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K-LAB: A LABORATORY FOR IMPROVING GAS FLOW METERING ACCURACY

PRESENTED AT

NORTH SEA FLOW METERING WORKSHOP

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1. INTRODUCTION

K-LAB or Kårstø Metering and Technology Laboratory is a natural gas test facility being built close to the gas processing terminal at Kårstø which Statoil operates on behalf of the Statpipe group.

K-LAB is a Joint Venture project between Statoil and Total Marine Norsk whose main purpose is to provide a calibration and proving stand for gas flow meters and components where field conditions can be obtained.

The petroleum industry has a considerable economic interest in using accurate methods for measuring the large quantities of gas which are transported between producer and consumer.

The most commonly used method for metering large gas flows makes use of the orifice meter. In international trade this method is implemented according to an international standard, ISO-5167. Other orifice meter standards are the British standard BS 1042, the American standard AGA-3 and the German standard DIN 1952. Methods based on other metering equipment are currently being discussed.

There are strong indications for a systematic underprediction of the flow rates in commercial standard orifice gas flow meters and it is of primary importance to have full understanding and knowledge of the limitations in the systems which are currently used.

In order to influence the development of the gas metering technology it is necessary to operate an advanced experimental facility for testing, calibration and development of large scale gas meters.

The most obvious economic incentive for such a facility is the potential of reducing the anticipated systematic errors in the current orifice metering method, to test components and develop/calibrate new instruments.

2. BACKGROUND

2.1 The problem of accurate custody transfer metering

To calculate the mass flow rate through an orifice meter the following parameters must be known:

- the geometrical dimensions of the meter pipe and orifice,
- the differential pressure over a set of standard pressure tappings,
- the density of the fluid in the plane of the upstream pressure tapping,
- the meter discharge coefficient.

If the energy content of the gas is the basis for custody transfer one also needs to determine:

- the calorific value of the gas.

The uncertainties of all the above parameters must be controlled simultaneously to achieve the lowest possible overall uncertainty. Using the best of current technology the uncertainty of the discharge coefficient is the dominating one when mass flow is concerned. Parallel to the flow laboratory research, efforts in the field of calorimetry and densitometry must be emphasised to assure the best possible overall accuracy.

2.2 Current status on orifice gas metering

In February 1980 a new international standard for orifice plate metering, ISO-5167, was issued as a revision of the previous ISO-541. The ISO-5167 standard contains a new correlation formula for the discharge coefficient. The standard gives the uncertainty of the discharge coefficient to be equal to ± 0,6% when the diameter ratio is less than 0,6 and equal to the numerical value of the diameter ratio when the diameter ratio is between 0,6 and 0,75. See ref./1/ for more details.

According to the plans of ISO/ TC30 (Technical Committee dealing with differential pressure devices) which are a change of the ISO-5167 revision, an updated version will be available within 2 to 4 years. The modifications which will be sent to hearings concern certain requirements on plate installation, some minor changes in the Stolz equation, and changes due to experience obtained since 1980. In addition a Code of Practice for ISO-5167 will be edited probably in 2 years. This is a handbook which will provide the users with practical information on how to use the standard. In the USA a similar revision of AGA-3 is nearly completed and will go public in the next two years.

2.3 Intercomparison between ISO-5167 and AGA-3

A comprehensive study comparing the standards with new experiments has been carried out by Miller in 1979, ref. /2/. In this report ISO-5167 and AGA equations with new flange tapped orifice meter calibration data from the Foxboro laboratory are compared.

2.3.1 Analysed data

The orifice meter runs were commercially available flange tapped meter runs fabricated to AGA specifications.

The data analysis were made on the full dataset (Group 1) and on two subsets (Group 2 and Group 3) defined as shown in table 1.

2.3.2 Results of Miller's analysis

Miller's analysis gave the results presented in table 2 as regards the systematic error and equation efficiency (the random error obtained if the systematic error had been corrected for) for both the AGA and the ISO-5167 equations and the three data groups.

It was observed that both the AGA equation and the ISO-5167 equation systematically underestimated the flow in the Foxboro laboratory. For the full dataset compared with the ISO-5167 the systematic error was estimated to +0,49%. Around this value the group 1 data were scattered within ±1,13% with 95% confidence.

The data of Miller also show two orifice meters of the same size having systematic errors differing with as much as 0,5%.

2.3.3 Conclusions

For all three data groups there is a positive systematic error for both equations. The systematic error for the ISO-5167 equation being less than the systematic error for the AGA equation.

Having in mind that the accuracy of the calibrations is equal to or better than ±0,15% there must be some design parameters not properly defined in the standard with the consequence that permitted variations of design parameters contribute to the wide scatter of the measurements. If this hypothesis is correct it should be possible to determine design parameter values which result in small systematic errors. Another possibility is that the calibrated meters for some reason did not comply with the standards.

