A STATUS REPORT ON K-LAB

by

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K-Lab

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SUMMARY

First gas in to K-LAB was obtained on 8 December 1987. After a settling in period of 3 months, calibration of the reference sonic nozzles began on the smallest size sonic nozzles at 55 bars absolute in April 1988, and first calibrations on these nozzles at 156 bars absolute were obtained in July 1988. The results of all the calibrations obtained, the early problems that arose, and the proposed plan of future work are reported in this paper.

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1 INTRODUCTION

K-LAB, the Kårstø Metering and Technology Laboratory, is a natural gas metering laboratory in Norway. it is a joint venture between Statoil (66 2/3%) and Total (33 1/3%) with Statoil as operator. The purpose of K-LAB is to carry out testing, calibration, and research within the field of metering components and systems. In addition there are take off points around the flow loop for testing and research on activities related to production and transportation of hydrocarbons. The present scopes covers single phase (dry) gas metering.

The mode of operation of the laboratory is as a closed loop having an operating pressure range from 20 to 156 bars absolute with an accompanying temperature range of 20°C to 60°C above ambient.

Fig. 1 shows a schematic for the loop. At the present time only one compressor and associated cooling train has been built. This provides a maximum mass flowrate of 65 kg/s and corresponding volume flowrate of 6.5 Million sm^3/d. These flowrates will, of course, be doubled when the second compressor and cooling train is installed in 1990.

Sonic nozzles are used as reference flow meters and they are calibrated within the loop using a gravimetric primary calibration system. The project to build K-LAB commenced in January 1985 and first gas in to K-LAB was obtained on 8 December 1987.

2. DESIGN CONSIDERATIONS

K-LAB has been designed, engineered and built as a process installation, but with stringent requirements with respect to achievable performance since the main purpose of K-LAB is to carry out accurate calibration of gas flow meters. Some major concerns during the design of K-LAB were:

- the proper sizing of all volumes: to avoid introducing pressure fluctuations and other flow instabilities into the flow; to enable a reasonable number of primary calibrations to be made without refilling the loop.
- prediction of the thermodynamic behaviour at critical locations around the loop, and particularly the behaviour of the flow into the weigh tank during a primary calibration of a sonic nozzle.
- ensure that high precision on all relevant measurements (pressure, temperature, time, frequency, mass measurement, and sonic nozzle throat dimensions) is compatible with the design requirements of 180 bars in the test section.

During the first half year of serious operation, K-LAB has been found to operate as thermodynamically designed, and no adverse flow flucturations have been observed. Handling of the heavy pieces of equipment, moving of the sonic nozzle spool pieces between the reference nozzle section and the primary calibration location, are performed with no major difficulties.

In order to ensure complete traceability on all measurements relating to gas composition, an on-line gas chromatograph supplied by Combustion Engineering has been installed. This gas chromatograph is connected by an RS232 link to the Scientific Data Acquisition System.

3 PROTOTYPE EQUIPMENT

Due to the fact that the K-LAB is unique, there are several important items on the system which are prototypes. These are:

- Gyroscopic weighing system
- Scientific data acquisition system
- Diverter valves
- Disconnect system
- Sonic nozzles
- Mechanical dry seals for compressor
- Swirl sensor

3.1 Gyroscopic weighing system

The K-LAB requirement during a primary calibration test is to measure a mass of gas in the range 0kg to 600kg contained in a 9 tonne tank. The balance chosen which has been supplied by Wöhwa (FRG) operates on a gyroscopic principle and has the following stated uncertainties.

Range	Uncertainty
0 to 25kg	25g
25kg to 600kg	50g

On site calibration of the balance carried out in accordance with the requirements of the Norwegian Office of Legal Metrology has confirmed these uncertainties.

3.2 Scientific data acquisition system

A computerised system is needed to acquire the data from the scientific instruments around the loop during a test run. In addition this system produces test reports, calibration reports, keeps track of instruments calibrations, and has an archiving system to store safely all the results. The main supplier of the system is Fraser Nash Scientific Ltd (UK) who supplied the software.

The subcontractor supplying the hardware was Databasix (UK), and the hardware is built around a DEC. Microvax 2 computer. Again, this system is working well at the present time.

3.3 Diverter valve

In order to divert the flow from the test loop into the weigh tank and back again during a primary calibration of a sonic nozzle, a diverter system is required. The K-LAB diverter system is based on two 3 inch ball valves having a common actuator. The maximum design diversion time was set at 0.030 seconds.

BIFFI (I) is the supplier of the actuator. This system is working well.

3.4 Disconnect system

The mass of gas is obtained by taring out the mass from the tank containing natural gas at atmospheric pressure and then measuring the mass of the tank full of gas. To carry out this each time, the weigh tank must be disconnected from the pipework so that it is freely floating on the balance. The automatic disconnect system has been manufactured by Destec Engineering Ltd (UK) and at this present time is working well.

