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NORSKE SIVILINGENIØRERS FORENING

MEASUREMENT OF GAS AND LIQIUDS

June 7-10, 1982

Rogaland Regional College

Stavanger

CALIBRATION OF GAS METERS

Lecturer: H. Bellinga
Engineer
N.V. Nederlandse Gasunie

Introduction

Right from the start of the gas industry the necessity to measure the product that was sold was appreciated. The way this measurement was accomplished strongly depended on the use that was made of the gas and of its origin.

In the early days, i.e. early 19th century the gas was manufactured gas, almost exclusively used for lighting so the customer was charged for the number of lights and the time he was allowed by contract to burn them. As the application of gas became more diverse the development of gas metering equipment started, finally resulting in the gas meters as we know them today. As manufactured was an expensive product there was a strong incentive to aim at high accuracy. The manufactured gas history mainly took place in Western Europe.
In the United States, however, the start of the gas industry was different. The gas to be handled was natural gas that was won associated with oil which was the target of the drilling activities. Initially it was considered as a waste product and the quantity was quite large. The result of this was that the applications were quite different from the applications of manufactured gas. As the quantities of natural gas were larger its price was lower.

In view of the circumstances mentioned above it is understandable that simplicity and robustness of the measuring system was appreciated more than accuracy. Under this climate the pressure differential flow measuring system was developed resulting in the orifice plate metering system as we know it today.
With the increase of the price of energy the demand for accuracy became the same for all metering systems.
However different the various measuring systems are in construction they have one thing in common. The need for calibration. The methods of calibration are just as different as the constructions.

In the case of the orifice plate the calibration is carried out by carefully measuring the dimensions of the orifice plate and the adjacent tubing and checking if the whole fulfils the requirements of the relevant standard. It is remarkable that there are more than one, quite deviating standards for the same measuring device.
This indicates that development is still taking place.

The other gas meters are of a more complex construction than the orifice plate. The result of this is that it is not possible to predict their behaviour from their dimensions.
The consequence is that this group of meters, and among them the turbine meter, has to be calibrated by comparing their output signal with the output signal of some standard metering device of which the characteristic is known.
According to most of the international and national regulations this calibration had to take place with atmospheric air. The reason for that is the fact that air under atmospheric conditions is a universal medium which easily could be agreed upon at the completion of international directives.
However, it is concluded from experiments that correct registration of atmospheric air is not always a guarantee for good measuring capabilities of gas at high pressure (1).
For this reason several calibration facilities operating with a medium of higher density have been built or are under construction in a number of countries.

In the Netherlands the Metrology Act has been amended to give the results of high pressure calibration facilities a legal status.
In the late seventies an intercomparison measurement campaign has been carried out between the British, French and Dutch calibration facilities (2).
Preparations are being made to give all these installations a common basis, acceptable for the Community Bureau of Reference of the Commission of European Communities.
As soon as this has been accomplished the high pressure calibration can be introduced in the international directives.

In the following a number of high pressure test facilities traceable to primary units or a primary standard for gas measurement will be described.

2. Installations

2.1 France

Of the basic installations in Europe the installation of Gaz de France in Alfortville is the oldest one and for that reason it will be dealt with first.
The GDF has 3 test facilities, namely a primary one (fig. 1) and two secondary ones, for measuring the flow of natural gas at high pressures (3).
Only the installations designated as the secondary test facilities, however, are suitable for the calibration of normal commercial high-pressure gasmeters at higher flowrates. Although diffe-rent in size the secondary installations do have the same layout and operating principle (fig. 2). Here critical flow nozzles serve as standards for the flow measurement, their coefficients C_D having been determined with the aid of the volumetric method in the primary test facility, fig. 1. The GDF estimate that the measuring uncertainty on the primary test facility is of the order of ± 0.25 per cent (4).

In the primary test facility (fig. 1) first of all the gas passes through a filter and subsequently it is controlled by an adjustable presure-regulating valve to give the desired pressure for the nozzle to be tested. During the measuring phase the flow fills the measuring vessel which has a volume of approximately 2 m^3. The density of the gas in the vessel in the initial and final state of each test is calculated by means of the pressures and temperatures measured after a period of stabilization and related to the density measured at a location ahead of the nozzle. The instrument, which works on the basis of the principle of the vibrating cylinder and is calibrated with methane, serves as a densitometer.

The density is checked by being calculated from the measured composition of gas as well as from the indication of a measuring instrument for relative density which can be made available.

The volume of the vessel at atmospheric pressure was determined by measuring its content by filling it with water with the aid of a calibration bottle. At the test conditions the increase in volume because of the higher gas pressure is taken into account analytically. In order to achieve a better and quicker stabilization of temperature, the nozzles, measuring vessel, control devices and the inherent piping are placed in a water bath which is temperature controlled.

The measurement is then carried out in the following manner : with the aid of the pressure regulator the desired mass flow through the nozzle which is to be calibrated is set with valves R_1 and R_2 open and a period allowed to obtain stabilization of the flow conditions.

The following measurements are taken :

a the pressure p_1 ahead of the nozzle,
b the density ρ_1 ahead of the nozzle,
c the temperature T_1 ahead of the nozzle,
d the initial pressure p_i in the vessel, and
e the initial temperature T_i in the vessel.

Both of the last named measurements serve to determine the initial density ρ_i and thus the mass of the gas contained between the valves R_1 and R_2 inclusive of the vessel at the beginning of the measurement. The second phase of the measurement begins with the closing of valve R_2. At the same time an electronic timer is started. The gas then flows into the vessel.

The values, p, T and at the inlet of the nozzle have to remain constant and so the filling of the vessel has to be finished before the pressure crosses the threshold given for the maintenance of the critical pressure ratio.

With this design of nozzle this amounts to approximately 90 per - cent of the pressure ahead of the nozzle. The valve R_1 is then closed and at the same time the electronic timer is stopped. The stabilization of the temperature of the gas in the volume shut off between the valves R_1 and R_2 has now to take place before the final values p_f, ρ_f and T_f can be measured for this volume.
From these values the discharge coefficient of the nozzles is calculated.

The primary test facility is not used (and not suited) for the calibration of meters. The secondary test facilities therefore serve this purpose They are also fed from the high-pressure natural gas pipeline. In the smallest one (fig. 2) seven sonic nozzles with flowrates, 1.5, 5, 10, 20, 40, 100 and 200 m^3/h relative to the standard condition (p_n = 1.013 25 bar and T_n = 0°C) are available. In the framework of these flowrates other values can also be obtained by connecting the nozzles in parallel.

