V-Cone meter : Gas measurement for the real world

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Summary

This paper describes the performance of the V-Cone meters used for Embla test separator gas measurement, starting May 1993. The advantages and disadvantages for use of this technology on the partially processed gas at an offshore platform is discussed.

It has been shown in tests that the V-Cone meter functions well with wet gas conditions. The long term repeatability of the meter is documented. Also the low influence from upstream disturbance is confirmed. It is shown that calibration curvefit to ISO5167-1 based equations, can give dry gas accuracy inside the fiscal requirements for gas at Reynoldsnumber above 1 million. The experience from Embla shows that the V-Cone meter tolerates rough operation : The V-Cone meter dimensions certified at six month intervals identifies no changes to the meter. Also the flow calibrations carried out at the same time intervals presents no significant changes ; the results match close to the accuracy of the equipment used in the flow calibrations.

1 Introduction

The remote operation of the Embla platform was a challenge in selection of reliable equipment with low maintenance requirements for the test separator measurement used in fiscal allocations. The gas measurement criterias ; no moving parts and high tolerence to particles and condensate, is not complied with by any of the well proven measurement equipment.

Our thorough evaluation of the V-Cone meter design for this application showed no apparent weakness, apart from possible vortex noise introduced bv the V-Cone holder. The design with the central cone allows for the liquid to continue along the wall, and liquid buildup can therefore be avoided. The thin film of condensates at the wall will not introduce upsets to the flow pattern. Also the contineously increasing velocity up to the minimum area by the edge of the V-Cone, produces a uniform flow profile at higher flow-rates; thus the requirement for upstream straight lenghts is reduced or eliminated. In a gas experiment by McCrometer, it is documented on video that the profile is smoothend out before the edge of the V-Cone, and that the swirl appears to be removed . In any case, the vortex noise would be seen as stochastic and eliminated thru square rooth averaging of the differential pressure.

Previous tests by Phillips Petroleum in New Mexico over months of operation showed repeatable long term results. We were therefore satisfied that the V-Cone meter would fulfill the requirements on Embla. On this background, it was decided to qualify the V-Cone meter for the Embla gas measurement.

The V-Cone meter functional performance was verified at the Rogaland Research wet gas test loop facilities , where both installation tolerence and tolerence to liquid in the gas were tested in the spring of 1992.

Calibration of the V-Cone meters before offshore installation at Embla and every six months for the first year, was agreed with the NPD. Initial testing with high differential pressures were carried our at K-Lab in the first pan of 1993. Certification of the coefficient of discharge was carried out at NMI, Bergum before startup of Embla in the summer of 1993. and recertification was carried out by NMI in the end of 1993 and again in the summer of 1994. Dimensional certtjication procedure was developed bv Con-Tech and the V-Cone meter certification was peformed each rime before the flow calibration centfication of the coefficient of discharge.

2 Phillips Petroleum New Mexico comparison with orifice

Early gas measurement comparison tests where the V-Cone meter was put in series with an Orifice meter, was carried out in 1991 by Phillips Petroleum New Mexico. The monthly mass comparison from May to July repeated within +/- 0.01 % and the daily comparison was mainly within + /- 0.1 %, However, a consistent bias of approximate + 0.75. % , made it clear that traceable calibration close to operating conditions would be required for accurate measurement.

