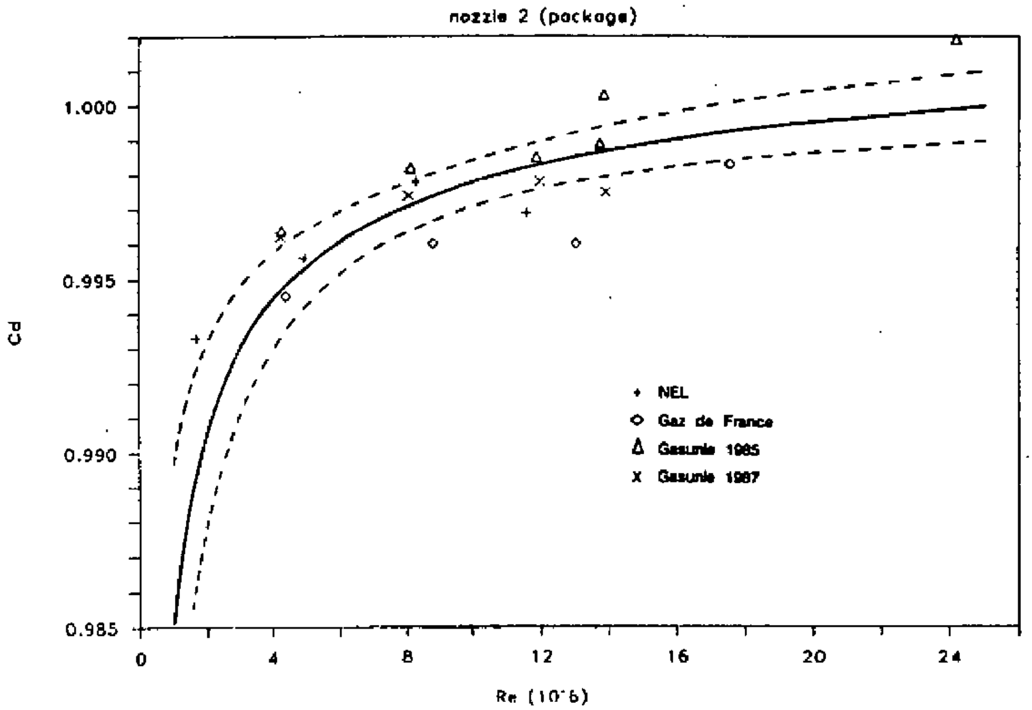
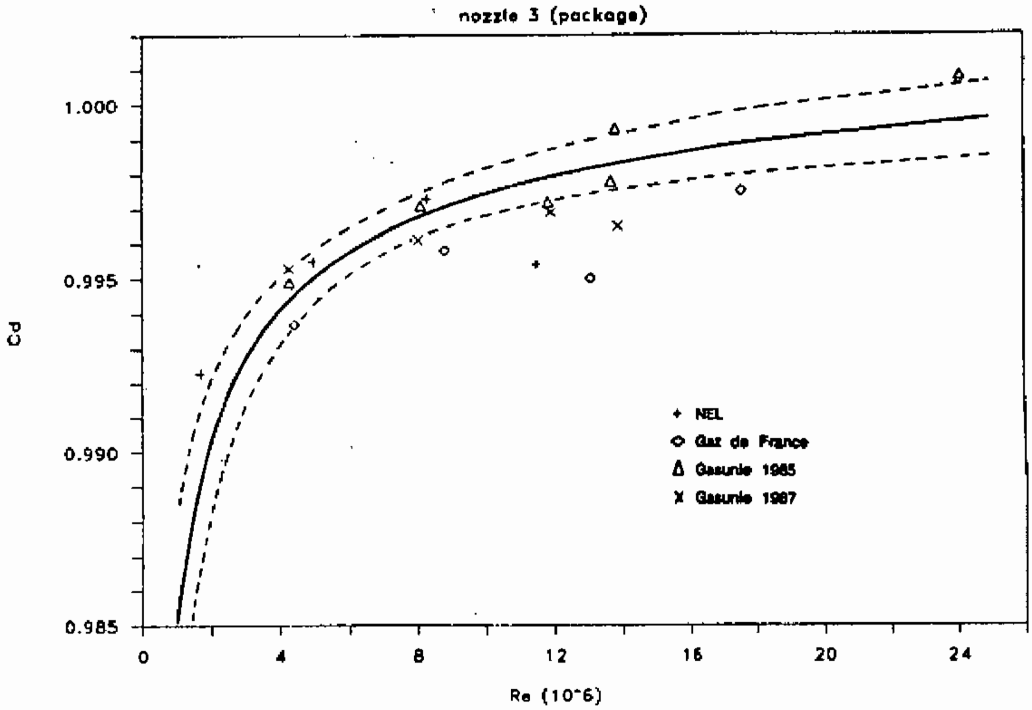