3.5 Sonic nozzles

The sonic nozzles are the reference flow meters for K-LAB and must be calibrated prior to carrying out tests in the metering sections. The sonic nozzles are the first of their kind as regards size and pressure rating, and have an integral silencer for noise reduction. The supplier of the sonic nozzles is Sofregaz (F) with sub-contractor Gas de France (F).

3.6 Mechanical dry seals for compressor

If the loop gas compressor were to use a conventional oil-lubricated seal system, it would be possible for oil to enter the gas loop. The effect of oil inside the loop would be disastrous, for it would probably alter the calibration of the sonic nozzles in an indeterminate manner, and gradually alter the composition of the gas in the loop as the test proceeds.

This problem has been overcome by installing dry mechanical seals in the loop gas compressor. The seals were manufactured by Crane (UK).

3.7 Swirl sensor

As is well known, the effect of swirl impinging on an orifice plate can noticeably change the value of the discharge coefficient. No set of measurements in a test section would therefore be complete without providing a measurement of the swirl angle in the test section.

At the present time (August 1988) no probe exists for measuring swirl covering the K-LAB pressure range, we are working on designing and manufacturing such a probe, and more details will be given at the workshop.

4 EARLY PROBLEMS ARISING DURING PRIMARY CALIBRATION

Before we can carry out tests in the test sections we need to have calibrated all the sonic nozzles which are used as reference flow meters. The sonic nozzles are characterised as follows:

Nozzle number	1	2	3	4	5	6	7	8	9	10	11	12	13
% max flow	1.25	1.25	2.5	5	10	10	10	10	10	10	10	10	10

At the present time as we have only one compressor giving 50% of the maximum flowrate, we have only installed the first eight nozzles.

Figure 2 shows a sketch of the layout of the primary calibration section. It is possible that over the life of the laboratory the composition of the gas in the loop can change. To overcome the effect of possible changes in gas composition from the time the sonic nozzle was calibrated to a later date when a test is to be carried out in the test section, we proceed as follows:

Primary calibrations are carried out in pairs. We calibrate each reference sonic nozzle against a standard nozzle. Let us denote any one of the reference sonic nozzles by subscript i, and let us denote the standard nozzle (which incidentally is a 1.25% nozzle) by the subscript s. We will compare the result of a calibration on the i'th nozzle with a calibration carried out on the standard nozzle at similar values of pressure and temperature.

The two calibrations are consecutive to ensure that the change in gas composition that takes place between the two calibrations is negligible.

Thus we have:

$$q_{mi} = (A_t C_D)_i \, C_{Ri} \sqrt{p_i \rho_i} \qquad (1)$$

$$q_{ms} = (A_t C_D)_s \, C_{Rs} \sqrt{p_s \rho_s} \qquad (2)$$

Hence

$$\frac{(A_t C_D)_i}{(A_t C_D)_s} \cdot \frac{C_{Ri}}{C_{Rs}} = \frac{\sqrt{p_s \rho_s}}{\sqrt{p_i \rho_i}} \cdot \frac{q_{mi}}{q_{ms}} \qquad (3)$$

Now since C_{R_i} and C_{R_s} are only dependent on p, T and gas composition we have:

$$C_{Ri} = C_{RS} \qquad (4)$$

Hence

$$\frac{(A_t C_D)_i}{(A_t C_D)_S} = \frac{q_{mi}}{q_{ms}} \cdot \sqrt{\frac{p_s \rho_s}{p_i \rho_i}} \qquad (5)$$

At some later date, prior to running a test in the test section, we carry out a run on the standard nozzle at conditions say po, and To which are close to the desired test section conditions p, T.

Then

$$q_{mso} = (A_t C_D)_{so} \; C_{Rso} \sqrt{p_o \rho_c} \qquad (6)$$

where ρ_c is the measured density at po, To.
So if we now carry out a test with all i nozzles at a pressure and temperature p, T which are close to po, To respectively we have:

For the i'th nozzle:

$$q_{mi} = (A_t C_D)_i \; C_{Ri} \sqrt{p \rho} \qquad (7)$$

Rearranging equation (7):

$$q_{mi} = (A_t C_D)_{so} \cdot \frac{(A_t C_D)_i}{(A_t C_D)_{so}} \cdot C_{Ri} \sqrt{p \rho} \qquad (8)$$

Now, since p, and T are close to po, To respectively and because the gas composition is similar between the primary calibration having subscript 0 and the gas composition during the run in the test section:

$$C_{Ri} = C_{Rso} \qquad (9)$$

It follows from equations (6), (8) and (9) that during the test run:

$$q_{mi} = \frac{q_{mso}}{\sqrt{p_o \rho_o}} \cdot \frac{(A_t C_D)_i}{(A_t C_D)_{so}} \cdot \sqrt{p \rho} \qquad (10)$$

Since every parameter on the right hand side of equation (10) has been measured, q_{mi} during a test run can be obtained.
The factor $(A_t C_D)_i / (A_t C_D)_{st}$ is, of course, a geometric factor which is determined from equation (5) as a function of throat Reynolds Number.

Amongst the early problems that arose during the calibrations of the sonic nozzles were the following items:

- Density measurement
- Water condensation on weigh tank.
- Effect of the "dead leg" in V3.