The coefficients of the standard nozzles were determined using the primary test facility. The nozzles, with straight inlet lengths between 8 and 20D, are installed in the secondary test facility so that the smallest length is applicable to the nozzle with the smallest throat.

The test facility is in the open air. In order to guarantee adequate temperature conditions those parts of the installation which are essential for the test are supplied with thermal insulation. This secondary test facility allows the testing of nozzles and gasmeters up to pressures of 41 bar and flowrates up to 2.6 kg/s at, for all practical purposes, an unlimited duration of the test.

Recently in Alfortville another secondary facility of larger capacity has been built. The standards used are of the same origin as those in the first installation.

The layout of the installation is quite the same as the smaller installation. It is also in the open air which requires thermal insulation. The maximum capacity is 60.000 m_s^3/h at pressures up to 50 bar.

In Poitiers at the premises of the Centre d'Etudes Aérodynamiques et Thermiques a calibration facility is installed (5). In this case sonic nozzles, calibrated at the primary installation in Alfortville are used as standards.
The fluid is compressed air. Maximum flowrate is 150.000 m_s^3/h at a pressure of 50 bar. At maximum flowrate the measuring time is limited to 120 seconds (fig. 3).

2.2 United Kingdom

In the UK two facilities do exist in which gasmeters can be calibrated with gas or air at elevated pressure. Of these installations one is directly coupled with a primary installation, the other is a secondary installation derived from the primary installa- tion.
The test facility of NEL in Glasgow (fig. 4) is operated with air (6).

First of all a compressor feeds the air into a 12 m^3 storage volume by way of a plant which dries the air and virtually eliminates oil vapours and dust. From the container a loop system with a volume of 6 m^3 is filled with high-pressure air at a pressure of up to 82 bar. When the temperature conditions in the ring conduit are 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 which serves as a standard and which adjusts to a mass flowrate corresponding to the inlet pressure and the temperature.

From the nozzle the compressed air flows through a switching device either into a high-pressure spherical vessel (diameter 1.5 m) which can be weighed on a scale or into a testline where the flowmeter which is to be calibrated is installed.

Downstream of the testline the air flows through a silencer unit into the open air; various valves make possible an adjustment of the pressure in the testline to the desired value.

Thus the NEL facility is a primary test facility based on the gravimetric method and is combined with a secondary test facility. 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 of known temperature which flows from the loop to the critical flow nozzles is replaced by air from the storage container. It is true that this air from the storage container cools off as a result of the decrease of pressure, but the temperature of the air in the testline is not influenced by this so long as there is still warmed air between the inflowing air from the storage container and the outlet of the loop.

Before a gravimetric test can be started the flow conditions through the standard sonic nozzle have to be stabilized. As soon as the readings of pressure at the critical flow nozzle indicate that the conditions are stabilized, the diverter can be switched. An electronic timer is started at the same time by this switching. The spherical vessel that had been weighed previously when it was empty, is now being filled for a given diversion period. At the end of this period the diverter is switched back to its starting position again and the timer is stopped automatically. The vessel can then be disconnected from the filling line and lowered onto a weighbridge scale. From the difference of the weighing in the initial and final state and the time interval of the switched period the mass flowrate can be obtained. From the readings of the pressure and temperature ahead of the nozzle registered during the measuring period the nozzle coefficient can then be calculated.

The direct gravimetric calibration of a flowmeter installed in the testline on the other side of the diverter is not possible. Either a secondary calibration test can be made measuring the mass flowrate with one of the standard sonic nozzles installed upstream of the diverter or an indirect connection with the gravimetric rig can be made.

Calibrations can be carried out at the National Engineering Laboratory at pressures up to 70 bar and at flowrates up to 5 kg/s. The accuracy obtained in the primary measurement as estimated by NEL is approximately ± 0.1 per cent at the 95 per cent statistical confidence levels. The overall uncertainty of a calibration of a flowmeter is estimated to be better than ± 0.3 per cent.

At present British Gas is constructing a calibration facility in Bishop Auckland. This installation is installed in the connection between two gas transmission systems.
In this installation turbinemeters will be used as standard meters which are calibrated with sonic nozzles that have been calibrated at NEL. The medium will be natural gas and the maximum flow rate will be 8,5 x 10^5 m^3st/h at pressures ranging from 35 to 70 bar.

2.3 The Netherlands

In the Netherlands there 5 installations available to carry out gasmeter calibration with a medium of high density. In four cases this is natural gas, in one case it is ethylene.

The testinstallation in Groningen (fig. 5) has been set up in the laboratory of Gasunie.

The gas after having passed through the test installation flows into the piping system of the local distribution company.
The temperature of the gas in the installation equals the room temperature. Temperature drop due to reducing pressure is compensated by heat exchangers.

Part A is called "the primary high pressure standard installation". It consists of 10 rotary meters of the CVM-type with a capacity of 400 m^3/h each. The CVM meters are calibrated individually with natural gas at atmospheric conditions by means of the 3.5 m^3 bell prover of the Service of Weights and Measures.
A CVM meter (nr. 11), tested with the bell prover as well, and installed at position D is calibrated at a gauge pressure of 8 bar.

The gas after having passed through this meter at high pressure is measured at low pressure by means of the 10 CVM meters arranged in parallel. In order to prevent great differences in temperature a heat exchanger is placed between the meter installed at D and the meters working at low pressure.
Subsequently each of the 10 CVM meters in the installation is calibrated separately at 8 bar gauge pressure with the calibrated meter no. 11. Then meter nr. 1 and nr. 11 were made to change places and the same test cycle is carried out with meter nr. 1.
By carrying out this series of tests with each CVM meter of the installation, sufficient results have been obtained from which accurate error curves could be deduced.
The "primary standard installation" is mainly used for the calibration of meters used as reference meters in other installations.
Meters installed at position D can be tested at pressures up to 40 bar. The maximum operating gauge pressure of the CVM meters is 8 bar. This means that the maximum capacity of the installation approximately amounts to 40.000 m^3_{st}/h (m^3_{st} = m^3 at base conditions).
Part B is the installation with which the normal verifications and calibrations are carried out. As shown in fig. 4 the standard meters, being a CVM meter of 400 m^3/h and turbine meters of 650 - 1.600 and 4.000 m^3/h, can be calibrated directly with the CVM standard installation.
Meters to be tested are installed at position C. If necessary a heat exchanger is installed between the meter under test and the standard meters.