These results do not add confidence to the stated accuracy of ISO-5167. It should, however, be mentioned that the Foxboro calibration tests do not conform to ISO-5167 regarding the installation of the flow straightener. Miller describes the distance between the flow straightener and the primary device to be a minimum of 20 diameters not 22 diameters as required by ISO-5167. Miller does not give information enough to judge whether the sections upstream of the flow straightener do conform to ISO-5167.

It must be a problem for the users of ISO-5167 that well known flow calibration laboratories obtain results as presented above when using commercially available orifice meter runs fabricated according to the existing standards. From the above data it seems to be room for significant improvements in the orifice meter standard. The efforts should primarily be directed towards reducing the systematic error component of the uncertainty.

2.4 Other views

In the open literature there is little information available for assessing the validity of the ISO-5167 standard. The referenced paper of Miller is the most comprehensive comparison between new experiments and the standard.

A meter calibration intercomparison campaign is going on between flow laboratories in the EC. Data have been produced and some of these were recently presented at a conference /3/. In the USA several laboratories are carrying out tests similar to the ones obtained in Europe. These results will serve as new data base for future revision of US standards. The main laboratories involved are National Bureau of Standards in

Gaithersburg and Boulder, Natural Gas Pipeline Company of America, Colorado Engineering and Experimental Station.

2.5 Degradation of standard installations

An orifice meter designed according to ISO-5167 has a precisely defined geometry. For various reasons the geometry of the meter may be modified during operation:

- Flow transients may buckle the orifice plate.
- Extraordinary operating conditions may result in accumulation of liquids in the pipe upstream of the orifice plate.
- Dirt may accumulate on the meter tube walls and on the orifice plate itself.
- The sharp upstream edge of the orifice plate may be rounded by erosion.

The surface roughness of both the meter tube and the orifice plate may be increased beyond the limits specified by the standard. The surface roughness may be increased by dirt in the gas attaching to the surfaces. Also erosion or corrosion may influence the surface roughness.

An important installation parameter is the eccentricity of the orifice bore relative to the meter tube bore. There are very strict limitations to the maximum allowed eccentricity. The eccentricity can be measured when the meter is installed for the first time. However, during normal maintenance it is difficult to measure the eccentricity, and in practice it is not measured at all.

The errors observed when standard metering installations are degraded have proved to almost always underpredict the actual flow, see ref. /4/. Errors due to non standard conditions will not cancel each other, they will all contribute to a measurement bias. Central to measurement accuracy is, therefore, assuring standard measurement conditions throughout the whole life of a metering station.

When discussing the measurement standard the principal question is: What were the conditions during the fundamental experiments generating the data base on which the current discharge coefficient equation is based. These conditions should be the basis of the standard conditions. The documentation of the original experiments shows an awareness of the problems, but the original installation parameters (e.g. edge sharpness, orifice eccentricity and surface roughness) were not quantified. One also regrets that the actual meter runs have been lost. The possibility therefor exist that todays standard does not cover the original conditions properly. This is an important argument for new experiments.

The tendency of creating a measurement bias emphasises the need of close inspection and control. A test of full scale meter runs will make it possible to identify necessary modifications to the existing maintenance procedures.

3. THE PURPOSE OF THE EXPERIMENTAL GAS TEST FACILITY

Generally the purpose of the Kårstø Metering and Technology Laboratory is to have the opportunity to create large gas flows, measure them very accurately and have the ability, in a flexible test section, to insert all kinds of test objects. With this facility it will be possible to check and ensure application of optimal equipment and methods for sales operations. With the large gas production in the North Sea small measurement errors have significant economic consequences.

3.1 Influence on new international standards

Research and development efforts in the field of gas flow measurements have increased considerably over the last years. A number of projects have been initiated by ISO and by institutions within EC. Still experiments are performed on a scale well below what is experienced in todays commercial gas metering stations.

K-LAB will give an important supplement to already existing experimental facilities and an active and constructive role in ISO and its committees dealing with metering standards is foreseen. Data obtained in K-LAB may be included in revisions of the relevant standards.

3.2 Influence on metering station design

There are two approaches to the improvement of metering station design. One is to improve the design of the existing meter and the other is to use another type of meter. Both ways have a considerable potential for metering improvement.

As discussed in section 2.3.3 there are reasons to believe that variation of design parameters within the orifice meter standard creates the relatively wide distribution of calibration points observed by Miller. With the test facility, as it is proposed it is possible to examine the influence of different design parameters on the orifice meter discharge coefficient. Such information will make it possible to avoid design requirements generating systematic losses. The experiments in such a program will have the objective to define those parameter ranges within the standard that do not generate a measuring bias.

The process of modifying an international standard lasts several years. If new experiments in the test facility confirm for instance the Miller results, a more rapid correction of the systematic error may be obtained if a meter requiring individual calibration is used instead of waiting for revision of the relevant international standard. It implies however that all parties involved agree on the type of meter to be used. Today the turbine gas flow meter, which is employed instead of the orifice meter in many installations, is a realistic alternative. An international standard of the turbine gas flow meter is in the process of being developed.