These problems will now be discussed in turn.

4.1 Density measurement

There are two alternative formulae available for calculation of mass flow rate through a sonic nozzle. The first form is used in equation (1) above, and is repeated in its general form here:

$$q_m = A_t C_D C_R \sqrt{p \rho} \qquad (11)$$

The alternative form is:

$$q_m = A_t C_D C^* \frac{p}{\sqrt{RT}} \qquad (12)$$

Prior to the commencement of project engineering it was decided to use the formula as given in equation (11) for calculating the flow through K-LAB sonic nozzles. This was because C_R is less dependent on variations in p and T than C* and at that time the accurate measurement of density was not considered a problem. To measure density in K-LAB we use Solartron 7810 or 7811 density meters in pockets in the inlet header to the primary calibration section. We then correct this measured density value using measured pressure, and temperature to obtain the value of density just upstream of the sonic nozzle being calibrated.

We have chosen an operating temperature of 37°C as the temperature we can achieve all the year round on K-LAB. Immediately we commenced carrying out primary calibrations we discovered that even though the density meter was enclosed in a lagged box, the pocket temperature was of the order of 1°C to 2°C lower than the free stream temperature.

Improvements to the insulation inside the lagged box followed, but the temperature difference between the freestream and the pocket could never be completely eliminated. This is probably due to the manner in which the loop is operated, commencing from cold every morning, and the actual volume of gas passing the pocket. On fiscal metering stations operating on a continuous basis with high flow rates, this effect would probably be negligible.

As of August 1988 we have just installed heaters inside the lagged inclosures with thermostats set at 37°C, and if this fails we are toying with setting the 7810's and 7811's directly into the gas flow. However this does have the considerable drawback that we must depressurise part of the loop to change out a density meter.

In addition, to keep our options open, we have obtained calibration curves based on equation 11 in two different forms:

$$q_m = A_t C_D C_R \sqrt{p \rho_{meas}} \qquad (13)$$

$$q_m = A_t C_D C_R \sqrt{p \rho_{CALC}} \qquad (14)$$

And we also have calibration curves using the equation (12). These 3 calibration curves are shown in Figures 3, 4 and 5 respectively. Note how the measured density calibration curve of Figure 3 is different, compared with Figures 4 and 5.

4.2 Water condensation on the weighing tank

As described previously in section 4, the calibrations are carried out in pairs in an attempt to have little variation in gas composition between a calibration pair. After carrying out one primary calibration the gas in the weigh tank can be flared off so that the weigh tank can be weighed "empty". Our first sequence of primary calibration was 55, 90, 120 and 156 bars absolute, and as the pressure increased the cooling effect from flaring became stronger and stronger leading to water vapour condensing on the outside of the weigh tank and associated pipework, which possibly affected the second run of the pair. To overcome this problem, much pipework was lagged with a non-absorbent foam and the rate of flaring was kept to a minimum.

4.3 Effect of the dead leg in V3

Referring again to Figure 2, prior to the insertion of the 3 way valve, the early primary calibration runs at fairly low pressure (55 bars absolute) were not affected by the "dead leg" - the volume containing the other sonic nozzle not undergoing calibration at that moment in time. However, as the calibration pressure was increased, the effect of this "dead leg" on the correlation became noticeable. Once the 3-way valve was installed, the problem disappeared. However, this meant that we had acquired a number of dubious calibrations on the first pair of nozzles.

5 FUTURE WORK

For the remainder of 1988 we are continuing the calibration of the remaining sonic nozzles. We are also installing a fully modular 6 ins diameter test section which will be completed in November 1988. In addition to this we are revamping the present 12 ins diameter test section so that from 1 April 1989 we will be in a position to calibrate turbine meters up to 156 bars absolute. In 1989 it is also planned to install a 24 ins test section in order to be able to accommodate the EEC 600 mm test run.

One of the first tests to be carried out in the modular 6 in test section will be investigating short length metering systems having (hopefully) the same accuracy as the present horrendously long fiscal gas metering systems using orifice plates.

In our view, 1988 sees the start of a change in emphasis in gas metering technology. The change began with the advent of ultrasonic meters. We now have non-intrusive multi-beam ultrasonic meters requiring only a small number of upstream pipe lengths to achieve comparable accuracy to that obtained using long upstream pipe lengths in conjunction with orifice plates.

It is our strong conviction that if the velocity profile is uniform, if the swirl angle is less than 1°, if the centre-line turbulence intensity value approaches that obtained in fully developed turbulent flow then the number of upstream pipe lengths needed to produce this condition is irrelevant. This is what we will be examining in 1989!