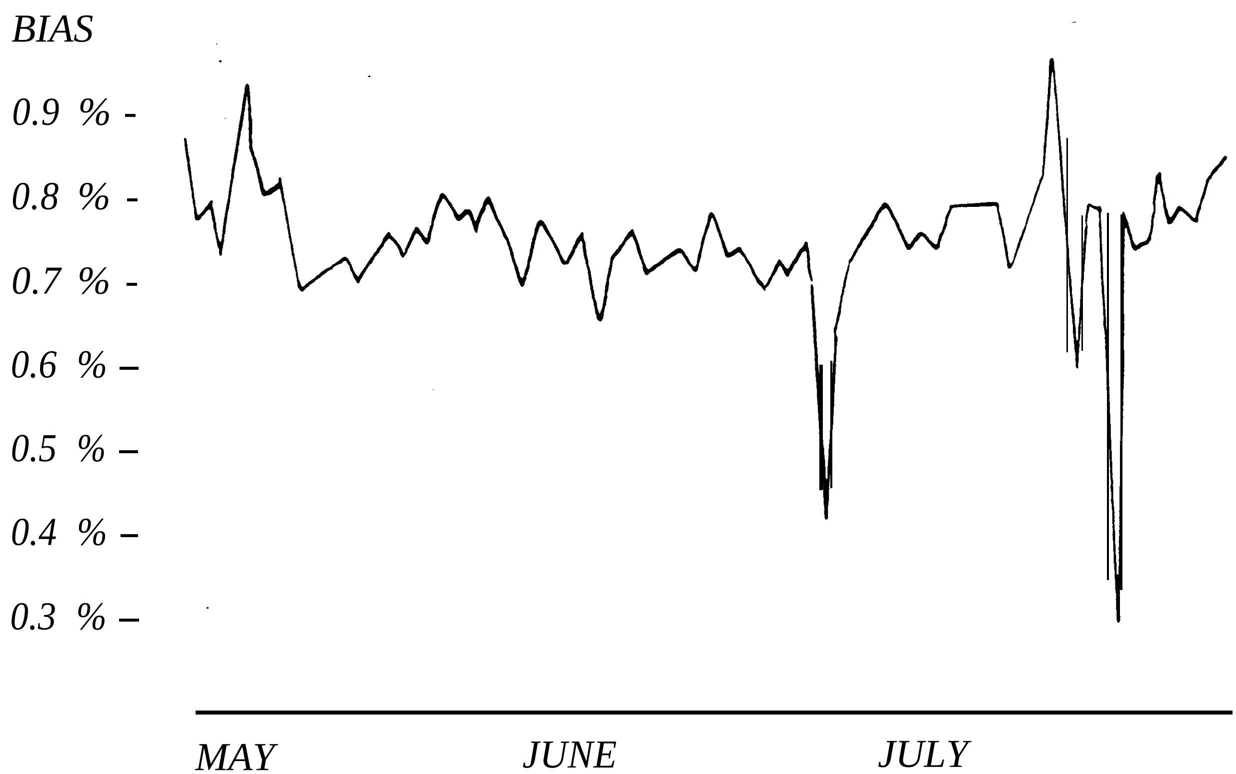


FIGURE 1 COMPARISON OF V-CONE WITH ORIFICE 1991

3 V-Cone meter functional performance verification at RF

The functional performance test at Rogaland Research was carried out to quantify the V-Cone meter tolerence to free Liquid in gas, and also to check the tolerence to upstream disturbance and eccentric In the closed loop wet gas testing facilities, a V-Cone meter was tested in series with an Orifice meter. It should also be noted that the vortex noise imposed on the

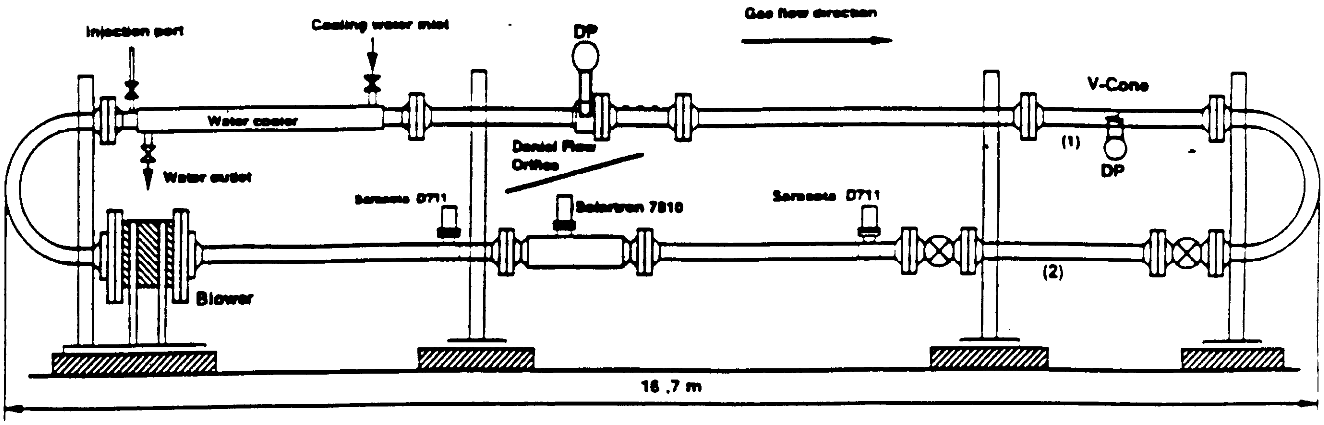


FIGURE 2 THE WET GAS TEST LOOP WITH V-CONE

differential pressure can be removed. This was confirmed by the consistency whereeever averaging over more than 30 readings was performed. Possible vortex effect can therefore be removed over shon time.

Before the first functional performance test, a dry nitrogen reference ratio between the V-Cone meter and the Orifice meter differential pressure at three flowrates was established at Rogaland Research; using long straight upstream Lengths upstream of the V-Cone meter (Position 1).

With the V-Cone meter remaining in the same position, high amounts of water was injected, only to show that the smoother flow profile effect that liquid causes on the Orifice meter, is not similarly imposed on the V-Cone meter. The relative reduction in differential pressure for the Orifice meter was 3.5 % at the end of the water injection.

The second functional performance test at Rogaiand Research checked for the uneven profile and swirl effects, with the V-Cone meter installed immediately downstream of a U-bend (Position 2). The block valve between the U-bend and the V-Cone meter was used for further flow disturbance. With full open valve, the average offset from the ratio at highest flowrate in dry gas, was below 0.2 % for all three flowrates. No significant effect was registered up to 25 degrees valve choking. Approximate I % effect was seen at 30 degrees choked block valve. With the block valve close to the V-Cone meter, the pressure drop across the block valve is regaining when the gas reached the V-Cone edge. Significant pressure loss must be avoided 10 diameters upstream of the V-Cone meter. Uneven profile and swirl effect was not detected, in Line with the findings presented by McCrometer at the I992 NSFMW

The functional performance testdata from Rogalands Research, supported by the long term comparison data from Phillips Petroleum New Mexico, strongly indicate that the V-Cone meter can be better than Orifice meter , providing that the flow coefficient is determined thru third party calibration with pure gas . In particular the V-Cone meter will be superior in wet gas service .

4 Dimensional certification procedure developed by Con-Tech

Installed inside the meter, the practical limitation for the determination of the V-Cone diameter at the outer edge was found to be +/- 0.04 mm, which is negible for larger meters . For the 3 inch meter this amounts to +/- 0.2 % of the minimum flowing area. However, using the certified dimensions in the calibration for determination of the discharge coefficient, any error in the dimensional certification is almost eliminated. The dimensional certification is therefore intended mainly for identification of mechanical changes. A typical certificate is shown in Attachment A .

5 Initial testing with high differential pressure at K-Lab and certification of the coefficient of discharge by NMI

The initial testing at 20 BarG of the two V-Cone meters for Embla, carried out at K-Lab, showed some very surprising results. With a modified ISO 5167-1 based equation, using the Venturi meter expansibility factor, as advised by the manufacturer McCrometer, the discharge coefficient found at 20 BarG pressure showed a continual rising value as a function of Reynolds-number. From 1 to 6 million Reynoldsnumber, the coefficient of discharge increased by more than 5 % . It should be noted that the differential pressure at 6 million Reynoldsnumber was approximate 3 bar.