Figure 8 a,b: The discharge coefficient C_d as function of the Reynolds number Re for the individual nozzles.
The solid line depicts the least squares fit of the data points, the dashed lines the 95% confidence interval of the fit.



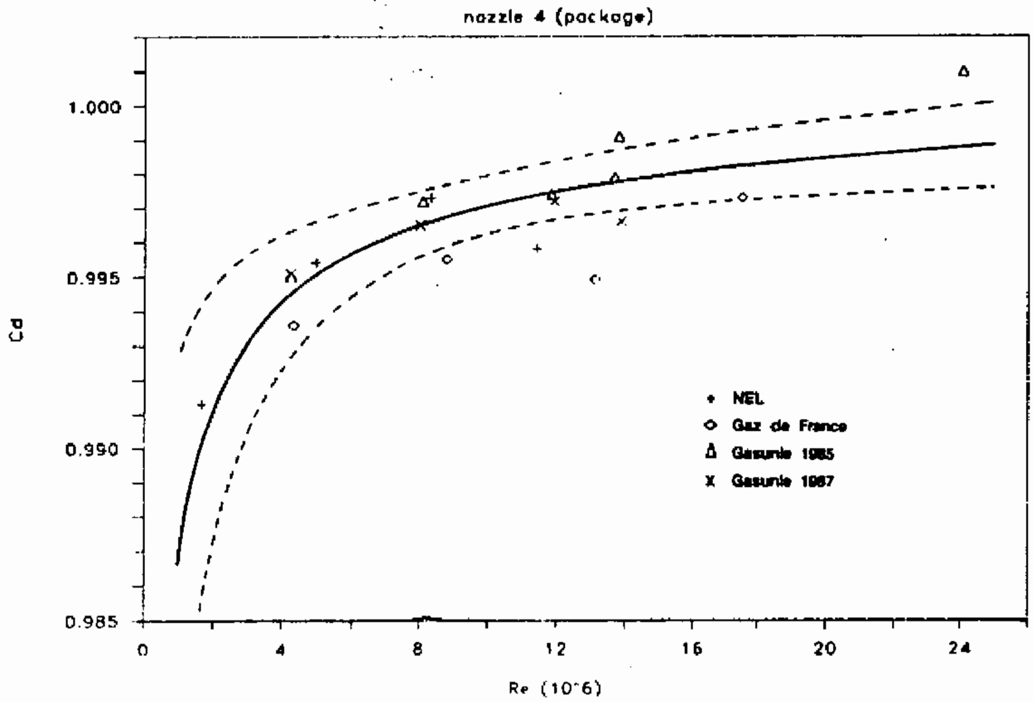
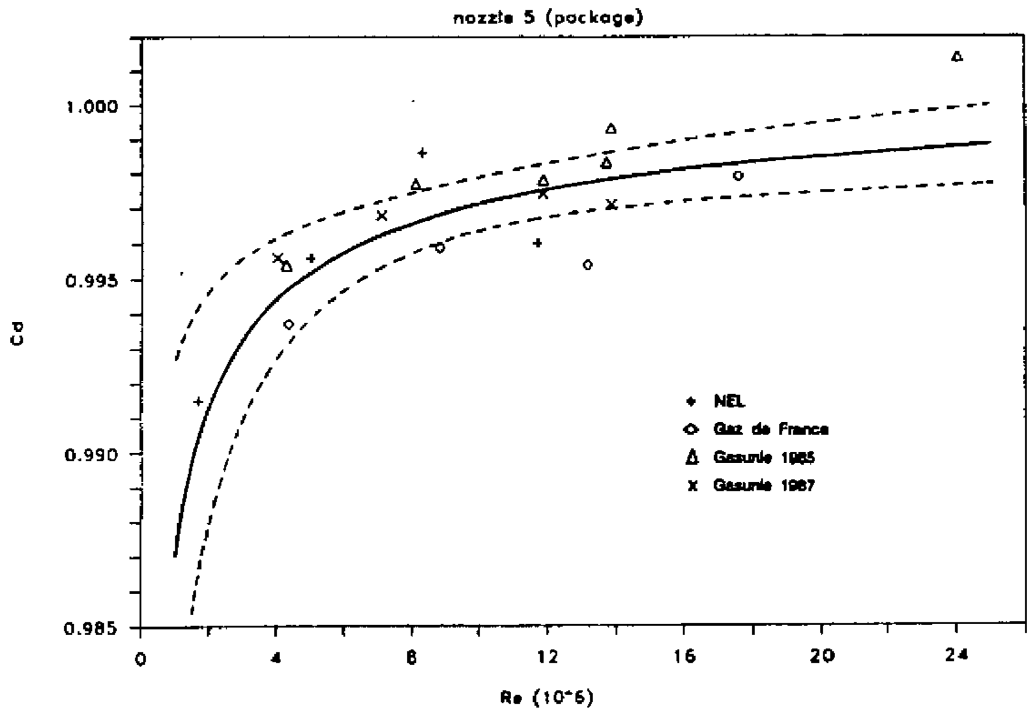