Flow diagram of the K-Lab test loop

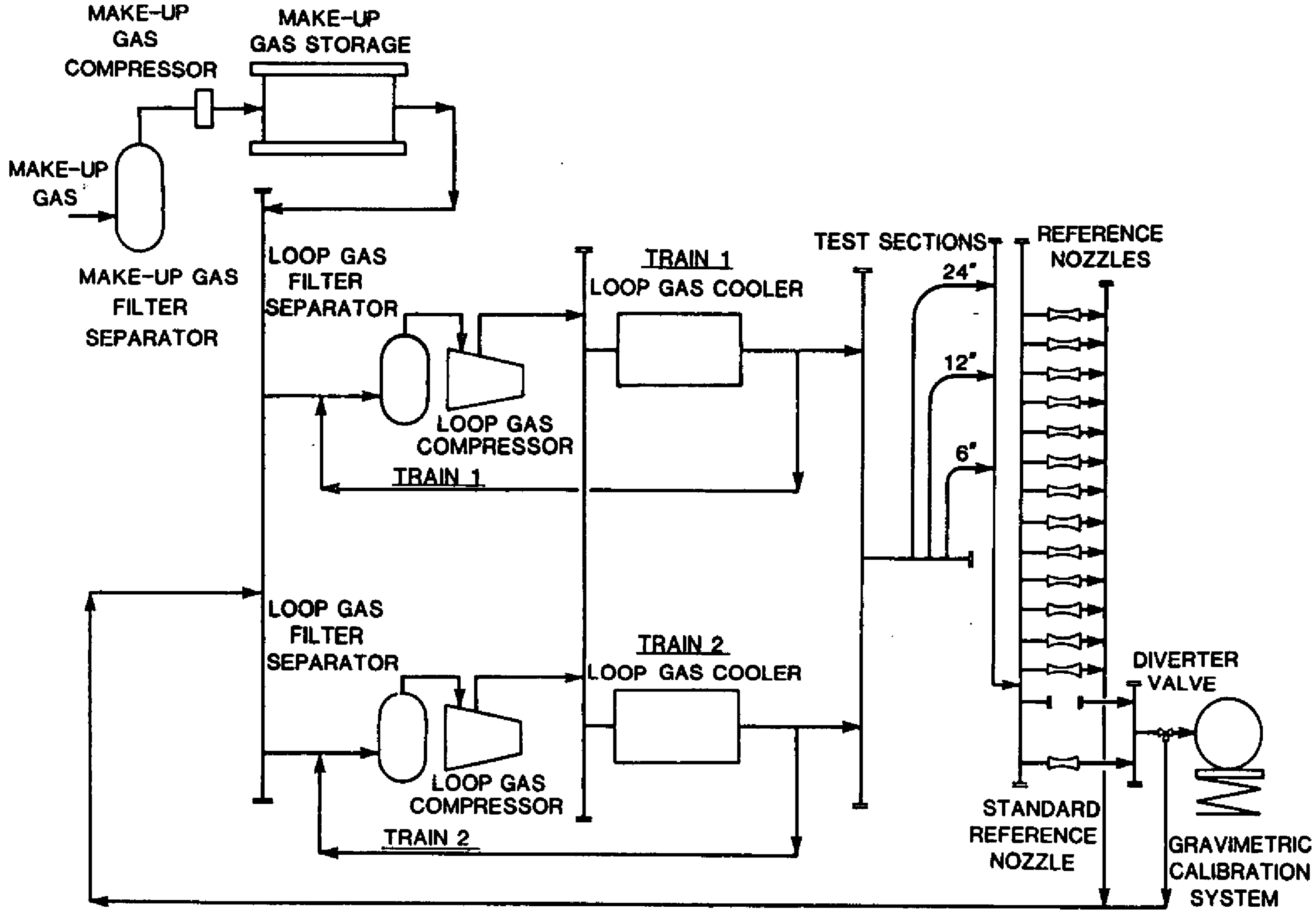

FIGURE 1.