Since this discharge coefficient characteristic seen, was not in line with the earlier findings for a V-Cone meter tested at 55 BarG pressure; the V-Cone meters for Embla were reverified at 85 BarG pressure. Now the contineous rising discharge coefficient with rising Reynolds number at the 20 BarG tests was proven to be wrong. In the 85 BarG tests where simular Reynolds numbers were acchieved with much lower differential pressure ratio, the discharge coefficient characteristic was almost flat. As the coefficient of discharge for one particular meter is mainly a function of Reynolds number, it was decided to run new independent tests at NMI in Bergum for the two V-Cone meters for Embla. Calibration at 50 BarG confirmed the almost flat *discharge coefficient characteristic. At the 20 BarG reverificaton, the high differential pressure ratio was not allowed. However, in the range tested, the 20 BarG results from NMI matched the 50 BarG flat characteristic as well as the K-Lab results at 20 BarG. At the lower differential pressures the NMI results showed high coefficient of discharge, indicating offsets in the differential pressure reading.*

When information was received from McCrometer that the phenomenon with different findings for the coefficient of discharge characteristic, at different pressures, had been observed in a number of earlier cases, it was evident to us that the Venturi equation used for expansibility is not valid for V-Cone meters.

To determine a more correct expansibility factor, the correct coefficient of discharge must be found as a function of Reynolds numbers. For the two V-Cone meters for Embla, data points were selected from 20 BarG data at NMI and K-Lab, 50 BarG data from NMI, and 85 BarG data from K-Lab, where the expansibility factor was still close to 1 and also where differential pressure offset errors would not add significant additional uncertainty.

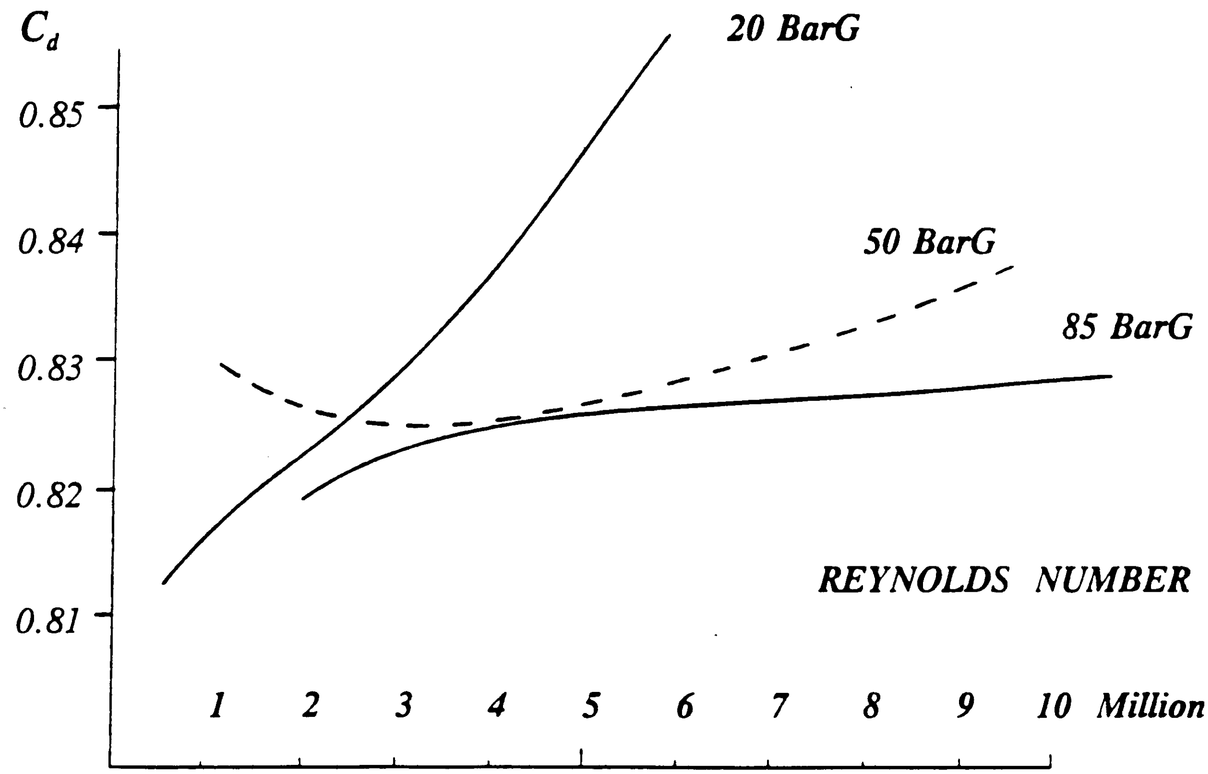


FIGURE 3 TYPICAL FINDINGS FOR DISCHARGE COEFFICIENT , USING VENTURI METER EXPANSIBILITY FACTOR

Using the function found for the coefficient of discharge based on the selected data , the expansibility factor required to give correct flowrate was plotted for the remaining points with high differential pressure to pressure ratio. The resulting expansibility factor characteristic found, was crystal clear: The expansibility factor for the V-Cone meters was linear with differential pressure to pressure ratio divided by heat ratio. Furthermore the expansibility for the V-Cone meter was found to be almost mid between that for the Venturi meter and the Orifice meter per ISO 5167-1.