Figure 8 c,d: The discharge coefficient C_d as function of the Reynolds number Re for the individual nozzles.
The solid line depicts the least squares fit of the data points, the dashed lines the 95% confidence interval of the fit.



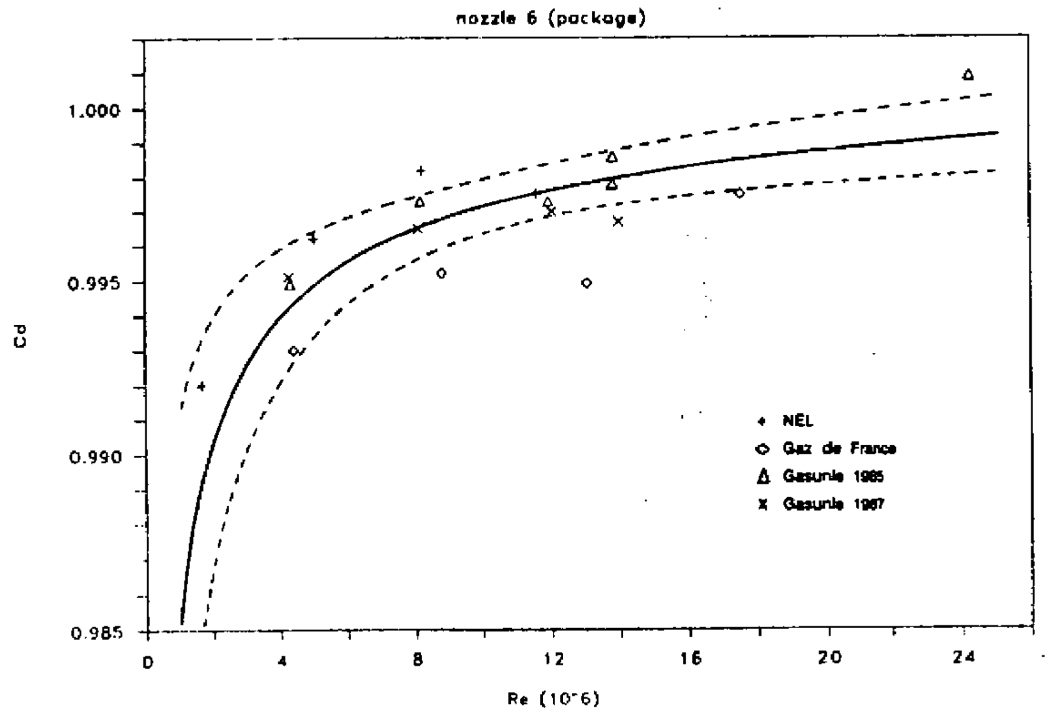


Figure 8 e,f: The discharge coefficient C_d as function of the Reynolds number Re for the individual nozzles.
The solid line depicts the least squares fit of the data points, the dashed lines the 95% confidence interval of the fit.