PRIMARY CALIBRATION SECTION

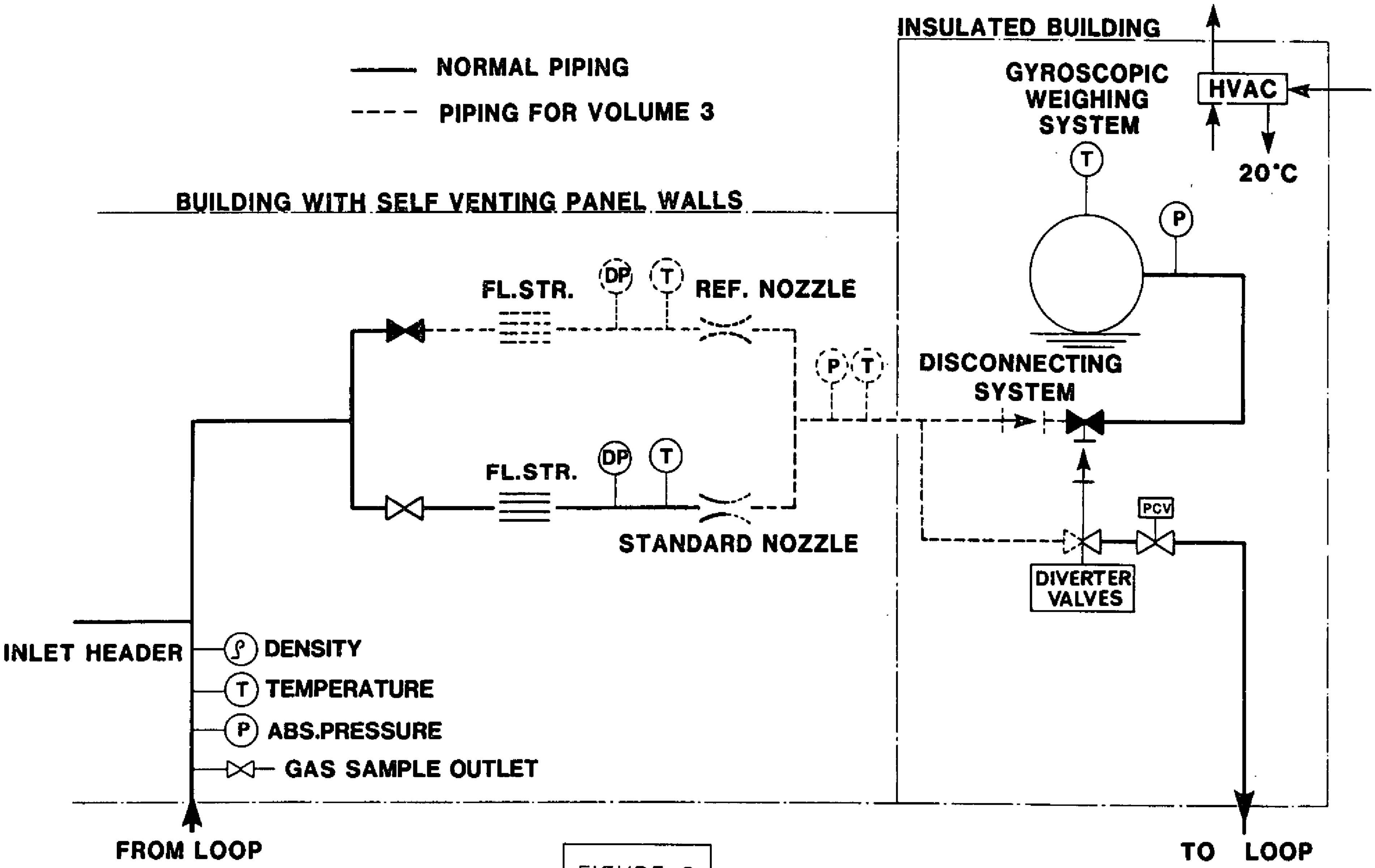

FIGURE 2.

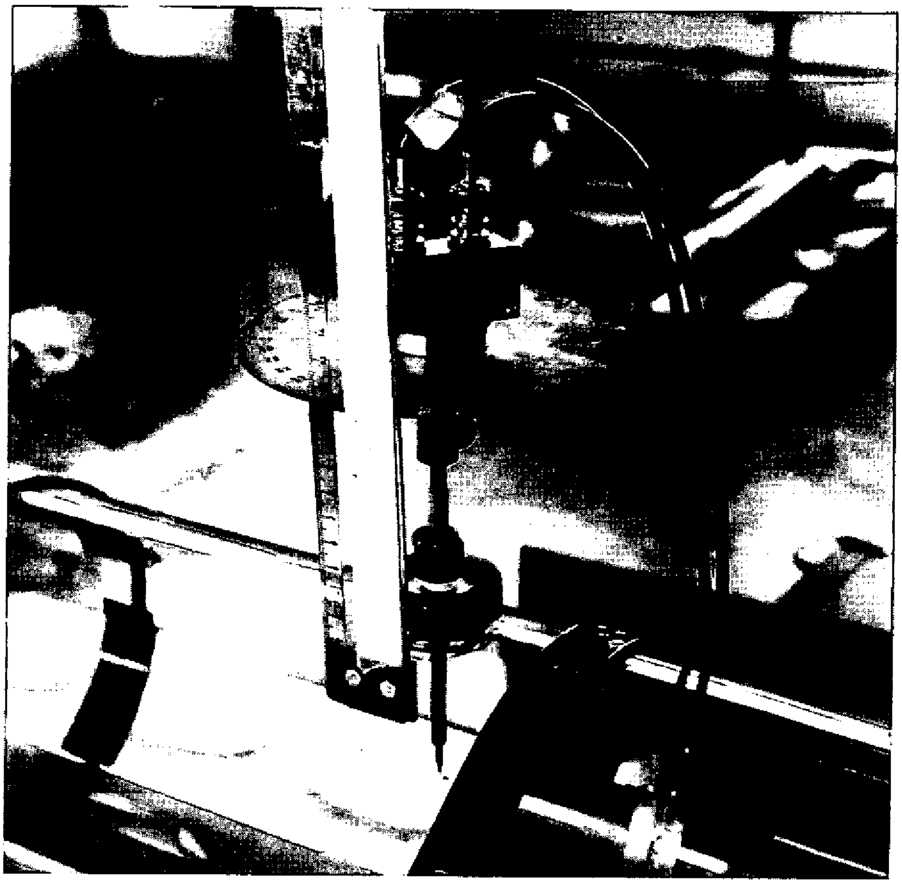

Figure 3. Detail of the probe support and the two rulers.