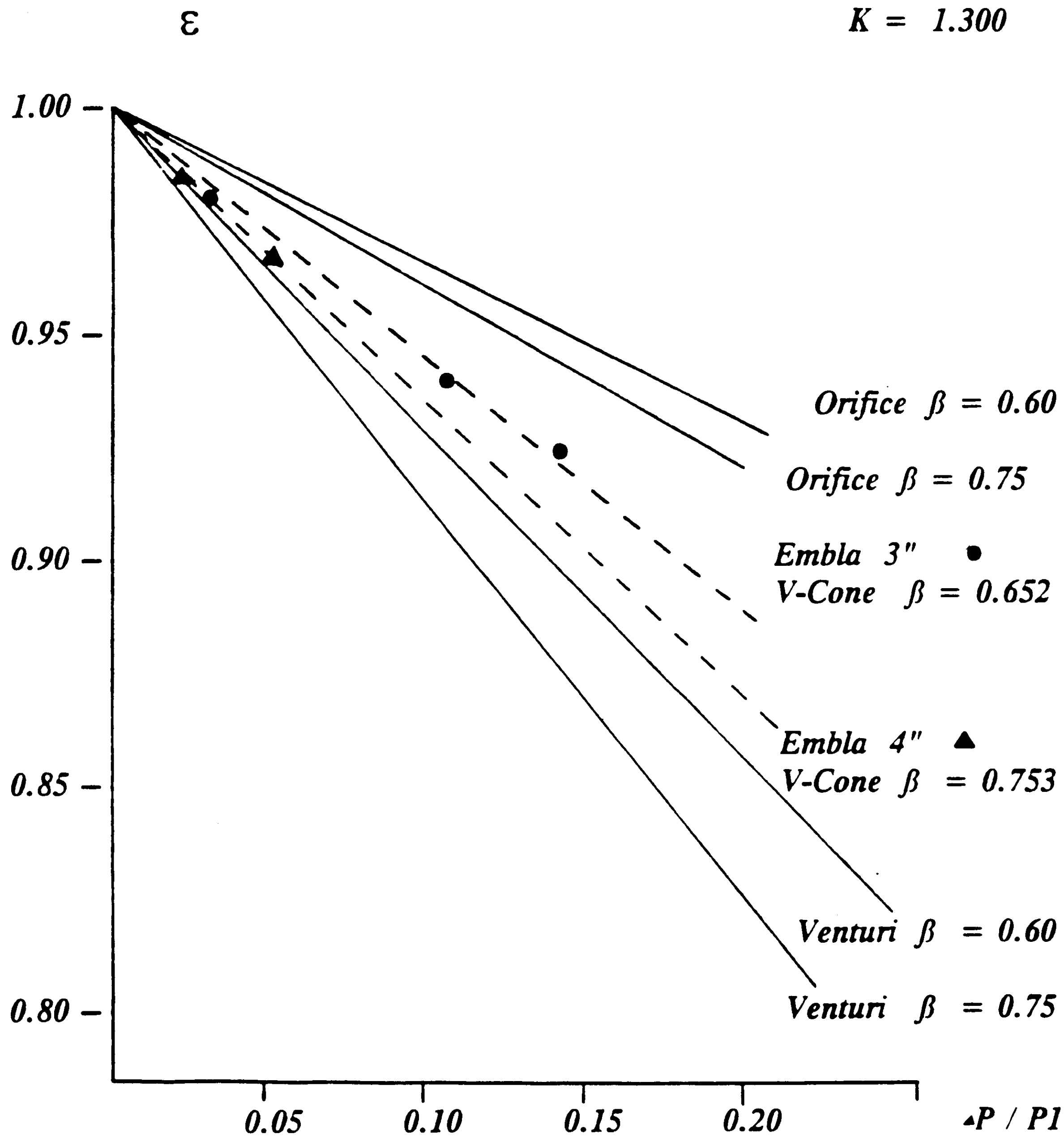


FIGURE 4 EXPANSIBILITY FACTOR PLOT FOR THE V-CONE

Based on the expansibility factor plot for the two V-Cone meters for Embla an equation for the expansibility factor was developed:

$$\varepsilon = 1 - (C_{\varepsilon 1} + C_{\varepsilon 2} * \beta^4) * X / 1300$$

$$X = (1.3 * \Delta P) / (K * P1)$$

This equation has a simular form to the expansibility factor used for the Orifice meter. However, X is made as an universal variable which will make it easier to compare data from different test facilities. The best fit for $C_{\varepsilon 1}$ and $C_{\varepsilon 2}$ is ; $C_{\varepsilon 1}$ equals 0.60 and $C_{\varepsilon 2}$ equals 0.75 . This is also confirmed with two different V-Cone meters. However, these other V-Cone meters did not have quite as high differential pressure to pressure ratio.

The V-Cone flow calculations, based on ISO 5167-1, and the V-Cone meter expansibility factor equation developed, as shown in Attachment B, has been used for all further determination of the coefficient of discharge. The plot of the coefficient of discharge determined from K-Lab and NMI data for the two V-Cone meters for Embla now showed more consistent results.

