Main Index

NORWEGIAN SOCIETY OF CHARTERED ENGINEERS

NORWEGIAN SOCIETY FOR OIL AND GAS MEASUREMENT

NORTH SEA FLOW MEASUREMENT WORKSHOP 1993
26 - 28 October, Bergen

Cariolis Mass Flow Measurement

by

Mr. Stewart Nicholson,
NEL, UK

CORIOLIS MASS FLOW MEASUREMENT

S Nicholson

NEL, East Kilbride, Glasgow

SUMMARY

This paper describes the work undertaken during a two year consortium funded project at NEL. The consortium consisted of nine members and was established to examine the generic behaviour of Coriolis Mass Flowmeters in practical applications.

To this end, eight manufacturers each supplied a one-inch nominal bore meter. The calibration results from tests on these meters are summarised. None of the results discussed are directly attributed to a particular manufacturer to preserve confidentiality arrangements.

The tests covered a range of liquid densities, viscosities and temperatures. Tests were also undertaken to quantify installation and air entrainment effects on the meters. NEL also undertook gas tests on six of the meters. LPG tests were undertaken by NMI in The Netherlands.

INTRODUCTION

Coriolis meters have been used in the market-place for some years, although it is fair to say that the market has been dominated by a few manufacturers.

Today there are many more Mass Flowmeter manufacturers and, to provide industry with comprehensive test data, meters from a range of manufacturers must be tested in any evaluation programme.

NEL* together with the consortium members decided that the project should support the testing of eight one-inch meters, which were supplied for the duration of the tests by the manufacturers listed below. This would provide a representative sample of the meters available at the time of the programme.

It was decided by NEL to form a consortium to fund test work on a range of coriolis meters and the nine member consortium comprised:

CONSORTIUM MEMBERS

Statoil
Philips Petroleum (UK) Ltd
Elf (UK) Ltd
Norwegian Petroleum Directorate
Total Oil Marine Ltd
Amoco (UK) Ltd
Amerada Hess Ltd
Kodak Ltd
DTI

MANUFACTURERS

Endress and Hauser
Schlumberger
Rheonik
K-Flow
Micromotion
Exac
Smith
Krohne

LEAD LABORATORY: National Engineering Laboratory (NEL)
LPG TESTS: Netherlands Measurement Institute (NMI)

The UK Department of Trade and Industry was represented by The National Weights and Measurements Laboratory.

---

* The National Engineering Laboratory Executive Agency (NEL) is an industrial research establishment within the Department of Trade and Industry concerned with most areas of mechanical engineering research. Within NEL, the Flow Centre is the holder of the United Kingdom National Standards for flow measurement. Facilities exist for calibration and research into water, oil and gas flow meters. All the facilities are fully traceable to the primary standards of weight, time, etc, and most are accredited by The National Measurement and Accreditation Service (NAMAS).

INITIAL TESTS

Each meter manufacturer or agent was initially invited to NEL to ensure that their meter was installed to their satisfaction before the first test.

All testing was carried out on the NEL low flow test loop. This consists of a gravimetric system using a 300 kg weightank with a pneumatically operated inlet valve which was fitted with switches to enable it to trigger start/stop timers and pulse counters. The tank was weighed using a mechanical weighbridge and the temperature taken using platinum resistance thermometers placed at either end of the test section and averaged over the duration of each test point. The test rig is illustrated in Fig. 1.

To enable standardisation, in meter package length, amongst all eight meters, an overall gap of 1.5 m was designated for the meters to be fitted into the test line.

Individual pipe lengths were manufactured to suit each package. Pressure tappings were located at either end of the 1.5 m package.

In an effort to gain some 'hands-on' experience of the meters, they were all given an initial calibration in kerosine at 20°C. This gave manufacturers an opportunity to comment on these tests and to resolve any initial faults encountered during them.

To enable a coriolis meter to perform within its specification the meter has to go through a zeroing process before being put into operation. This is to enable the meter electronics to establish a datum with which to compare future readings. To perform this duty it is important that the meter is purged of all air which may be contained within the meter's tubes. The meter should also be protected to some degree from external vibration from pumps etc, as well as being clamped according to each manufacturer's guidelines. The flow must then be stopped before the zero adjustment is undertaken.

Fig. 2 displays calibration results from a meter with the zero adjustment carried out satisfactorily. If the zero adjustment is not satisfactory then a meter will produce a calibration characteristic similar to the one shown in Fig. 3.

All of the meters were calibrated using the pulse outputs. Zero setting took place with the downstream valve closed before a test was undertaken, with the exception of the temperature tests. During the first test it was discovered that some of the meters 'download' pulse counts into a buffer memory which is emptied of pulses some seconds later. This allows the generation of 'real' pulses some seconds after the flow has been stopped. Obviously if these pulses are not counted this can cause errors in the calibration curve similar to that of an incorrect zero.