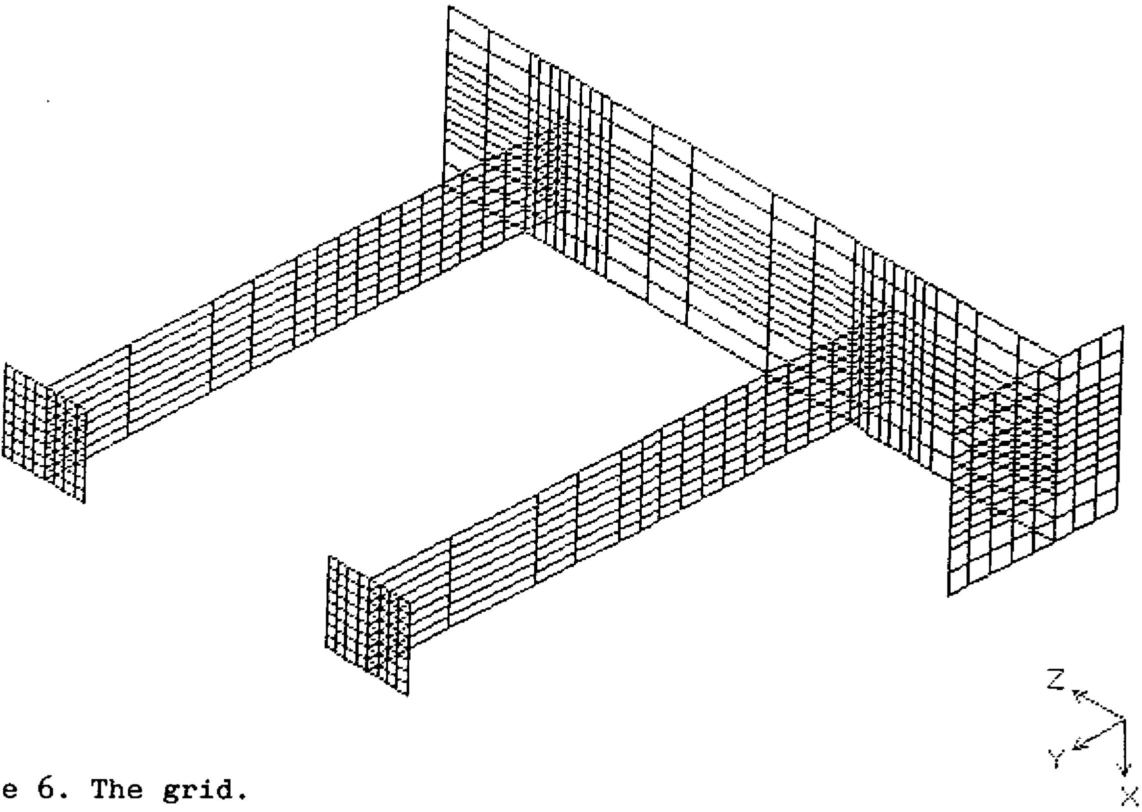

Figure 6. The grid.