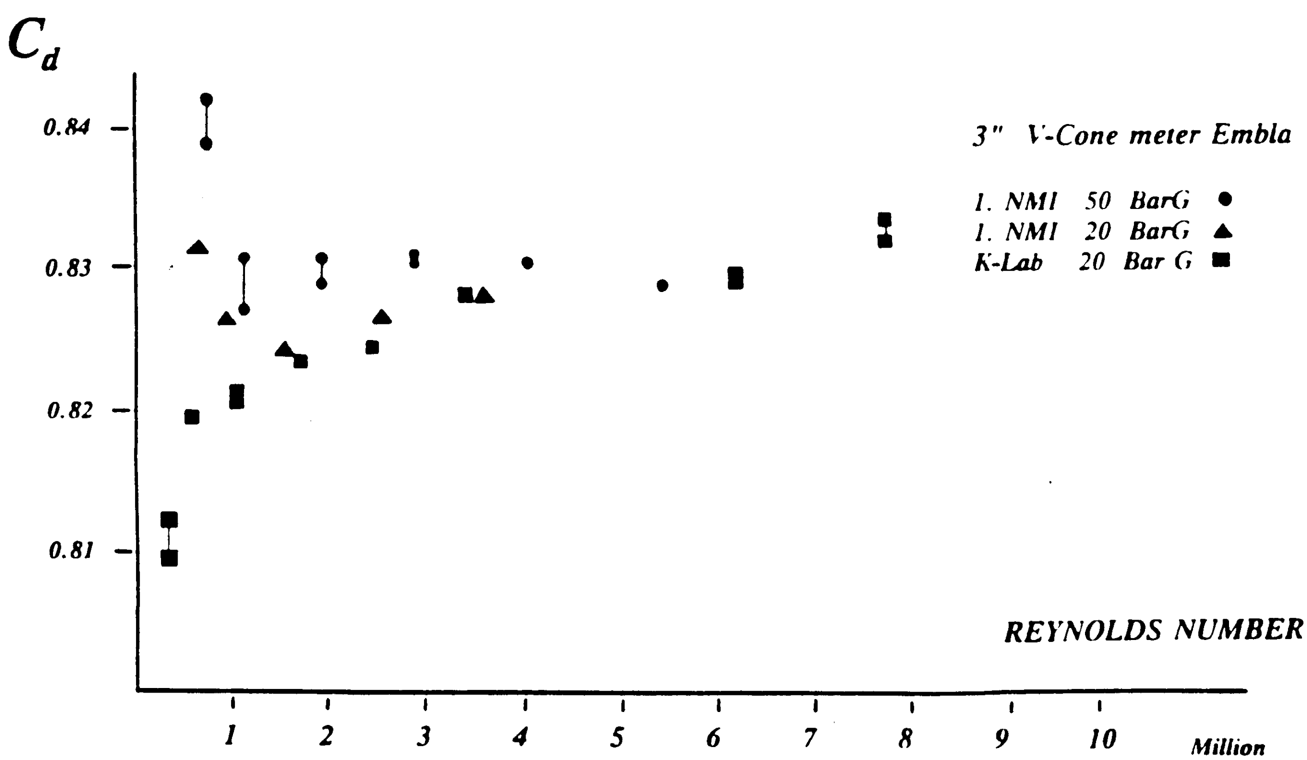


FIGURE 5 DISCHARGE COEFFICIENT FOR 3 " V-CONE METER

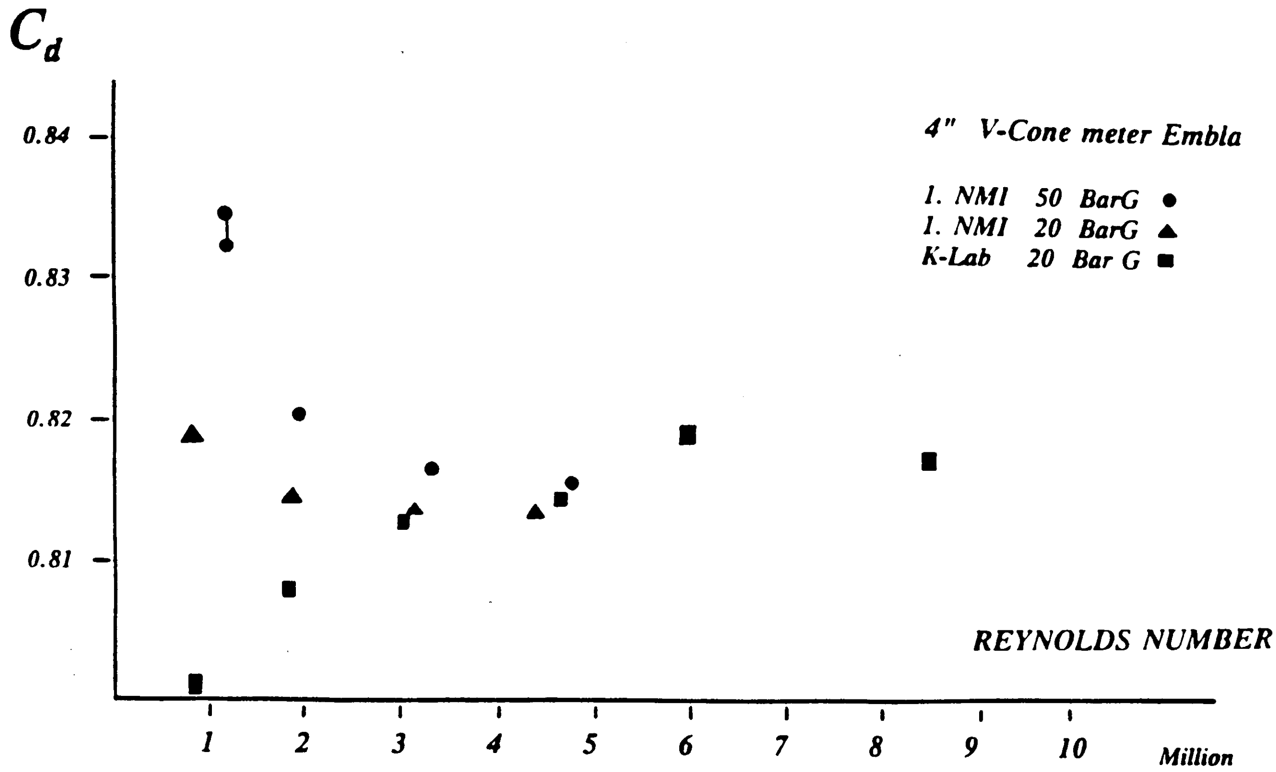


FIGURE 6 DISCHARGE COEFFICIENT FOR 4" V-CONE METER

6 Experience from Embla operation

The 3 inch and 4 inch V-Cone meters were designed to cover approximate 30 % and 70 % respectively , installed in parallell. This increase in rangeability that this gave, helped to cover the different well flowrates, thus avoiding changeout of V-Cone meter to match. Smart transmitters were used with direct digital communication for optimum rangeability accuracy.