3.3 Examination of the effect of degrading standard conditions

During operation many parameters important to the metering accuracy will experience a shift due to new operating conditions, wearing effects or sudden changes due to measuring equipment parts. This problem is an extension of the one presented in the previous section and much of the information gathered for one task will also serve the other.

The phenomena that should be monitored closely during operation are:

- Non-standard orifice plate geometry (bending, erosion, corrosion, eccentricity, edge sharpness, dirt accumulation etc.)
- Liquid holdup in front of the orifice
- Flow pulsations
- Swirling flow generated by upstream pipe fittings (bends, tees, valves, manifolds etc.)
- Effects of flow straighteners

In addition a very careful maintenance of the secondary instrumentation must be ensured.

Even small disturbances of the above mentioned types create serious measurement errors. During acute operational situations the disturbances may create measurement bias. Situations like this must be detected rapidly.

3.4 Examination of installation effects

From study of the required straight pipe lengths to various upstream fittings for a given discharge coefficient accuracy poor agreement is found between the ISO-5167 and the AGA standard. From the technical debate within ISO it is evident that this is a real disagreement not only a matter of standard revision. These aspects of the standard are still developing.

It is also known that unexpected flow instabilities may arise in a metering system when the flow is varied through the various legs of a manifold. Experiments should be aimed at testing the metering systems (and possibly also other systems) in advance in the test facility to ensure proper flow conditions.

3.5 Development and testing of new metering methods

The orifice meter is a robust and accepted standardised gas meter. However, compared to many other flow meters it also has inferior operating characteristics. Especially the orifice meter has a 3:1 rangeability while the turbine meter rangeability is between 30:1 and 40:1 depending on size and pressure. The vortex flowmeter rangeability is between 10:1 and 20:1. For all gas meters of differential pressure type the flow measurement uncertainty will increase with reduced differential pressure (reduced flow). In practice these problems may be partly circumvented. Interesting is also that the pressure loss of many new meters is much less than with orifice meters.

Important scientific and technical progress can be expected in the coming years in the field of developing new standardised gas flow meters. Improvements and extensions of methods based on the orifice-, turbine- and vortex principles as well as sonic nozzles represent important topics for research and development. In addition there is a considerable potential in less developed methods which do not disturb the flow field. Such methods include ultrasonic and laser based Doppler techniques and radioactive tracer techniques.

New, improved equipment will be accepted for commercial operation more rapidly if large scale tests in the K-LAB demonstrate the equipment performance without the risk of expensive production breaks.

4. REVIEW OF LARGE GAS TEST FACILITIES

All major gas consumer/producer countries operate gas flow test facilities either within national/university research centres or within gas companies (Gasunie, Gas de France, Ruhrgas, British Gas Corporation). A review of the major facilities in Europe is given in table 3 where also main characteristics are indicated.

When high flowrates are concerned the reference flowmeter is never calibrated directly against weight or volume. The reference meter is generally coupled in series with a set of parallel meters each one calibrated against fundamental quantities or against other meters. In this way a calibration chain is established making a high flowrate measurement traceable to fundamental standards of weight and measures. Central to the concept of accuracy is the traceability of the measurements to basic units by means of a chain of transfer standards. The concepts of traceability, calibration chain and accuracy are important for understanding the special features of K-LAB.

Increasing the number of transfer steps will increase the calibration uncertainty. Uncertainties are also introduced when theoretical extrapolations are made to adapt the calibrated meter for use with other gases and at higher pressures than calibrated for.

The reference flowmeter installed in the test facilities of table 3 are summarised in table 4.

At National Engineering Laboratory (NEL) sonic nozzles can be primary calibrated by a gravimetric method similar to the on described in section 5.1. The primary calibration uses air at a maximum pressure of 50 bar. The sonic nozzle can be used as a transfer standard and the process of calibrating another meter using the sonic nozzle as transfer standard is called a secondary calibration. The flow medium of the secondary calibration may be different from the primary calibration flow medium and corrections for another flow medium must be included in the secondary calibration; corrections which introduce additional uncertainties. In addition to another flow medium the operating pressure may be different introducing other corrections. The chain of transfer standards is often longer than in the case above. In those cases the secondary standard is used to calibrate an other meter and so on.

In the test facility operated by British Gas Corporation at Bishop Auckland turbine meters is used as reference meters. These turbines are calibrated against sonic nozzles originally primary calibrated at NEL. Corrections for different flowmedia at NEL and Bishop Auckland must be introduced.

The largest test facility operated by Gaz de France (GdF) is equipped with a reference meter consisting of a battery of 7 sonic nozzles. Each of these are calibrated in a smaller test loop where the reference meter has been primary calibrated according to a volumetric method.

The reference flow meter at the Poitiers test facility consists of 12 sonic nozzles calibrated at the GdF test station. Some of the nozzles are primary calibrated and the largest are secondary calibrated.

The reference flow metre installed in the Lintorf facility, owned by Ruhrgas, consists of 5 orifice meters individually calibrated with water.

Gasunie uses turbine meters traceable via a series of transfer steps to a 3,5 m^3 bell prover at the Dutch Service of Weights and Measure.