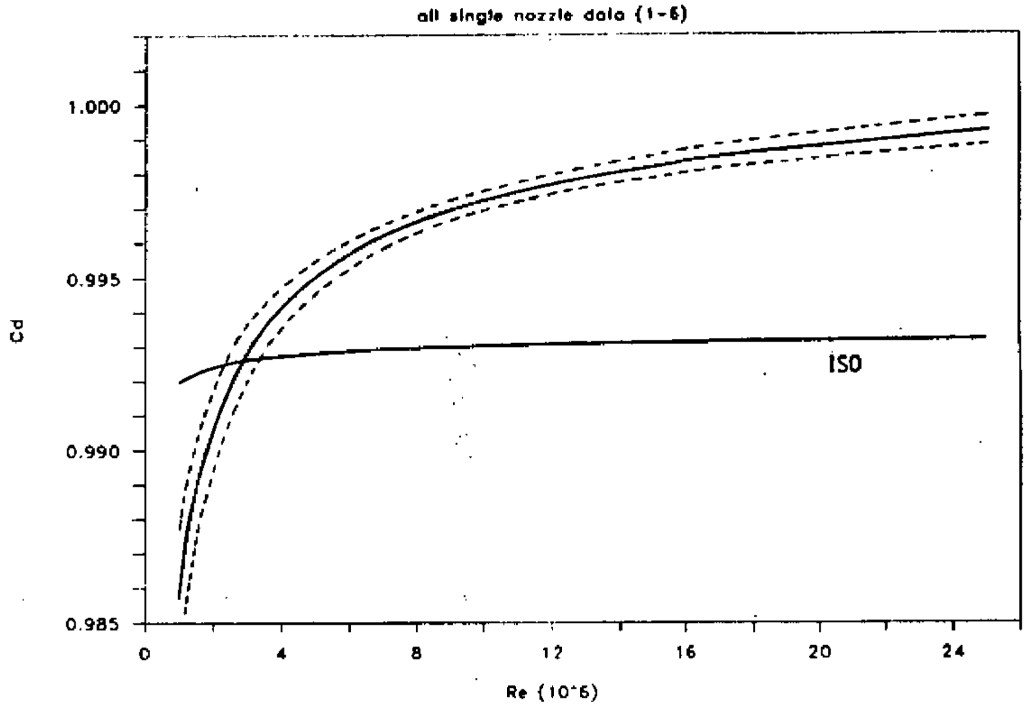
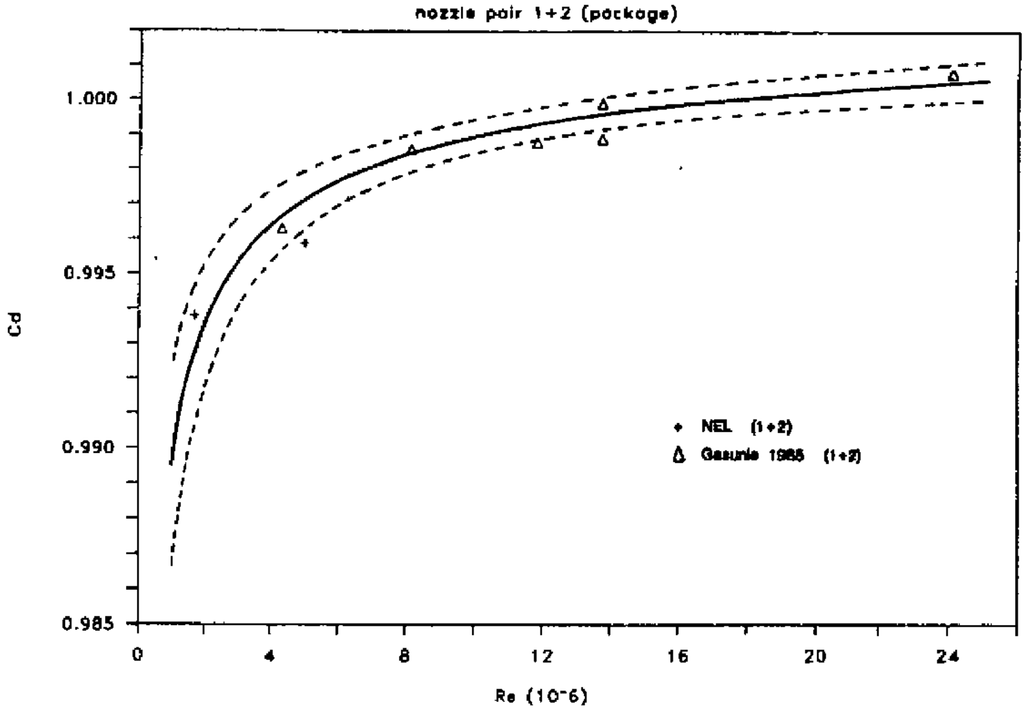


Figure 8 g: The least squares fit through all data points taken together. Shown is also the prediction according to the ISO draft international standard[1].