Turning on new wells for testing at Embla crashed the turbine meters in the first phase, before strict procedure for pressure equalisation between the test separator and the export line was established. The V-Cone meters stood thru this period without any damages. Our earlier experience is that in these situations, the Orifice plates would be buckled and relocated to some downstream restricting passage position.

No damages; wear, burrs or scratches have been found in the visual inspections carried out for either of the two meters during the almost eighteen months of operation.

7 Recertification after each six months of operation

The dimensional recertification after six and twelve months of operation showed identical results to the original certification, within the dimensional determination tolerence. There was no clear trend indicating increasing or decreasing dimensions.

The recertification of the discharge coefficient was carried out by NMI immediately after the six and twelve months dimensional recertification. The coefficient of discharge curvefit with Reynoldsnumber are within a band of +/- 0.5 % for all calibrations and tests at different pressures for each V-Cone meter, with the exception of where differential pressure uncertainty contribution take the data points outside this band for lower differential pressures. It became apparent that data points below 20 milliBar reading require a very strict procedure to be of any value in the calibration for the coefficient at discharge. In the recertification after twelve months, NMI adjusted their procedure ; at each flowrate datapoint the differential pressure static pressure zero offset was recorded and corrected for. Phillips brought in a special calibrated smart transmitter with digital readout, and confirmed the official corrected differential pressure used by NMI. The low differential pressure data points were , almost without exception , inside the +/- 0.5 % band for the discharge coefficient. The comparison between all tests and calibration points for the 3" and 4" V-Cone meters at Embla is shown in Attachment C and Attachment D respectively.

8 Recommendation for further work to standardize V-Cone meter

Presently the equation for expansibility is based on data from a limited number of V-Cone meters. Before using the equation developed for traceable calibration , it must be confirmed for each individual V-Cone meter: Verify that the discharge coefficient determined at low static pressure and high differential pressure to pressure ratio, is within tolerence from the discharge coefficient determined at the same Reynoldsnumber with high static pressure and low differential pressure to pressure ratio. An international data bank with this type of data is required to give the best fit $C_{\varepsilon 1}$ *and* $C_{\varepsilon 2}$ *factors in the expansibility equation.*

No direct comparison of different pipewall roughness effect is performed. Further work is needed in this area. Untill this is done, the pipe wall should be smooth in the minimum flowing area passage by the V-Cone outer edge.

*High accuracy calibration and research data is only available in a limited &ratio range from 0.65 to 0.75 , and in a limited size range. **For ß-ratio** required outside this range, the V-Cone meter performance should be reaffirmed. Obviously, with millimeter distance between V-Cone and pipe-wall, the V-Cone meter tolerence to wet gas effects will be low.*

9 *Conclusions*

*V-Cone meters selected with proper distance between V-Cone and pipewall and with V-Cone large enough to suppress the bluff body effects from the V-Cone holder, for a verified Reynoldsnumber range, and inside a verified **ß-ratio** range, the V-Cone meter can be bener than Orifice meter for gas service, providing that the flow coefficient is determined thru third party calibration with gas. In particular the V-Cone meter will be superior in wet gas service and in service with high kickoff flowrates.*

References

Pipe elbow effects on the V-Cone flowmeter
North Sea Flow Measurement Workshop , Peebles 1992
*S A **Ifft** and E D Mikkelsen , McCrometer*

V-Cone video
McCrometer

Erfaringer med V-Cone tiler
*Akkreditering, Flerfasenuiling og Forenklet **måling** i Olje og Gass-industrien , Stavanger 1994*
*M J **Dahlstrøm**, Phillips Petroleum*

Acknowledgement

K-Lab; their stamina in verification of the V-Cone meter characteristics made possible to develop methods for accurate calibration of the V-Cone meter without recreating the identical operating conditions.

MEASUREMENT OF "V-CONE"

METER MODEL : "V-CONE", Size 3"

METER SERIAL NO : 92012003

CLIENT : Phillips Petroleum Co.N.

MEASURED BY : John Eide, Con-Tech a/s

MEASURED DATE : June 15, 1994.

A and B = Diameter at weld
C = Diameter upstream of cone
D = Diameter downstream of cone
E = Diameter of cone

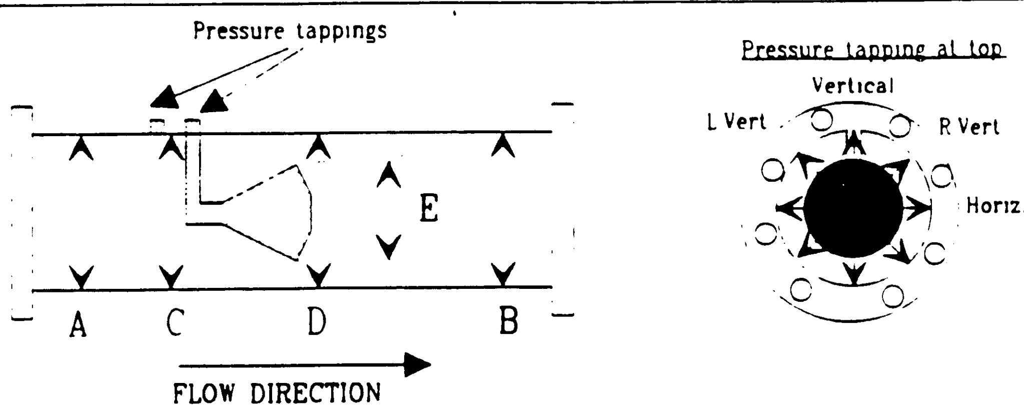
Measurements done at 20,0 deg.C

Radius cone edge = 0,200 mm

Readings	**Pos A**	**Pos B**	**Pos C**	**Pos D**	**Pos E**
Vertical	77,320	77,300	78,136	78,635	59,55
L.Vert.	77,180	77,400	78,433	78,566	59,49
R.Vert.	77,400	77,590	78,471	78,510	59,60
Horiz.	77,200	77,290	78,705	78,423	59,53
Avg.diam.	**77,275mm**	**77,395mm**	**78,436mm**	**78,534mm**	**59,54mm**