For further details on the calibration methods see ref./5/.

Compared with the listed facilities the K-LAB will be unique regarding maximum operating pressure and the obtainable accuracy. Remarkable is that there is only one transfer standard between calibration at high pressure and large flow rates and basic weight measurements. In addition, the flow medium and pressure is the same in both the primary and the secondary calibration. This ensures the excellent accuracy of the facility.

5. DESCRIPTION OF THE KARSTØ METERING AND TECHNOLOGY LABORATORY

5.1 Test loop

A flow diagram and a general view of the K-LAB are shown in figure 1 and figure 2 respectively. The operating conditions and main specifications are given in table 5.

The gas which is supplied from the Statpipe terminal is circulated by means of a centrifugal compressor, Q1, through a heat exchanger, E1, into a reference flow meter consisting of 8 parallel sonic nozzles, where 6 have 15% of full flow capacity and 2 have 5% of full flow capacity, enabling the flow to be varied in steps of 5% of full flow. Thereafter the gas flows into one of the branches of the test section, then back to the compressor.

The test facility is equipped with a primary calibration system. This system guarantees traceability of the gas flow metering system with only one transfer standard step. The primary calibration system is operated in a line parallel to the reference flow meter, It consists of a diverter valve, V1, and a weighing tank, T1. The nozzle to be calibrated is mounted in the primary calibration system. The reference flow meter is shut off and the flow is directed through the primary calibration system. Maintaining critical conditions in the nozzle the flow is diverted by a high speed diverter valve into an empty weighing tank, T1. The diverter valve is operated back to bypass mode at an appropriate time. The time and increased mass of the weighing tank is measured giving the mass flow rate through the nozzle. The property of sonic nozzles that make them suitable for this type of application is that the mass flow only depends on the conditions upstream of the nozzle as long as sonic conditions prevail.

The test section comprises a 24" pipe, a 12" pipe, a 8" pipe and a 4" pipe which consist of flange connected pipe sections of standard lengths. The 24" pipe is designed to be both an on site gas backup tank and an installation where it is possible to examine the performance of large gas flow meters. The configuration can be modified when required, depending on the different experimental programs to be carried out.

Particles larger than 3 microns are removed from the gas in a filter, C1, just before the gas enters the main compressor and starts a new cycle in the loop.

The gas is supplied from the terminal at a maximum rate of 3kg/s. When the required loop pressure exceeds the terminal gas pressure, a booster compressor, Q2, is used to increase the pressure.

5.2 Obtainable flow conditions

The volume flow rate through critical flow venturi nozzles is almost constant for all operating pressures. The range of the volume flow rates of the reference flow meter (RFM) is between 0,05 m^3/s and 1,0 m^3/s in steps of 0,05 m^3/s (referred to conditions upstream of nozzles). The operating pressure in the test section may be varied continuously between 140 bar and 35 bar, thus enabling a continuous range of mass flow rates between 130 kg/s and 1,5 kg/s.

The obtainable pipe Reynolds number in the 12" test section is $3,2 \cdot 10^7$. It is determined by the maximum mass low rate and the pipe diameter and may in addition be limited by the flow conditions in the test section (e.g. pressure loss or test object limitations).

The obtainable Reynolds numbers are well above the Reynolds numbers of the tests forming the basis of the ISO.5167 standard or orifice meters. This is shown in figure 4. The basic tests were performed at Ohio State University in the 1930ies. The Gasunie tests that were used by the International Standardisation Organisation to verify extrapolation of the discharge coefficient correlation to Reynolds number as high as 10^{O} are also shown. These experiments were performed at normal transmission line pressure in the Netherlands and the reference meter consisted of three parallel orifice meters operated according to the standard.

5.3 Obtainable accuracies

The sonic venturi nozzle is a very reliable and accurate gas metering device. A reference metering system similar to the one used in the K-LAB is used by Gas de France in its test rig in Alfortville, by Bureau National de Metrologie in its installation in Poitiers and by British Gas Corporation in its Bishop Auckland facility.

The present calibration and reference meter system is designed to an accuracy better than ± 0,25%.

In the following an orifice meter discharge coefficient uncertainty calibration is used as an example for discussion. The discharge coefficient has been estimated for a RFM consisting of precalibrated nozzles or nozzles calibrated in the first loop. The result is shown i figure 4.

With precalibrated nozzles the estimated uncertainty of the orifice discharge coefficient shows a significant variation both with the volume flow rate and the pressure. The uncertainty varies between 0,7% and 0,49%. The reduction of the uncertainty due to flow rate is mainly due to the increased number of independent measurements while the dependence on the pressure is due to corrections for the gas properties at elevated pressure. The curve for 140 bar in uncertain due to extrapolation of data for the sonic nozzle critical flow factor.

With nozzles calibrated in the K-LAB calibration rig the estimated uncertainty of the orifice discharge coefficient is considerably smaller than if precalibrated nozzles are used. This is because the primary calibration eliminates the need for determination of several uncertain parameters (dimension and gas properties). The variation of the orifice discharge coefficient calibration uncertainty with volume flow rate is due to the same effect as in the case with precalibrated nozzles. For illustration, the uncertainty of discharge coefficients of uncalibrated orifices according to ISO-5167 is also indicated in figure 4.