The test installation in <u>Bergum</u> is at the moment undergoing a total reconstruction. The reason to do that is three fold.
First : the installation is modified such that the meter under test and the standard meter always operate at approximately the same pressure.
This has the advantage that during the calibrations the knowledge of the gas composition, i.e. compressibility, only has a secondary influence on the results.

Second : a set of small standard meters is installed so also small meters can be calibrated.
In the new configuration the capacity of the installation will range from 90 m_s^3/h to 200.000 m_s^3/h at pressures ranging from 9 bar abs to 51 bar abs.
Third : by modifying the pressure in flow control system the influence of pressure changes in the outlet piping is minimised or completely avoided.

The gas that has been used in the installation is supplied to a power station.
Schematically the installation is shown in fig. 6.
The gas enters the installation at a pressure of approximately 60 bar.
After having passed a filter the gas is flowing through a combination of a heat exchanger and a bypass in order to compensate for the temperature drop during the eventual pressure reduction.
In the case the pressure during the calibration is below 15 bar gauge pressure the pressure ratio in the outlet control valve is subcritical.
In that case the outlet valve is switched in the pressure control mode and control the pressure in the installation.
The pressure controller at the inlet is set at such a pressure that the pressure drop in the flow control valve, which is set manually, is over critical, thus forming a strong "flow source".
If the pressure during the calibration is higher than 15 bar the pressure drop in the outlet valve is over critical and the outlet valve is switched in the flow control mode and is operated manually.
In this case the flow control valve at the inlet is fully opened and the pressure in the installation is controlled by the pressure controller at the inlet.

In the case the gasflow through the meter to be calibrated is so small that the temperature and pressure controler would be operating outside their range a bypass can be opened to bring the control system within its operating range.

The standard meters have been calibrated with the CVM standard meters in Groningen.
In addition to this another three meters are calibrated at Groningen and are used at Bergum as "transfer reference meters"
Periodically the standard meters are checked by comparing them with the "transfer reference meters".

In Westerbork, as part of the Bernoulli laboratory, a meter test installation is situated.
At full operating conditions the capacity of this installation amounts to 2.5 x 10^6 m^3_{st}/h.
The installation is constructed in a bypass around a valve in a main transmission pipe line and operates at line conditions, i.e. a pressure of approximately 60 bar and a temperature of about 7°C.
The gas after having passed through the test installation returns to the same transmission line (fig.7).
The standard meters, being 10 turbine gas meters to 4.000 m^3/h each, and the meter under test are operating at about the same pressure. The standard meters are installed in a building, the meter under test and a part of the tubing at the inlet is located under a pentroof.
The standard meters have been calibrated at Bergum over approximately 60% of their range and over their full range at Westerbork by installing the "transfer reference meters" at the position of the meter to tested. So all three Gasunie calibration facilities are metrologically connected and traceable to the standard of the Metrological Service.

At Utrecht, the Instromet test installation is situated in series with a measurement and control station delivering gas to a big gas distribution company. The standard meters are derived from the CVM-standard installation at Groningen.
The standard meters and the meters to be tested operate at a gauge pressure of 8 bar.
The facility is suitable for testing meters having a capacity of 100 m^3/h and higher. The maximum flow rate at which tests can be carried out depends on quantity of gas being delivered to the gas company. In winter time a maximum capacity of 6 500 m^3/h can be achieved.
At the SHELL refinery on the Netherlands a piston prover (8) is constructed for the calibration and legal verification of gas meters to be used for measuring supercritical ethylene (pressure 60 - 100 bar at ambient temperatures).
The ethylene behaves as a gaseous fluid with densities of about 180 - 400 kg/m^3. The prover system is shown in FIG. 8. It consists of a honed pipe (diameter 300 mm), a sealed piston (aluminium), detector switches (1,2,3,4,5), control valves (B, C, D) and a two-position fourway valve (A). The measuring section between the switches 2 and 5 has a volume of 1 m^3. To avoid leakage between meter and prover, the meter to be tested is placed between the prover and the fourway valve. So the prover can be used only in one direction.
When the piston is near switch 1, fourway valve A is in the position shown in FIG. 8, valve B is open, valve C is closed. Ethylene is flowing trough the prover and the meter under test. When the conditions of pressure and temperature are stable valve C is opened, valve B is closed. Then valve C is closed slowely. The increasing differential pressure over C will launch the piston. Valve C is fully closed before the piston passes the pipe in which C is installed. Switch 2 starts the counting of the pulses generated by the meter under test. Switches 3, 4 or 5 are used for stopping the counter. When the piston reaches the end of the pipe, valve D is opened by the differential pressure across the piston.

By turning the fourway valve the direction of the flow in the power changes. Valve D, closes, valve B is partly opened. The piston returns to its start position. When the piston reaches switch 1, valve B is fully openend, the fourway valve is returned to its original position and the next test can be started.
The piston prover is calibrated by the liquid department of the Dutch Metrological Service. The calibration is carried out with water the volume of which is measured with a calibrated meter.

A check on the accuracy of the prover is carried out periodically by:

- comparing the error curve of a turbine gas meter measuring ethylene with its original curve (the meter is only used for this purpose);

- determining the leakage across the piston with nitrogen;

- determining the switching moment of the swithces in the measuring section of the prover.

From calculations taking into account the sources which may contribute to an uncertainty in a measurement and from the statical treatment of the great number of test results available, it turns out that the uncertainty in the results obtained with the high pres- sure gas calibration facilities amounts to no more than 0,3%. The uncertainty in the results obtained with the piston prover is less than 0,2%.

2.4 United States.

An interesting gas flow referece system is developed as an extension of a cryogenic flow metering reference system at the National Bureau of Standards Laboratories located at Boulder, Colorado (7). The process is shown schematically in figure 9. Basically, the process is a closed loop thermodynamic cycle. The process fluid, nitrogen, is circulated between temperature limits of 85 K and 300 K at pressures of 5 bar (abs) to 41 bar (abs) depending on the point of the cycle under consideration. Work is done on the system by centrifugal pumps operating at 85 K which increase the liquid nitrogen pressure to 41 bar from 5 bar. Heat energy enters the system trough a steam heat exchanger which controls the gas temperature at the test section. Heat energy is extracted from the system by refrigeration provided by boiling liquid nitrogen in the subcooler, auxiliary liquid nitrogen introduced at the main heat exchanger and cooling at the water heat exchanger following the gas test section.