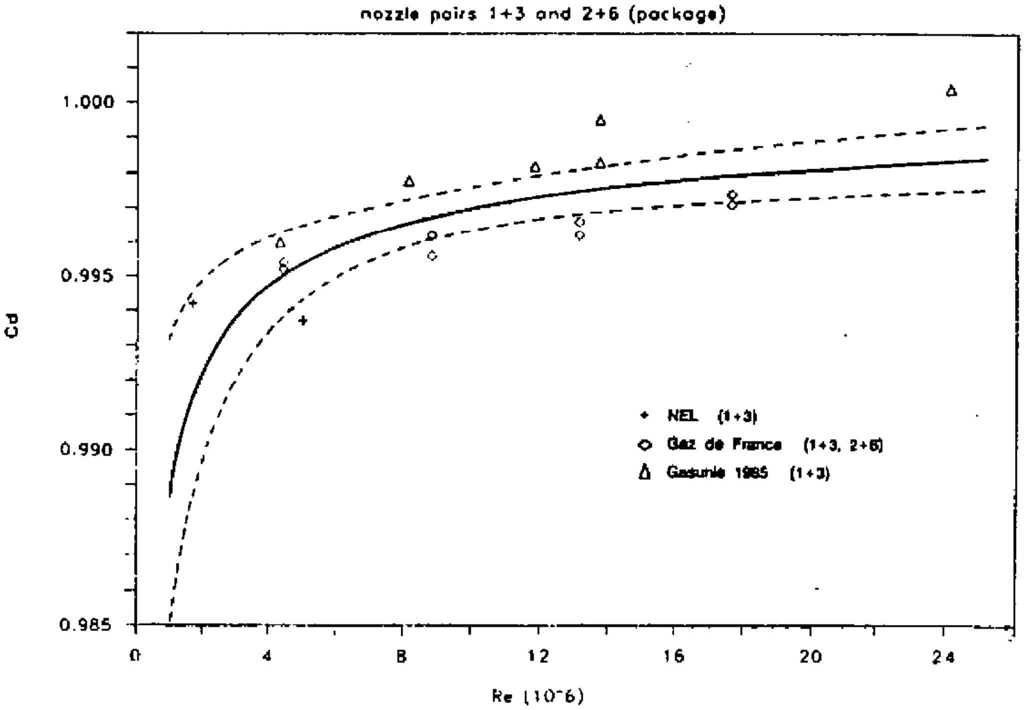


Figure 9 a,b: The discharge coefficient C_d as function of the Reynolds number Re for the nozzle pairs.
The solid line depicts the least squares fit of the data points, the dashed lines the 95% confidence interval of the fit.