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	Group 1	Group 2	Group 3
Min. diameter *)	2.067	3.853	3.853
Max. diameter *)	23.23	23.23	19.49
Min. dia. ratio	0.25	0.25	0.25
Max. dia. ratio	.7499	.7499	.7000
No. of orifices	28	26	18
No. of datapts.	422	395	288

*) Unit is inches.

TABLE 1. Grouping of Foxboro orifice data.

	Group 1	Group 2	Group 3
Systematic error AGA equation	+0.65%	+0.54%	+0.33%
Systematic error ISO-5167 equation	+0.49%	+0.36%	+0.25%
AGA equation efficiency	±1.18%	±0.87%	±0.55%
ISO-5167 equation efficiency	±1.13%	±0.62%	±0.49%

TABLE 2. Result of comparison between Foxboro calibrations and AGA and ISO-5167 equations.

Country/operator/location	Medium	Oper.pressure (bar)	Max. flow (m^{3}o/h)	Max. pipe Reynolds num.	Claimed accuracy (%)	Reference standards	Comments
FRANCE							
Gaz de France, Alfortville	Gas	5 - 50	$6 \cdot 10^4$		± 0.3	Sonic nozzl.	In operation
Bureau National de Metrologie/ Ceat, Poitiers	Air	3 - 50 (70)	$1.5 \cdot 10^5$	$1.5 \cdot 10^7$	± 0.3	Sonic nozzl.	In operation mid. 1982 Blow down
W.GERMANY							
Ruhrgas, Lintorf	Gas	8 - 60	$1.2 \cdot 10^5$	$1.5 \cdot 10^7$	± 0.24	Orifice plate calibrated with water	In operation
THE NETHERLANDS							
Gasunie, Bergum	Gas	8 - 60	$1.4 \cdot 10^5$		± 0.3	Turbine flowmeter	In operation
Westerbork	Gas	40 - 60	$2.5 \cdot 10^6$	$>3 \cdot 10^7$	± 0.2		In operation
NORWAY							
Kårstø	Gas	35 - 140	$5.5 \cdot 10^5$	$3.2 \cdot 10^7$	± 0.18 - 0.26	Sonic nozzl.	In operation mid. 1986
UNITED KINGDOM							
B.G.C. Low Thornley	Gas	11 - 56	$1.7 \cdot 10^5$		± 0.5		In operation
Bishop Auckland	Gas	60	$1.4 \cdot 10^6$			Sonic nozzl.	In operation mid. 1982
NEL, East Kilbride	Air	2 - 50	$1.5 \cdot 10^4$	$1.5 \cdot 10^6$	± 0.3	Sonic nozzl.	In operation Blow down

Table 3. Major european experimental gas test facilities

Test section	Reference flowmeter	Transfer standard	Primary Calibration
GDF. Alfortville	7 sonic nozzles 5 - 50 bar	Sonic nozzles (Gas)	Volumetry (Gas)
BNM, Poitiers	12 sonic nozzles 5 - 50 bar	Sonic nozzles GDF (Gas)	Volumetry (Gas)
RUHRGAS, Lintorf	5 orifice plates 8 - 60 bar		Gravimetry (Water)
GASUNIE, Westerbork	10 turbine flowmeters, 40-60 bar	Turbine flowmeter (Gas)	Gravimetry (Water)
KARSTØ	8 sonic nozzles 40-140 bar	none	Gravimetry (Gas)
BGC, Bishop Auckland	Sonic nozzles 60 bar	Sonic nozzles	Gravimetry (NEL)
NEL	Sonic nozzles 2 - 50 bar		Gravimetry (Air)

GDF : Gaz de France
BNM : Bureau National de Métrologie
BGC : British Gas Corporation
NEL : National Engineering Laboratory

TABLE 4. REFERENCE FLOWMETERS AND TRANSFER STANDARDS WITH METHODS OF PRIMARY CALIBRATION FOR MAJOR FLOW FACILITIES.

MAIN SPECIFICATIONS

* Maximum operating pressure: 140 - 155 bar

* Maximum mass flow: 130 kg/s

* Maximum volume flow: 1 m^3/s

* Operating temperature: ApproX. 35°C

* Diameter test section: 4" - 8" - 12" - 24"