The low pressure cryogenic portion of a cycle is maintained at a pressure of 5 bar (abs) by means of helium gas introcuced at the catch and weigh tank. This inert pressurant provides necessary over-pressure to inhibit boiling of the liquid nitrogen, allows liquid phase-gas phase separation for weighing of the liquid nitrogen and provides a controlled environment for the stable operation of the load cell and calibration weights. The interaction of the helium with the liquid nitrogen is negligible as the solubility of helium in liquid nitrogen is less than 0.1 percent. Pumping of the process fluid is accomplished in two steps. The boost pump increases the pressure about 2 bar to the suction of the proessure pump. The pressure pump in turn raises the process fluid pressure to 41 bar (abs). Both pumps are centrifugal types. The boost pump speed is variable while the pressure pump speed is fixed at about 8400 revolutions per minute. Mass flow rates are varied by operation of the expansion valve.

In preparation of a measurement the dump valve at the outlet of the weigh tank is held in the open position until thermodynamic and process equilibrium has been established at a chosen flow rate. This procedure allows liquid nitrogen under helium gas pressure to circulate through the catch to the pump suction. When a test draft is to be run, the weigh tank is closed and sealed and liquid nitrogen accumulates in the weight tank. The force resulting from the liquid accumulating in the weigh tank is measured by the load cell which in turn has been calibrated in reference to standard weights. Mass flow rate is determined by dividing the mass accumulated by the time lapsed since the dump valve was closed.

H.Bellinga/jt

Encl.: 1 up to 9

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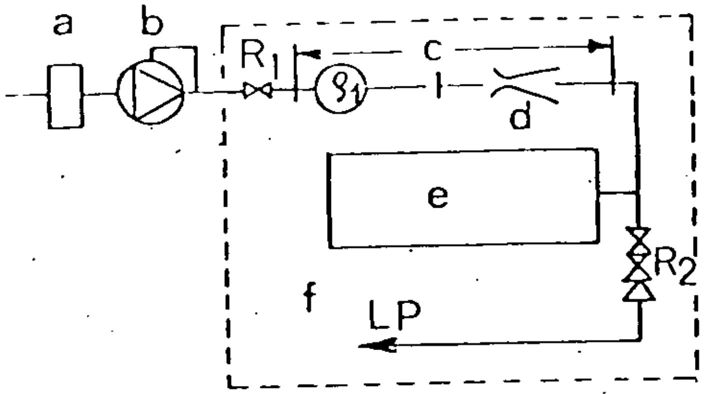
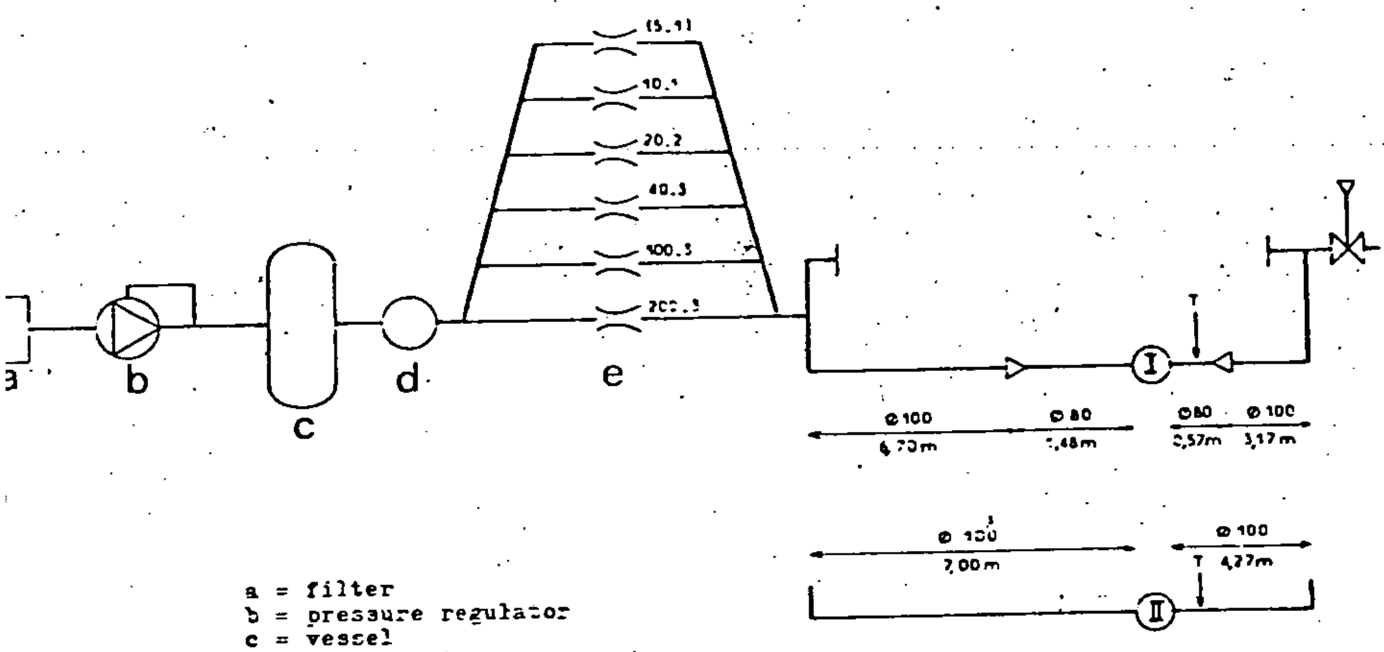


HP = high pressure 60 bar
LP = low pressure 1.1 bar
a = filter
b = pressure regulator
c = test line
d = venturi nozzle to be tested
e = vessel
f = water bassin, temperature regulated

FIG 1 PRIMARY TEST RIG OF THE GDF



a = filter
b = pressure regulator
c = vessel
d = densitometer
e = venturi standards