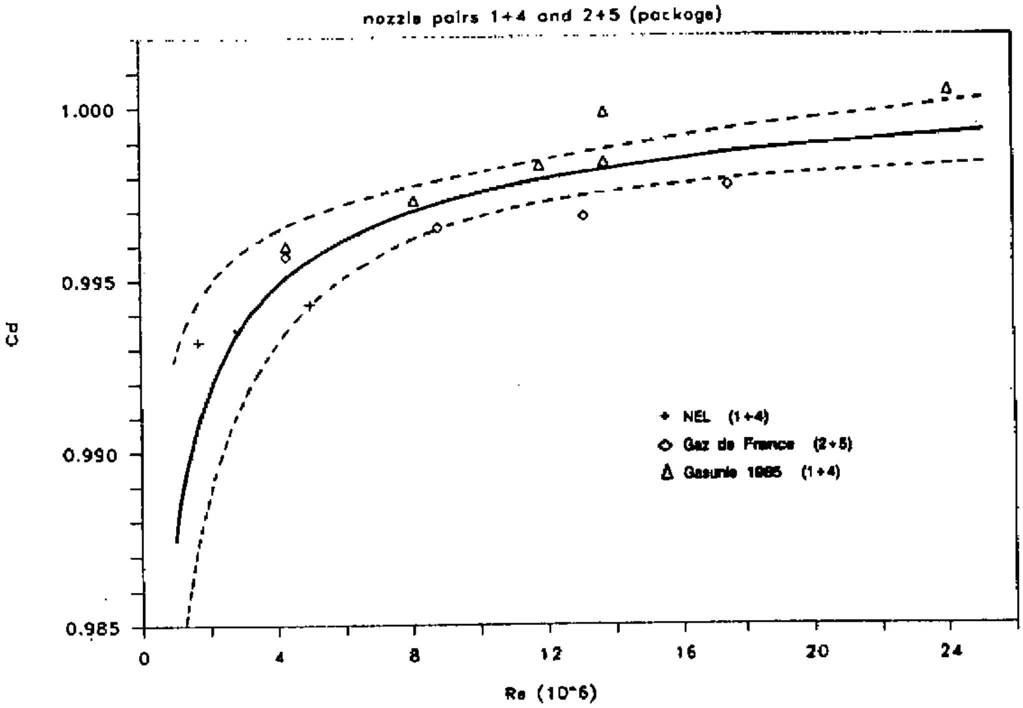
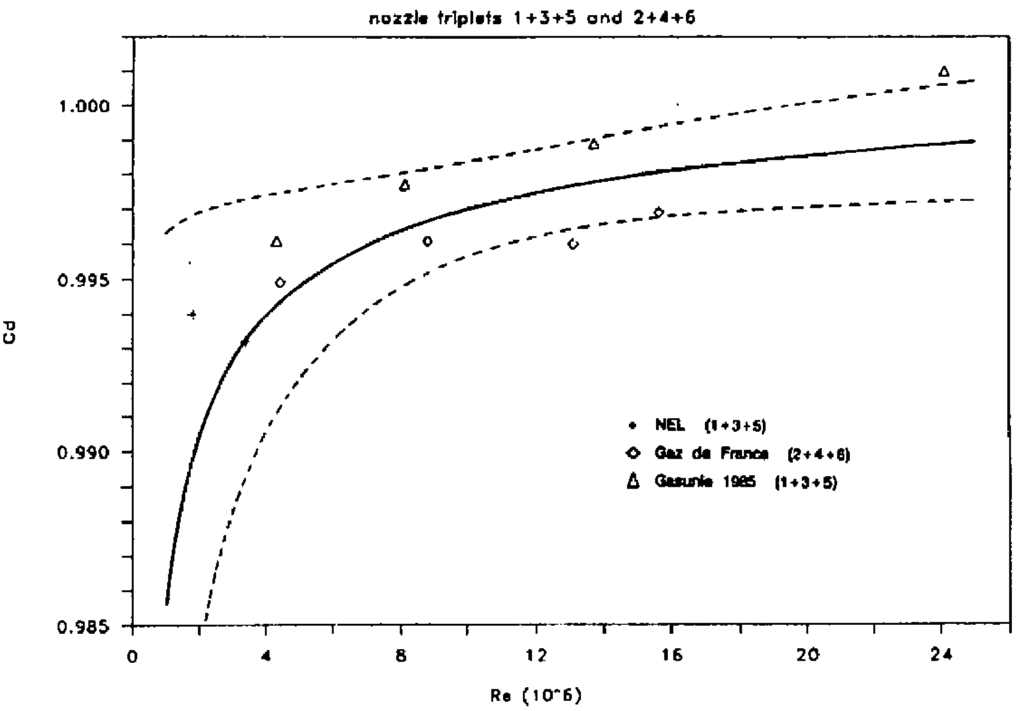


Figure 9 c: The discharge coefficient C_d as function of the Reynolds number Re for the nozzle pairs.
The solid line depicts the least squares fit of the data points, the dashed lines the 95% confidence interval of the fit.