* Straight pipe lengths: 500D - 250D - 170D - 110D

* Total gas volume: Aprox. 120 m^3

Table 5. Main operating conditions and specifications

Q1: Main compressor
4.8 MW ; 50 ton
1m /s

E1: Heat exchanger
5 MW ; 8ton

T1: Weighing tank
3.5m ; 10ton

C1/C2: Particle filters
C3: Oil filter
V1: Diverter valves

Q2: Booster compressor
70 KW ; 0.5ton

q_v = 1-0.05m /s
q_m = 130 kg/s-1.5kg/s

P_{des} = 172bar
$P_{max. test sect.}$ = 156bar

F: Feed drum
P = 220bar

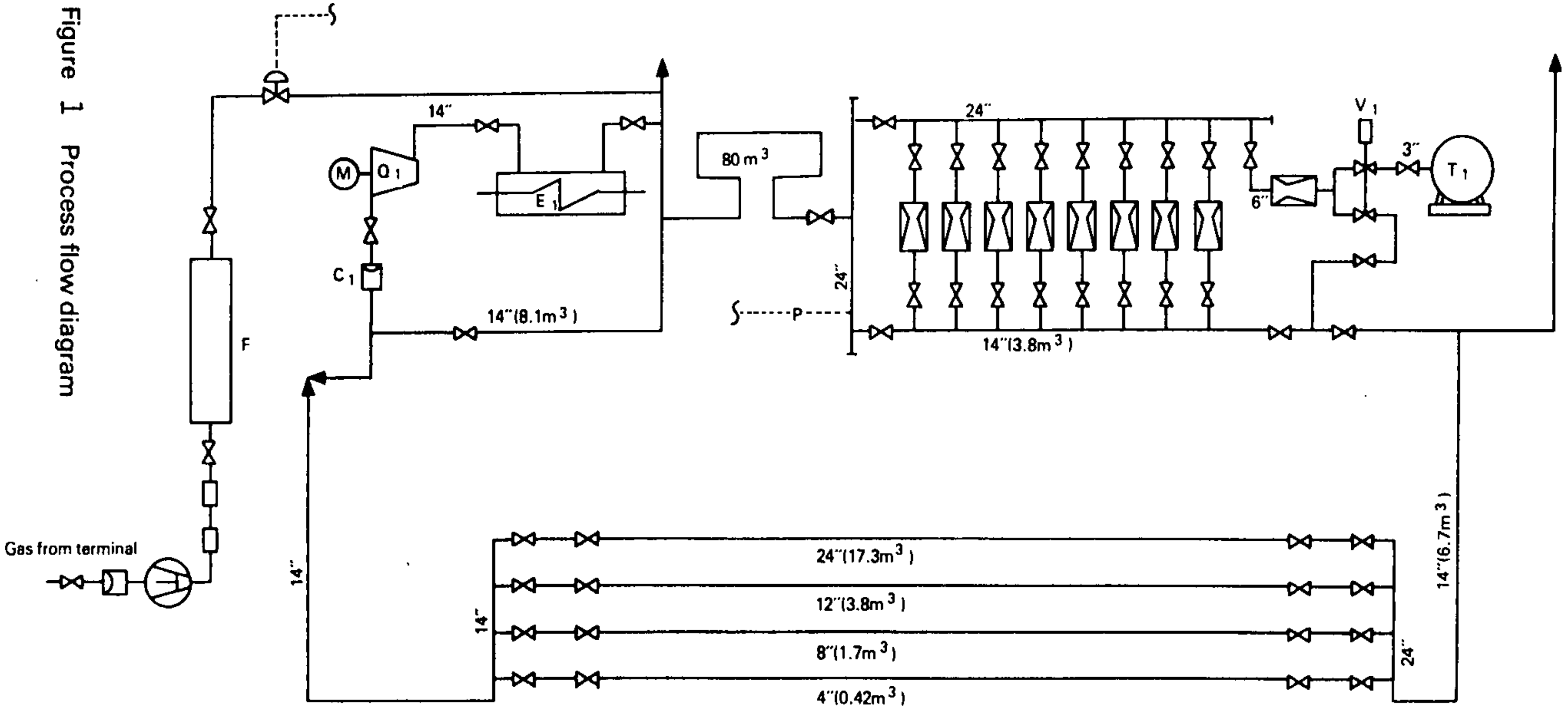

Figure 1 Process flow diagram

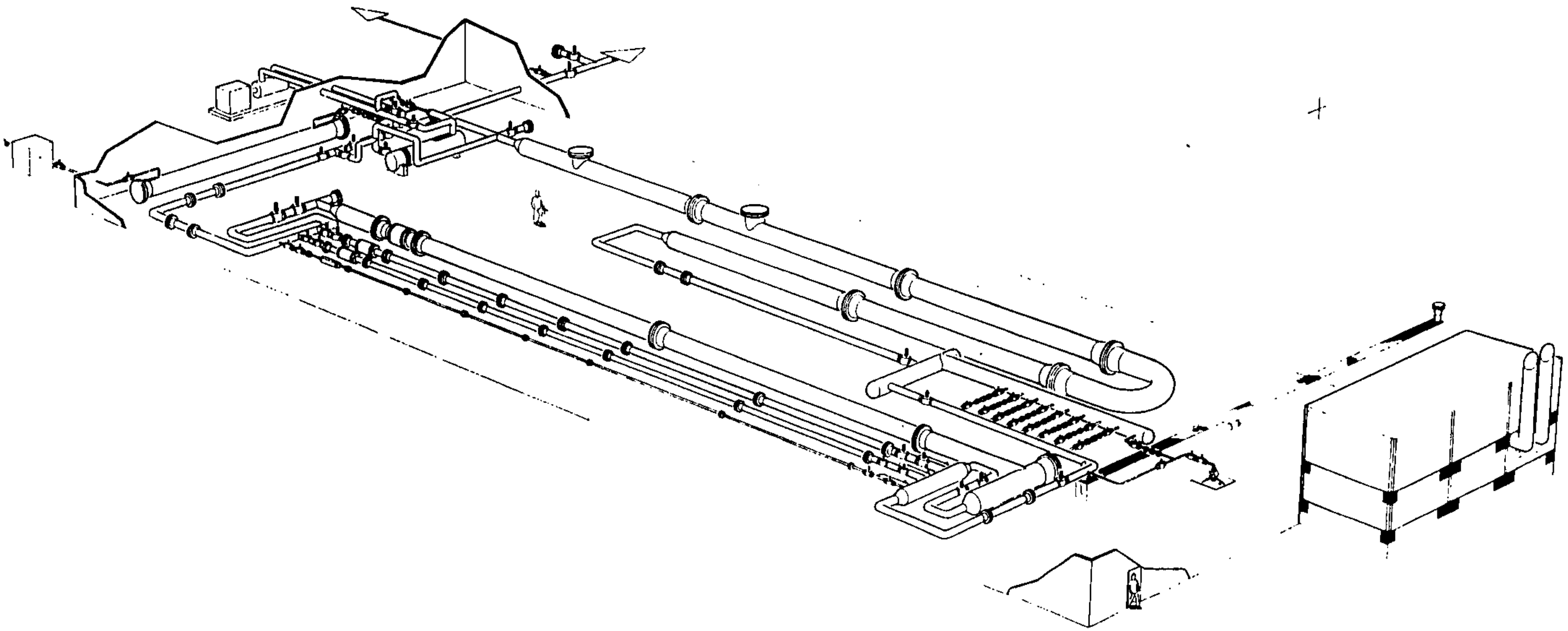