Measurement uncertainty: Position A - D = +/- 0,002 mm & Position E = +/- 0,04 mm

Measurements refers to gauge blocks traceable to national standards



V-Cone Flow Calculations, Based On ISO 5167-1

$$D_R = D_{R,CAL} \, (1 + E_{xR} (T_L - 20))$$

$$d_C = d_{C,CAL} \, (1 + E_{xC} (T_L - 20))$$

$D_{R,CAL}$ *Calibrated pipe internal diameter at downstream cone tap; mm 20°C*

$d_{C,CAL}$ *Calibrated cone diameter at the downstream bevel start; mm , 20°C*

E_{xR} *Metal width dimensional expansion factor for the pipe; per °C .*

E_{xC} *Metal width dimensional expansion factor for the cone; per °C .*

T_L *Measured line temperature , °C*

The discharge coefficient C_d , to be determined from calibration and curvefit for C_1 and C_2:

$$C_d = C_1 - C_2 * (10^6 / Re)^{0.75}$$

Note that the exponent is presently fixed to 0.75 from experience in the Reynoldsnumber range 1,000,000 to 10,000,000 .

$$\beta = (D_R^2 - d_C^2)^{0.5} / D_R$$

Expansion factor:

$$\varepsilon = 1 - (C_{\varepsilon 1} + C_{\varepsilon 2} * \beta^4) * X / 1300$$

$$X = (1.3 * \Delta P) / (K * P1)$$

Present : $C_{\varepsilon 1} = 0.60$, $C_{\varepsilon 2} = 0.75$

ΔP *Differential pressure in mBar*
$P1$ *Upstream pressure in BarA*
K *Isentropic exponent*

Reynolds number:

$$Re = \frac{4 * 10^6}{\pi} \frac{qm}{D_R * \mu}$$

qm *Massflow in Kg/sec*

μ *Dynamic viscosity in CentiPoise*

Massflow in Kg/sec :

$$qm = C_{ONST} * C_d * (1 - \beta^4)^{-0.5} * \varepsilon * (D_R^2 - d_C^2) * (\Delta P * \rho)^{0.5}$$

$$C_{ONST} = 10^{-5} * (\pi/4) * \sqrt{2} = 1.110720734 * 10^{-5}$$

ρ *Density in* Kg/m^3 .

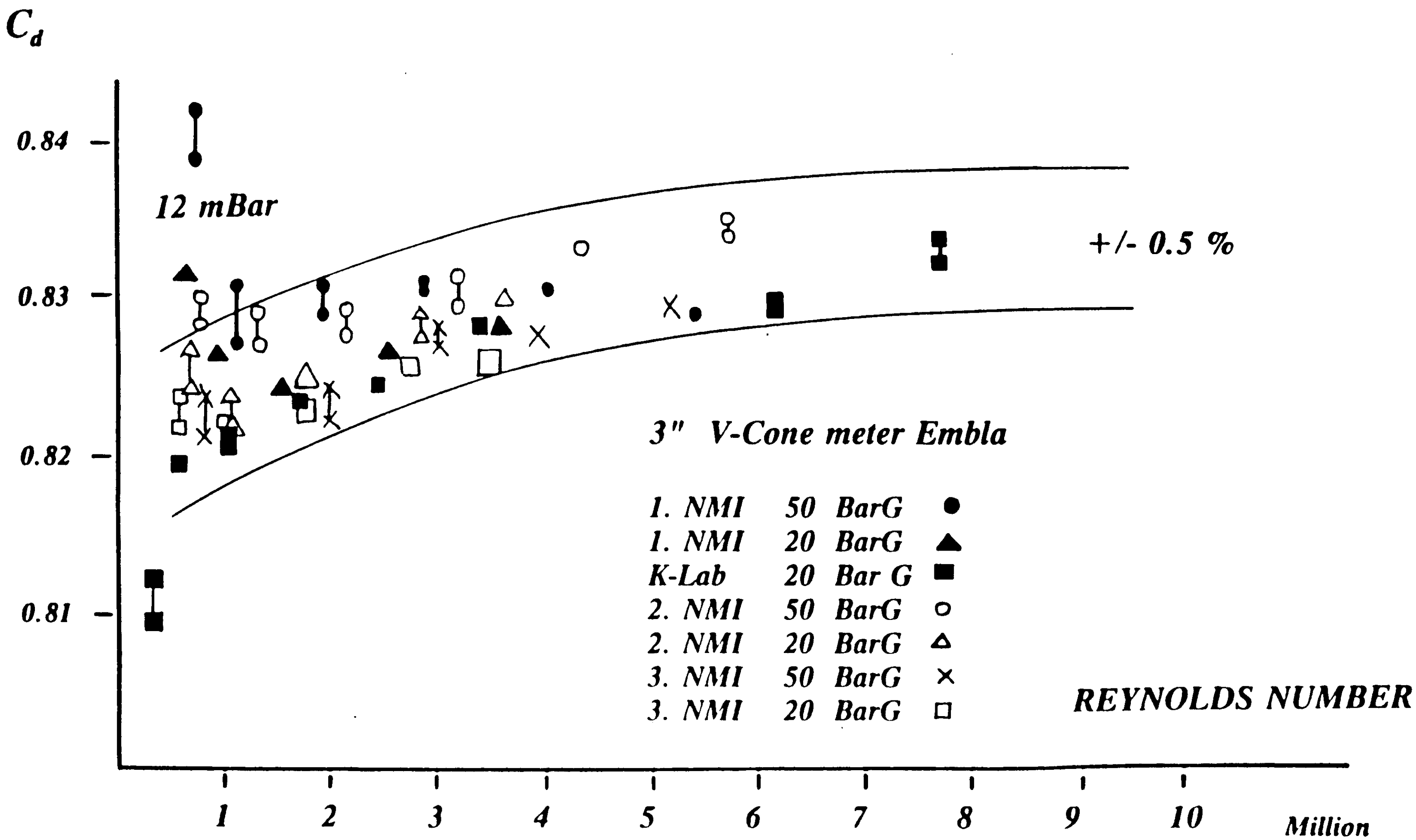
LEAST SQUARE CURVEFIT FOR C_d CONSTANTS C_1 & C_2