Transfer Standards

I = rotary-displacement meter
II = turbine meter

FIG 2 SECONDARY TEST RIG OF THE GDF

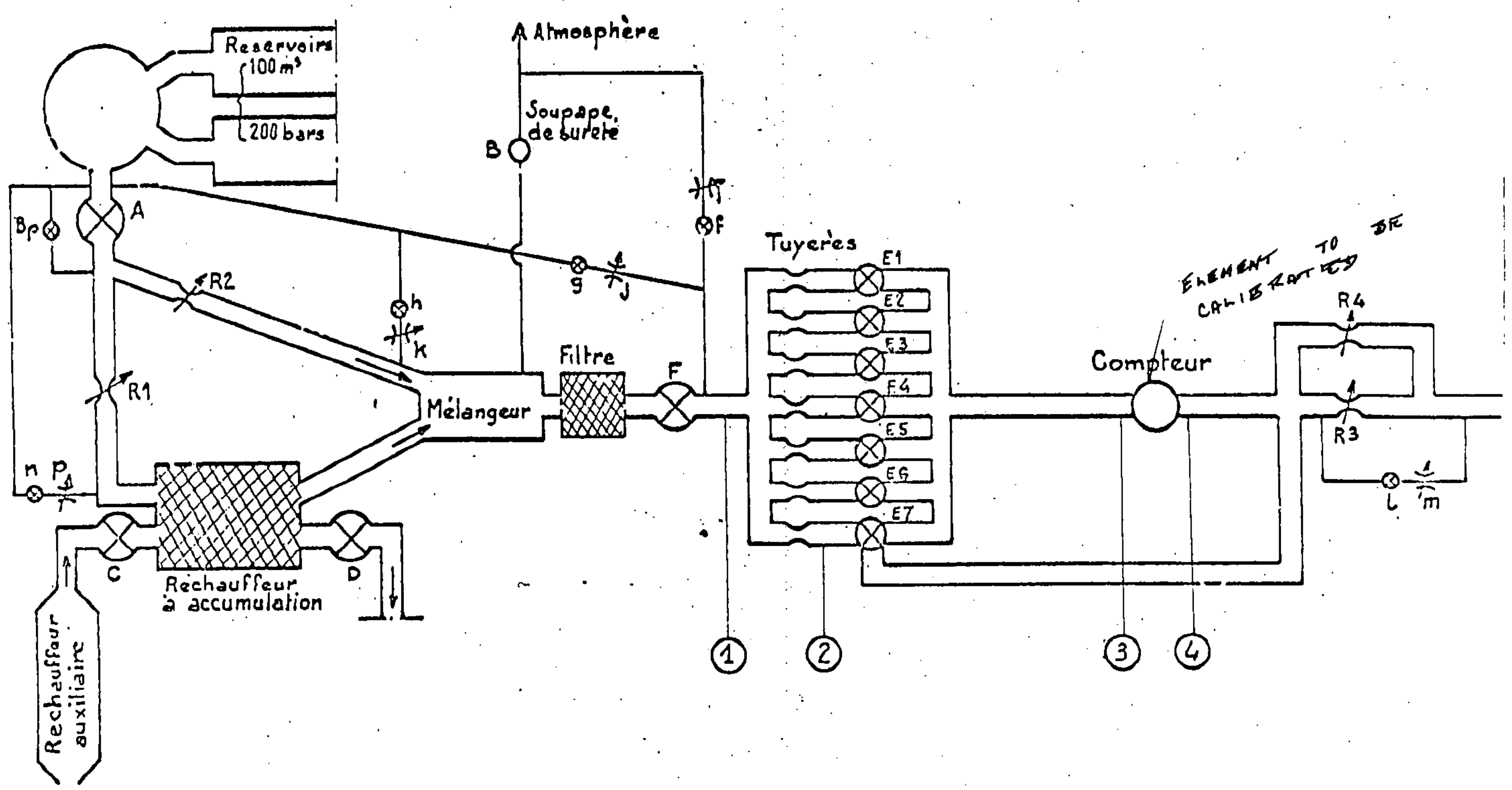


FIG. 3 FLOWSCHEME OF TEST AND CALIBRATION RIG FOR FLOWMETERS.