FIGURE 2. FLOW LOOP

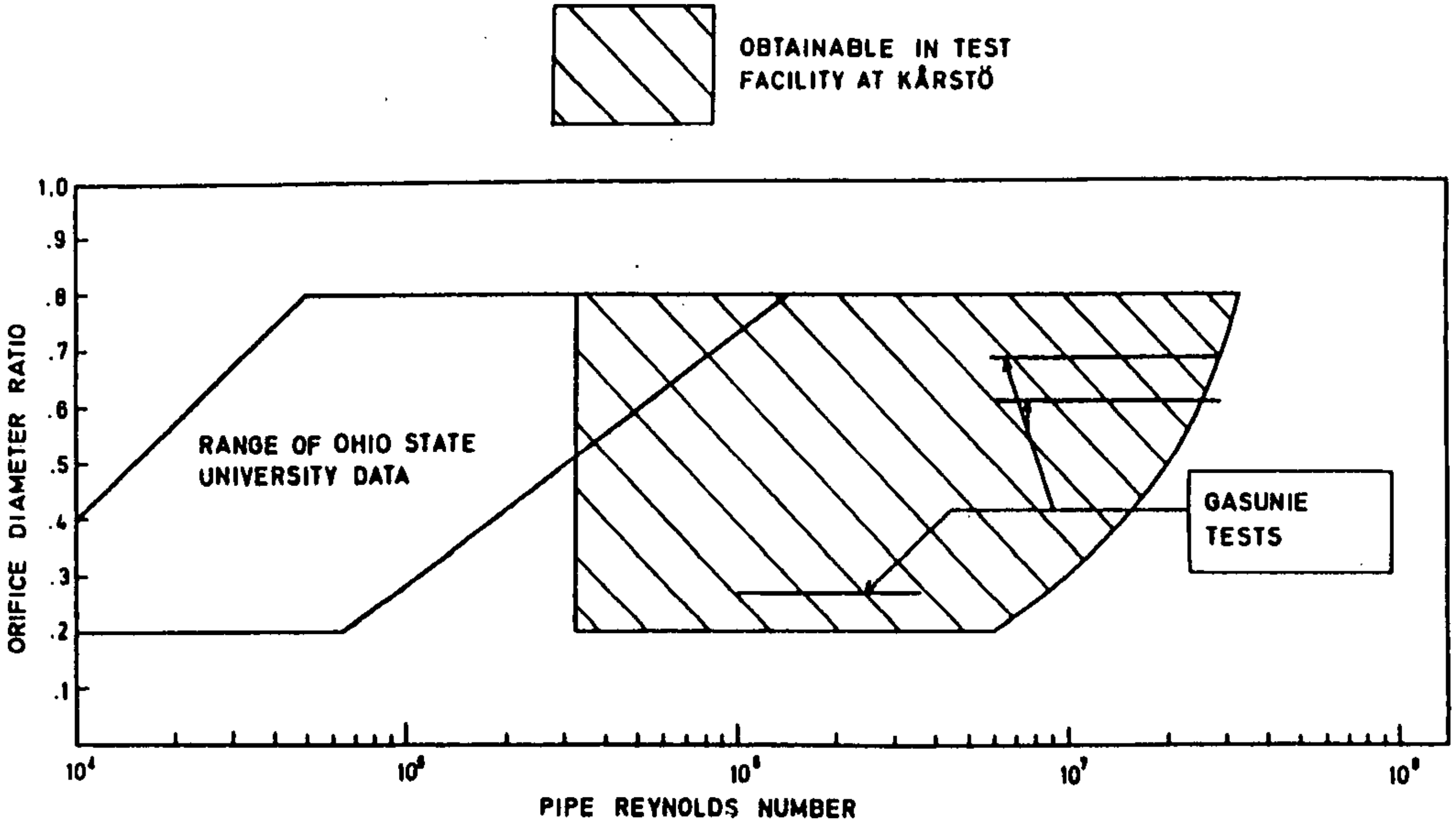

Figure 3. Obtainable Reynods numbers compared with ISO-5167 data base.

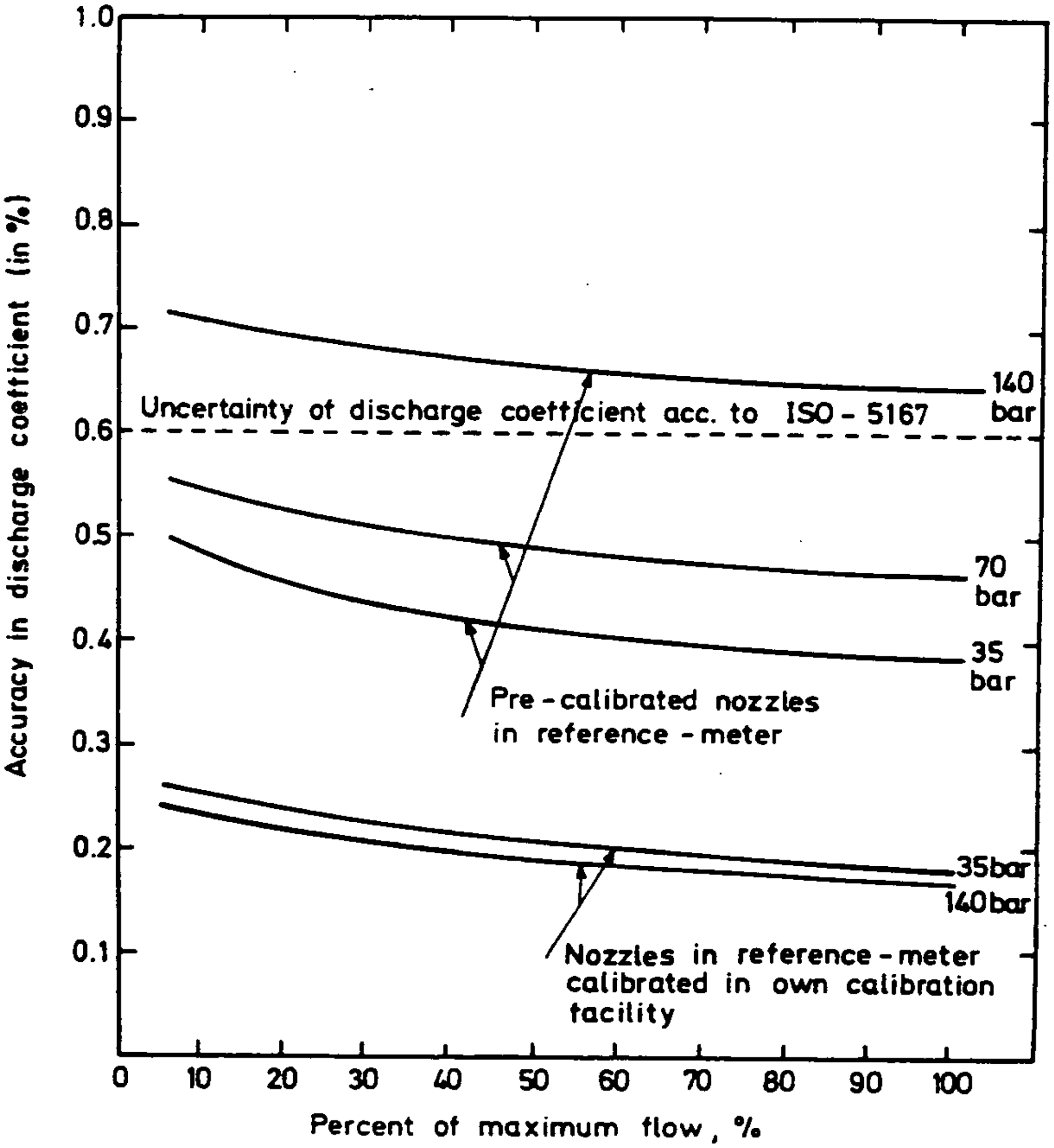

Figure 4. Obtainable accuracy in orifice discharge coefficient versus percent of maximum flow.