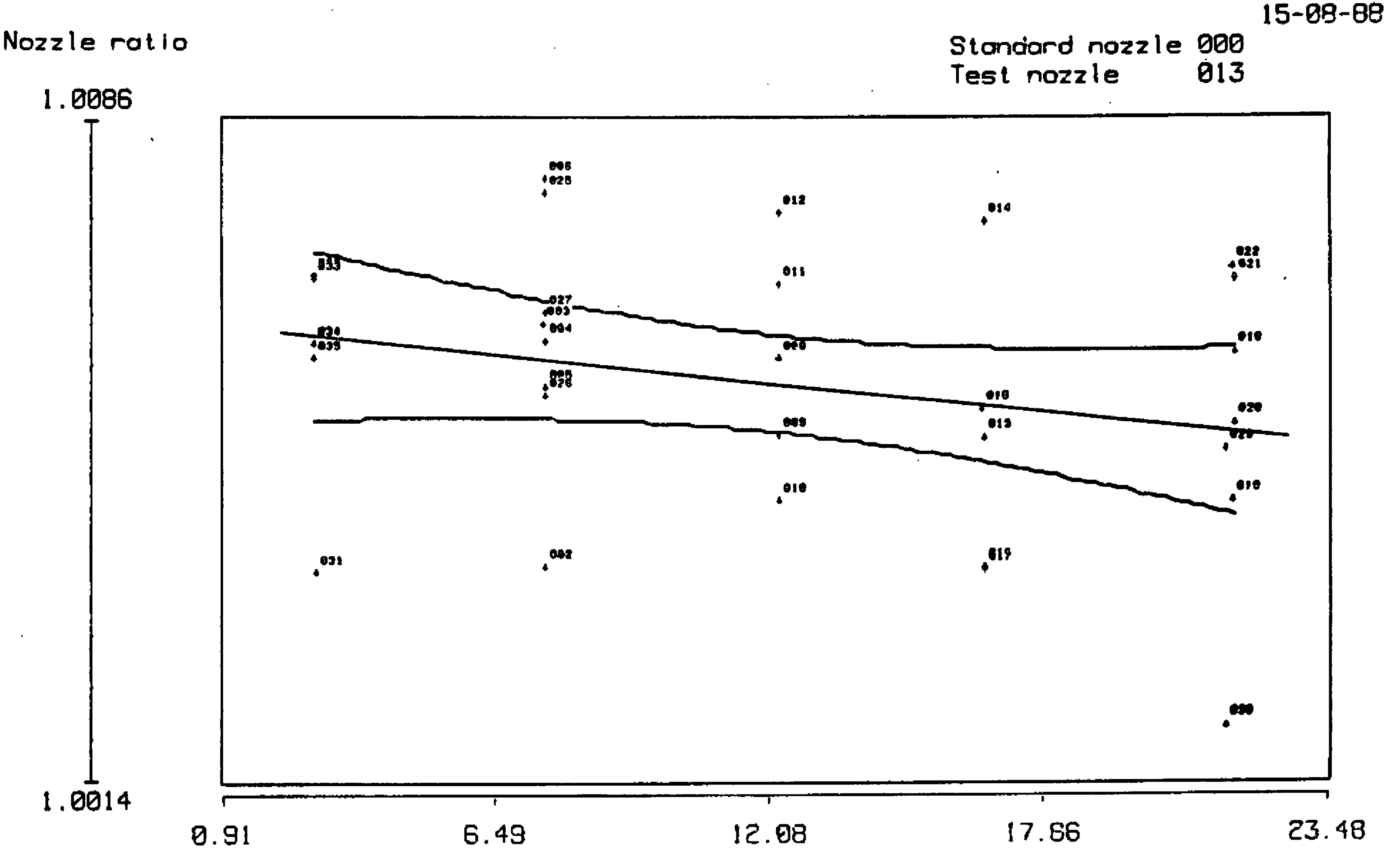

FIGURE 3 — CALIBRATION CURVE BASED ON MEASURED UPSTREAM DENSITY

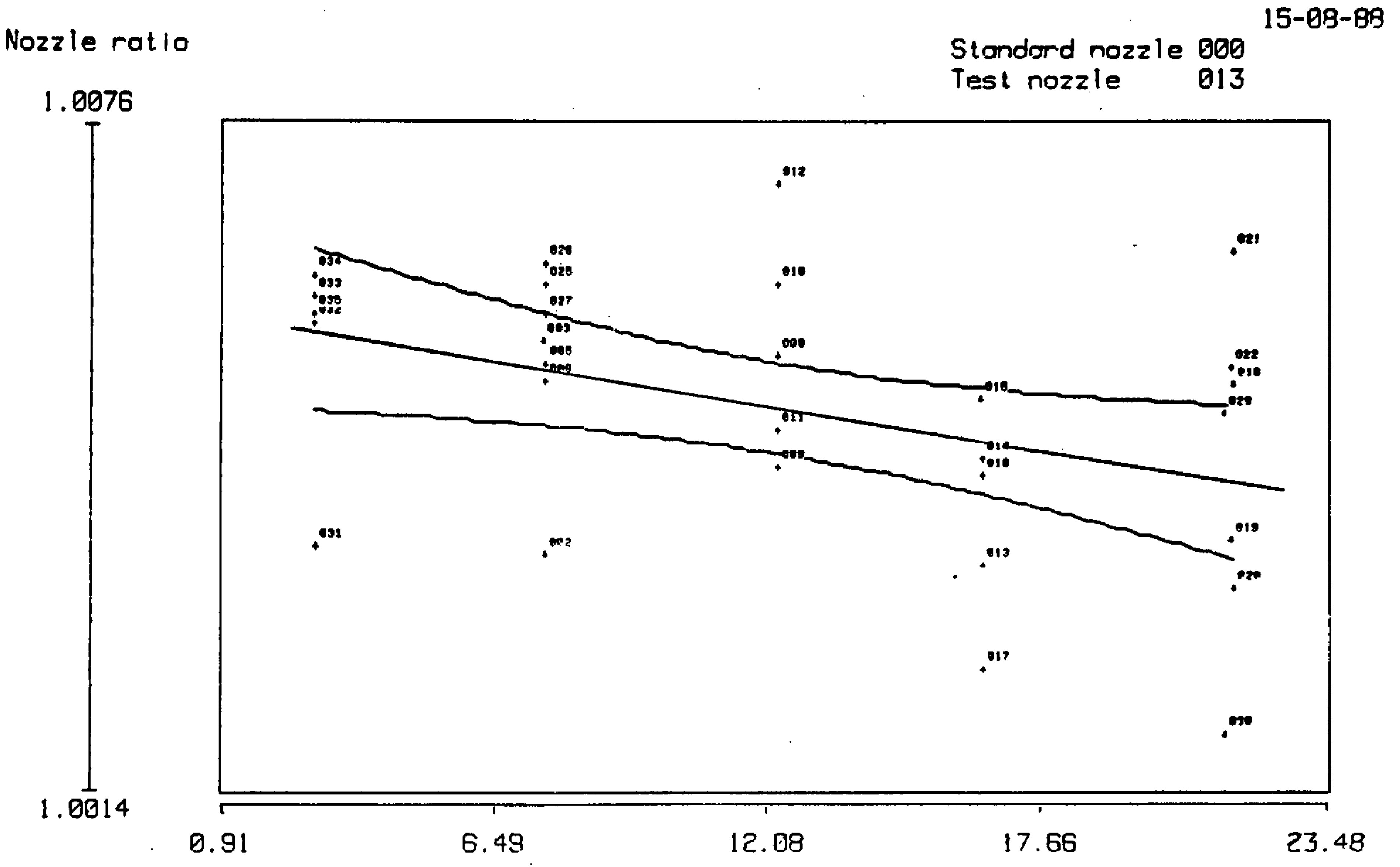

FIGURE 4 – CALIBRATION CURVE