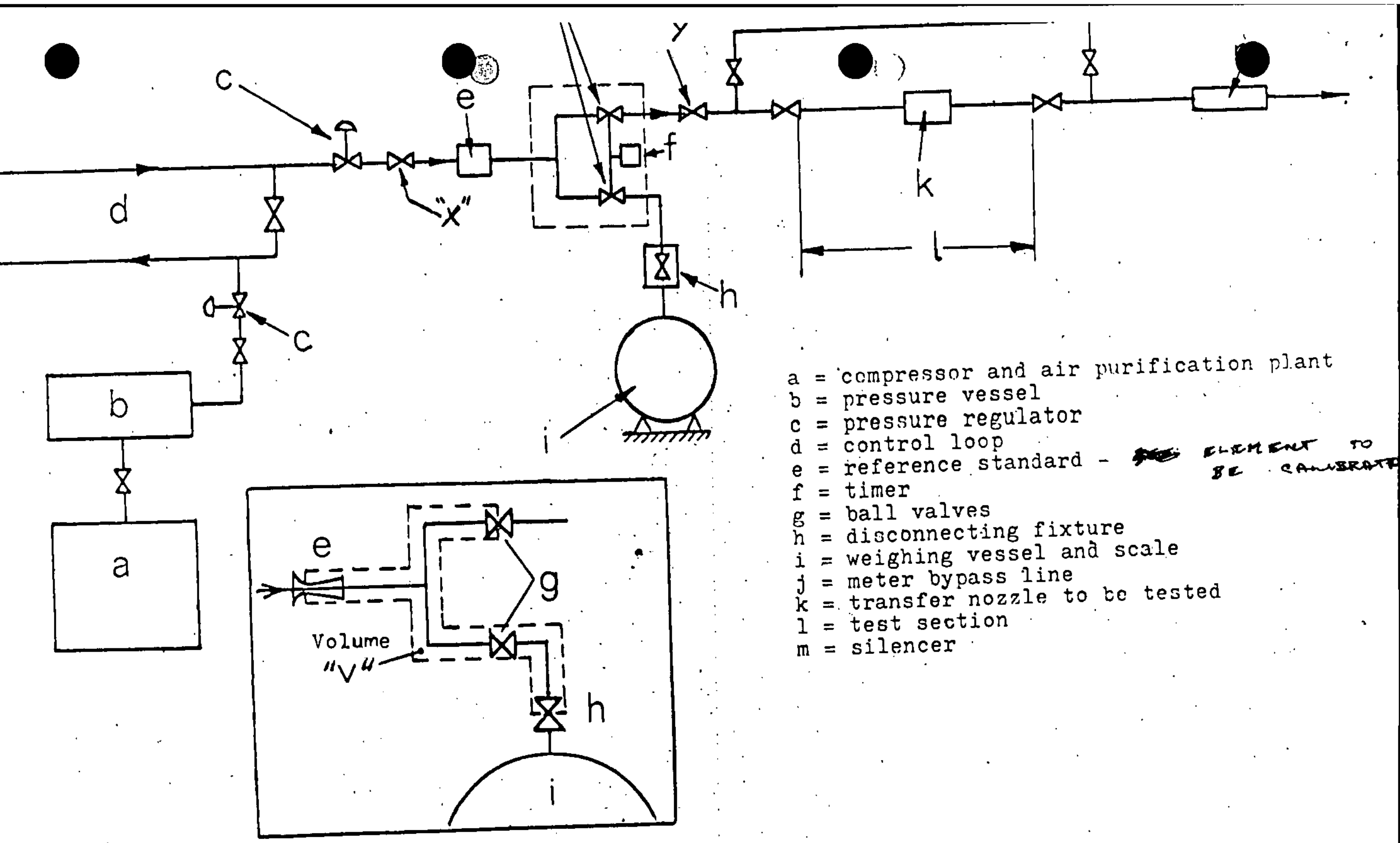


FIG 4 SIMPLIFIED LINE DIAGRAM OF THE GRAVIMETRIC SYSTEM AT NEL

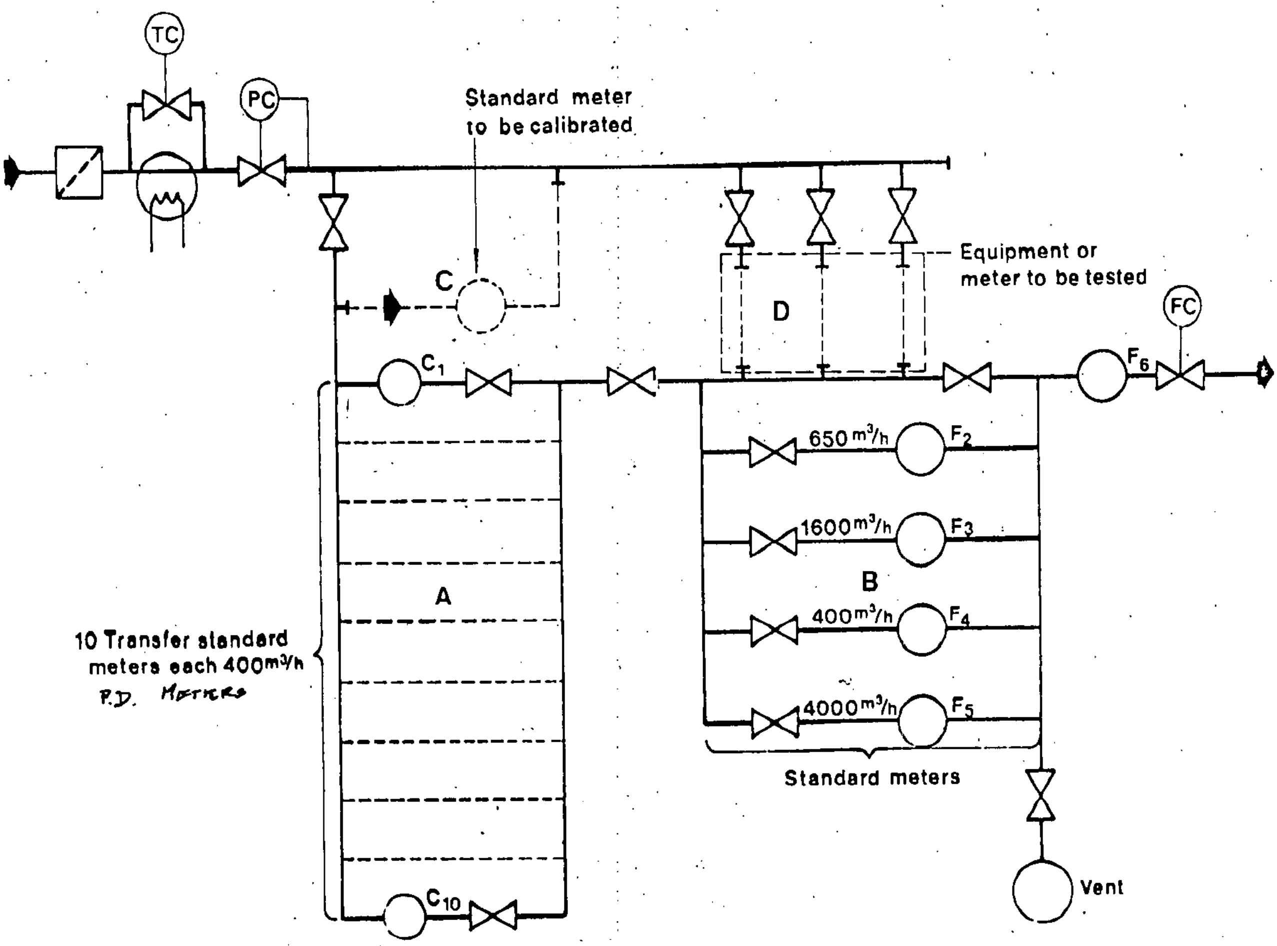


Figure 5; Research flow rig "Groningen"