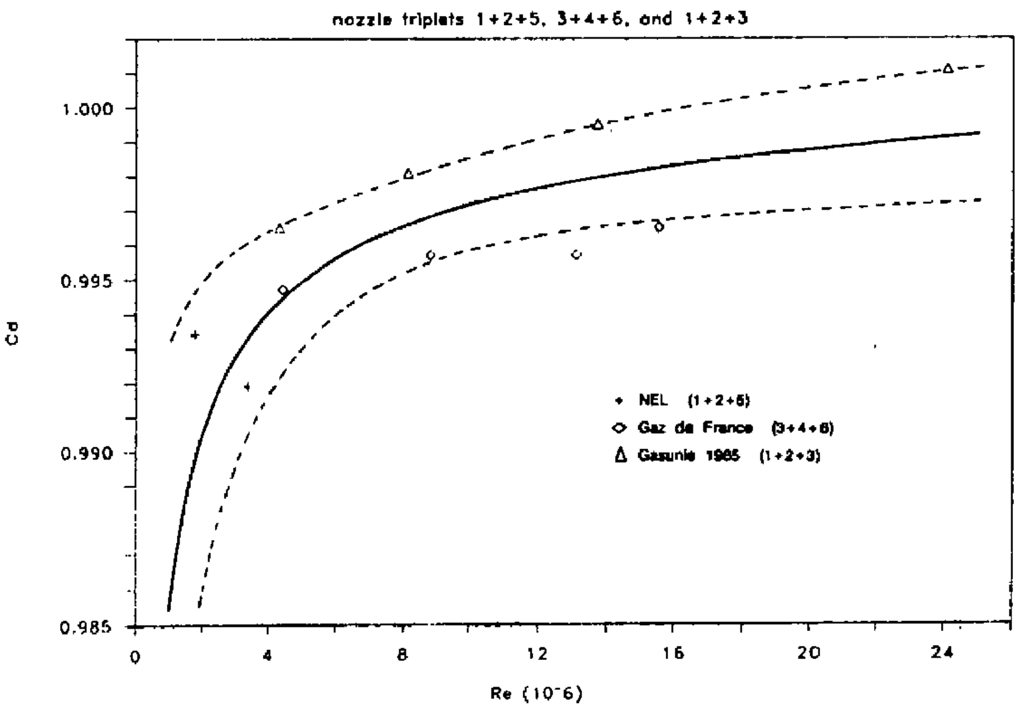


Figure 10: The discharge coefficient C_d as function of the Reynolds number Re for the nozzle triplets.
The solid line depicts the least squares fit of the data points, the dashed lines the 95% confidence interval of the fit.

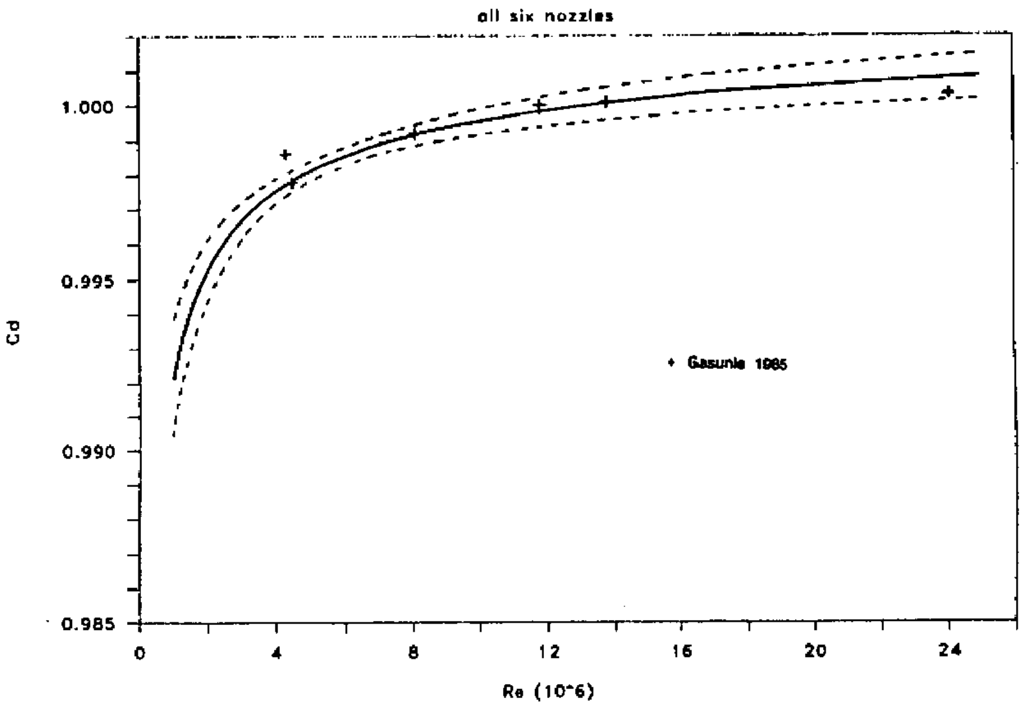


Figure 11: The discharge coefficient C_d as function of the Reynolds number Re for all six nozzle (results from Gasunie only).
The solid line depicts the least squares fit of the data points, the dashed lines the 95% confidence interval of the fit.