BASED ON CALCULATED UPSTREAM DENSITY

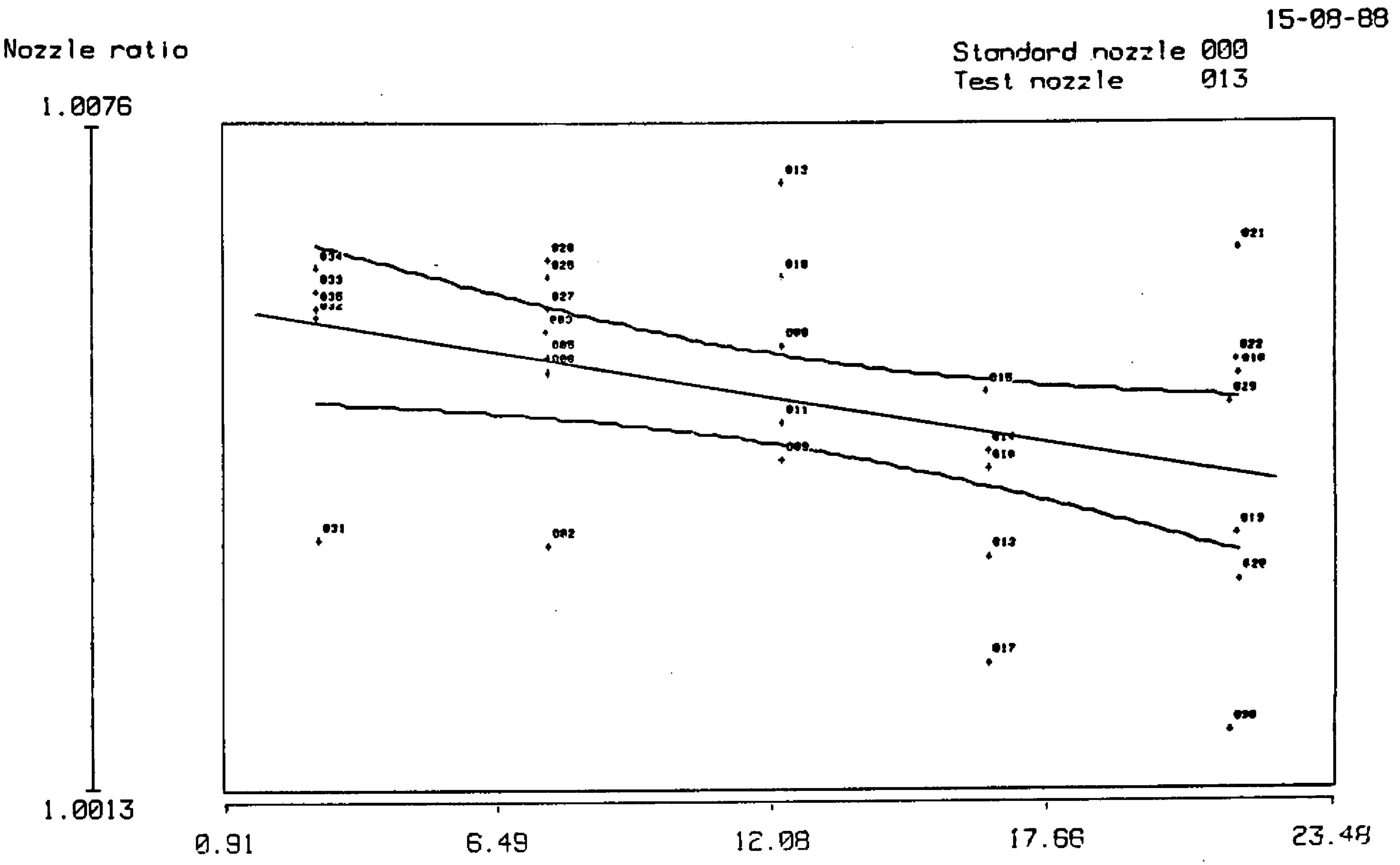

FIGURE 5 — CALIBRATION CURVE BASED ON C^*

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.