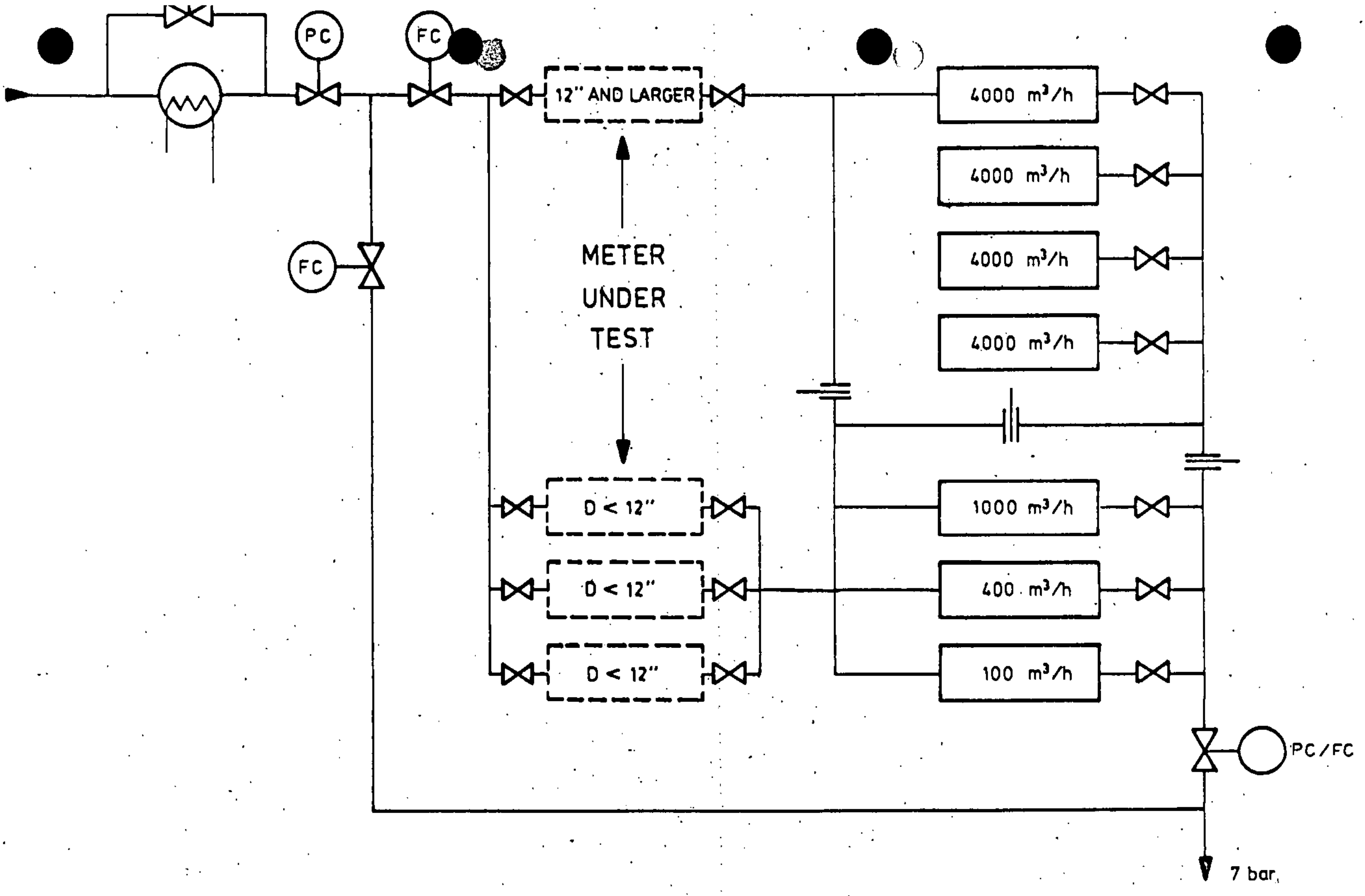


FIG. 6 CALIBRATION FACILITY BERGUM

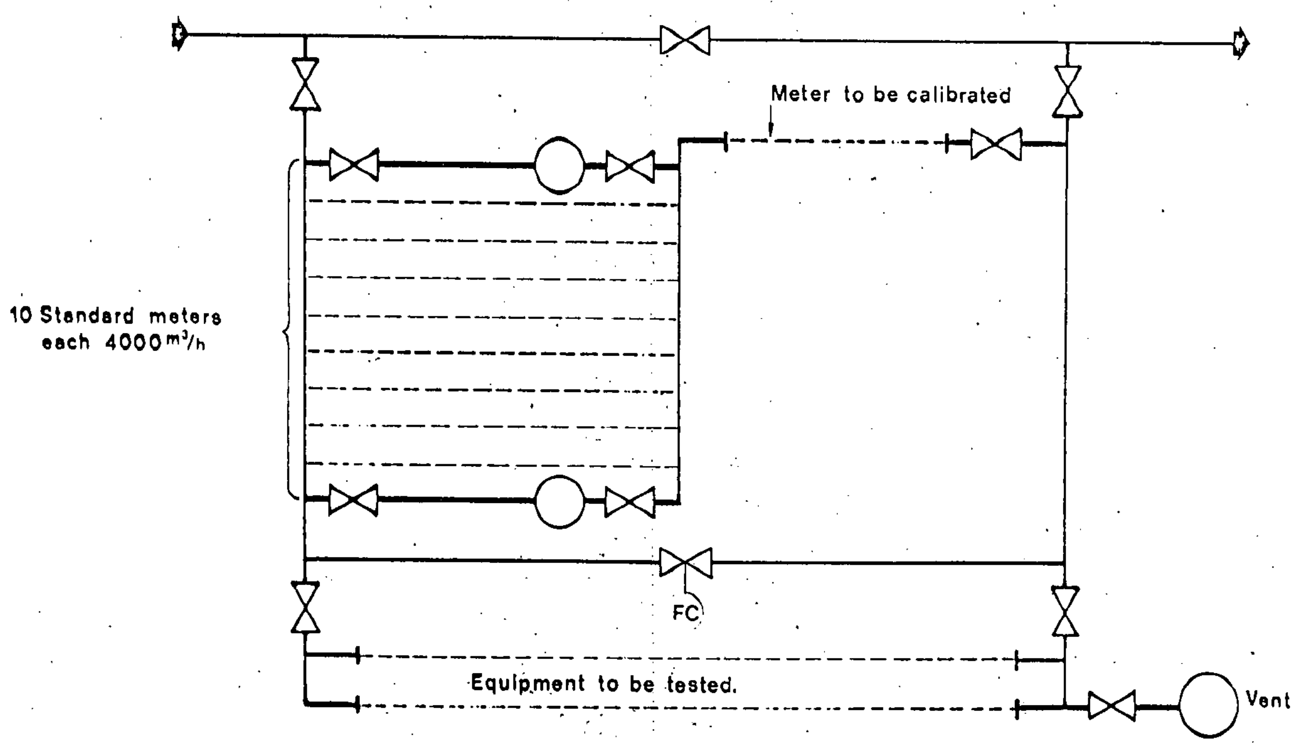


figure 7 ; High flowrate test facility "Westerbork"