For points where ΔP accuracy is better than 0.3 % (Recommended above 20 mBar , except where sufficient accuracy can be verified; as for Smart Transmitters with direct digital reading where 10 mBar is realistic).

$$C_1 \Sigma (1) - C_2 \Sigma \left(\frac{10^6}{Re}\right)^{0.75} = \Sigma (\underline{C_d})$$

$$C_1 \Sigma \left(\frac{10^6}{Re}\right)^{0.75} - C_2 \Sigma \left(\frac{10^6}{Re}\right)^{1.5} = \Sigma \left(\underline{C_d} * \left(\frac{10^6}{Re}\right)^{0.75}\right)$$

However if C_2 is found to be < 0 ; then $C_2 = 0$, and $C_1 = 1/n \Sigma (\underline{C_d})$
$\underline{C_d}$ is the average C_d in one Reynoldsnumber calibration point.



Attachment C

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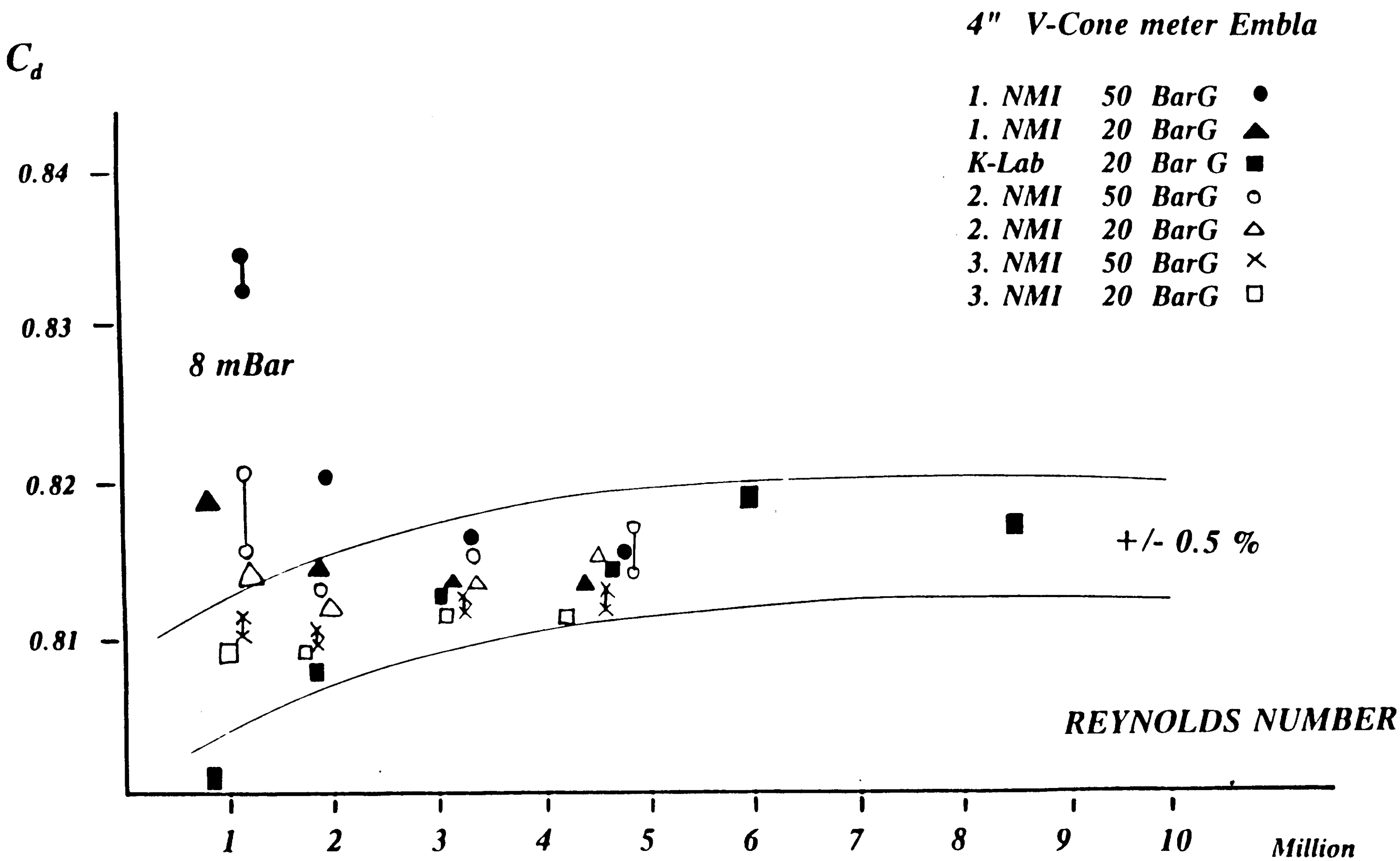

Attachment D