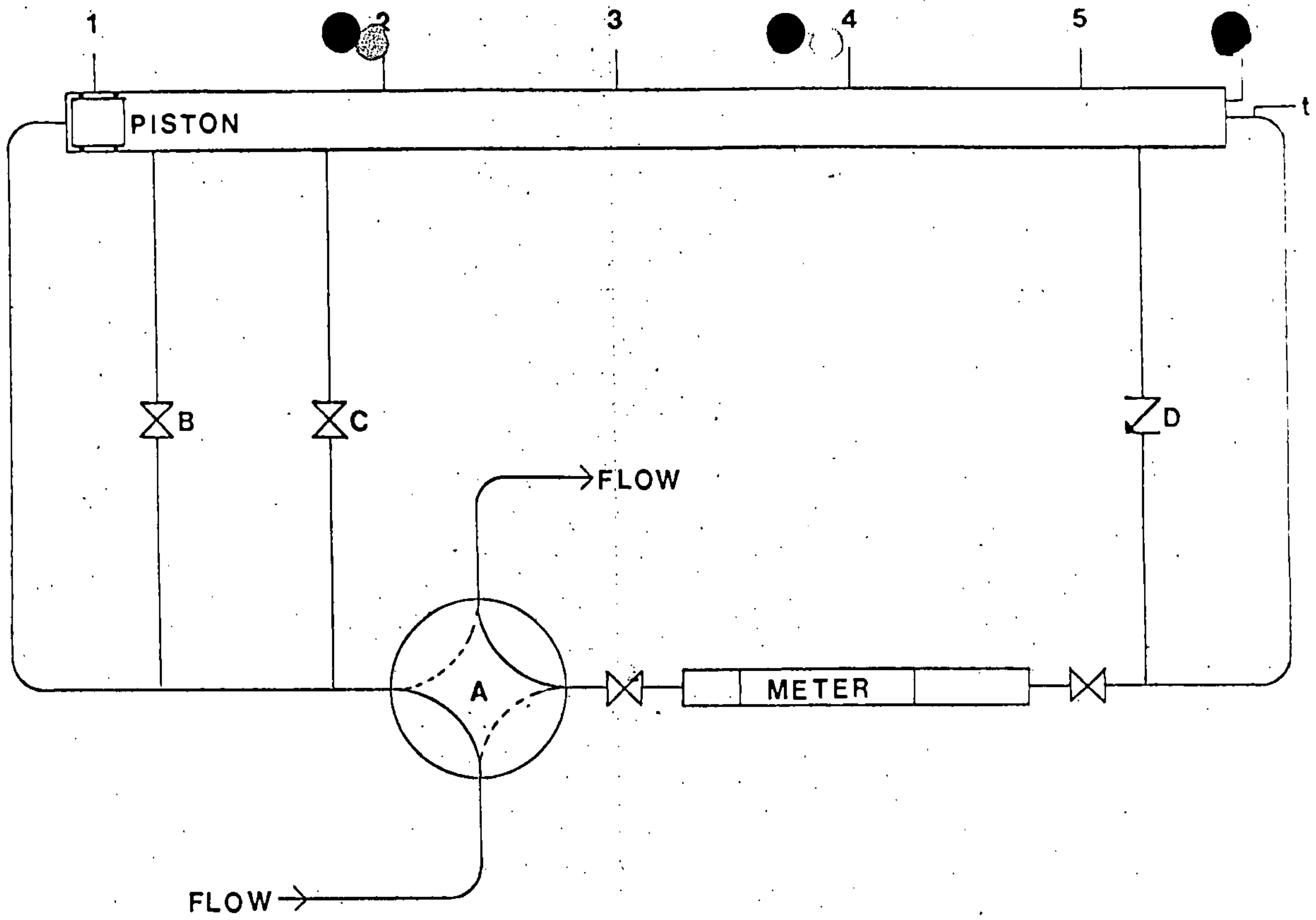


FIGURE 8

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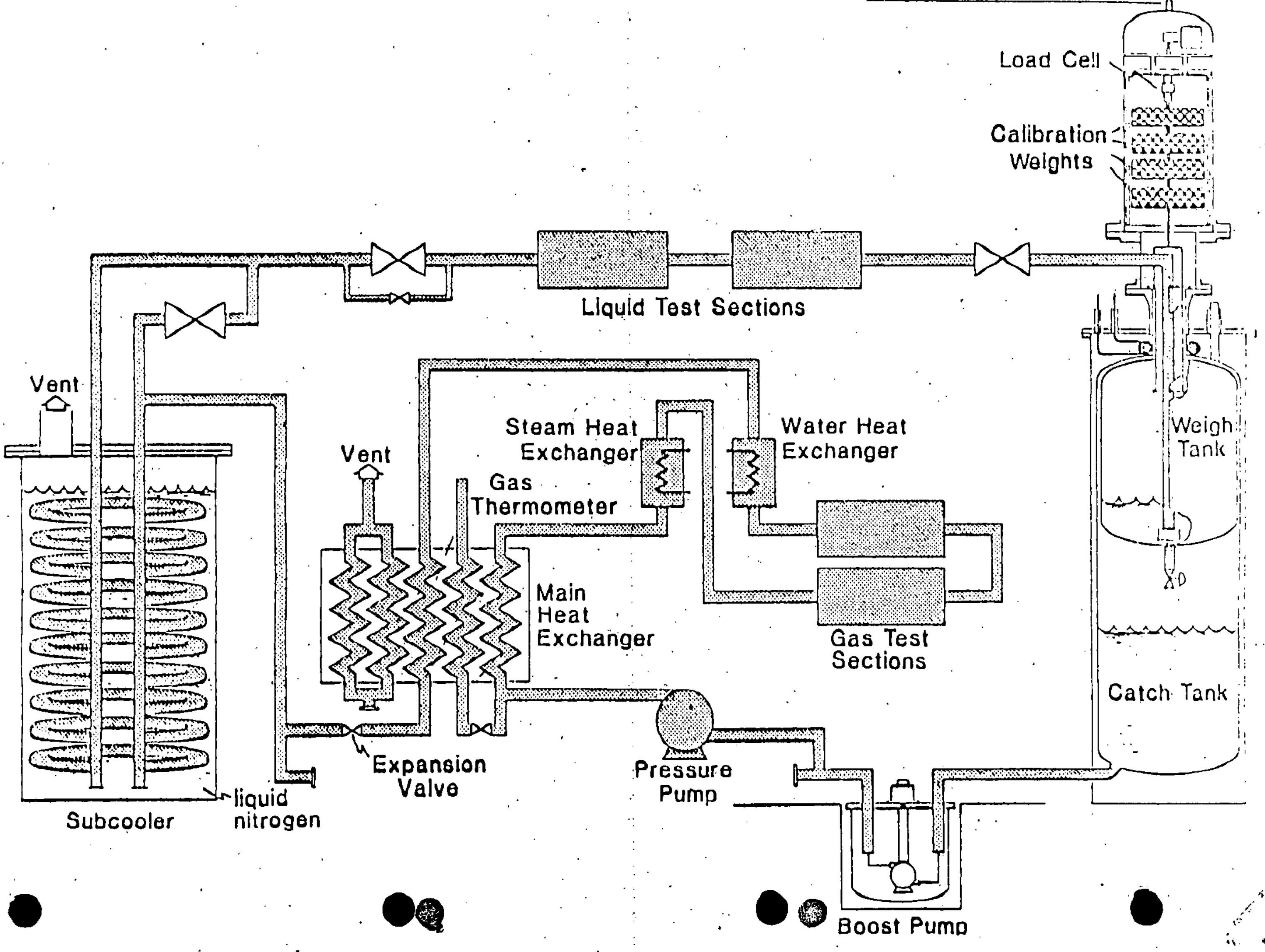

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Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.