FLUID VISCOSITY AND DENSITY TESTS.

Density was measured 'off-line' using a hydrostatic balance and a first degree equation of density as a function of temperature was derived. This equation was then used to calculate the density of the liquid at the test temperature.

Viscosity was measured by a falling ball viscometer. This was again done off-line with the viscometer connected to a hydrostatic bath. Water, kerosine, gas oil and glycol were used as test liquids, thus enabling significant ranges of density and viscosity to be covered. This gave a viscosity range of 1.0-29.5 cSt between water and glycol at 20°C and a density range of 0.78-1.11 kg/l for kerosine and glycol at 20°C. Results shown in Fig. 4 show a meter that was not affected by changes in viscosity or density, whereas Fig. 5 shows a meter that has a density effect and Fig. 6 a meter that suggests a viscosity effect.

Only one meter performed within the manufacturer's specification over the entire range of liquid tests. Two meters gave satisfactory results at high and medium flowrates but drifted outside the manufacturers specification towards true lower flowrates. The remaining meters showed large calibration shifts.

Density comparison readings ranged from the best meter giving results within 0.001 kg/l and the worst within 0.120 kg/l.

INSTALLATION EFFECTS

To simulate installation effects on the meters, tests were undertaken to investigate the effects of:

- Tensile loading
- Compressive loading
- Swirling velocity profile
- Vibration.

Tensile and compressive loadings were introduced using a hydraulically operated expansion piece upstream of the meter package. This was utilised to introduce compressive forces of up to 800 kgf and tensile forces of up to 350 kgf. None of the meters was affected by either of those tests.

Swirl was introduced by offsetting the meter package by means of a non-coplanar bend assembly followed by a further 90 degree bend. This arrangement was fitted immediately upstream and downstream of the meter package and is illustrated in Fig. 7. Pump vibration was isolated from the meter by utilising rubber bellows upstream of the offset pipework. Two of the eight meters showed signs of zero drift at low flowrates after swirl was introduced. This is illustrated in Figs 8 and 9. This effect may have been caused by the installation of this pipeline configuration rather than the fluid swirl as the high flow calibration was unaffected.

Finally, the meter package was vibrated in the vertical axis. This was done by installing an electromagnetic actuator to the upstream pipework of the meter package as illustrated in Fig. 10.

Acceleration forces of up to 10 m/s² were applied over a frequency range of 30-1000 Hz, although each test was concentrated over that particular meter's tube vibration frequency.

Only one meter showed an effect from these forces. This occurred at one particular frequency which was different from that meter's tube vibration frequency.

TEMPERATURE EFFECTS

The meters were tested at three temperatures between 5 and 40°C. The test liquid in this series of tests was water. Each meter was zeroed at the datum temperature, which could have been high or low temperature depending on the meter sequence in the test schedule. When the initial test was completed, the test temperature was then reset, the system allowed to settle and the next test completed. This was followed by the final test. During these tests, the meters were not rezeroed, switched off or drained of test liquid.

Fig. 11 illustrates a meter with poor temperature effect results, with an error of approximately 1.5 per cent at mid-flowrange. Fig. 12 shows a meter with a calibration which shows little or no temperature effect.

Of the eight meters, three showed no effects due to fluid temperature. Two meters showed calibration shifts in K-factor of 1.5 and 2 per cent. A further one had an increase in K-factor of 0.5 per cent and the remaining two had shifts of 1 and 1.5 per cent.

Temperature sensor location within the meter housing plays a significant part in how accurately the meter temperature readout reflects fluid temperature. If the sensor is attached to the outside of the tube then the sensor will be affected by the air temperature within the case as well as the tube material and fluid temperatures.

The variation in results from all the meter temperature read-outs is illustrated in Table 1.

DIFFERENTIAL PRESSURE

The differential pressure across each meter package was monitored throughout the tests using pressure tappings at either end of the package. These were connected to a calibrated Rosemount differential pressure transducer.

The pressure drop across the meter package was between 1.2 and 2.0 bar at a flowrate of 4.0 kg/s in kerosine.

Two of the meters tested gave audible signs of cavitation at 4 kg/s flowrate and their flowrate range was subsequently curtailed to prevent damage to those meters.

AIR ENTRAINMENT TESTS

The air entrainment test set-up is illustrated in Fig. 13. The air supply was taken from the NEL 7 bar supply and was controlled by a pressure regulator upstream of a critical flow nozzle package. This package contained a thermometer, a 0.508 mm diameter critical flow nozzle and an upstream pressure gauge. A non-return valve was fitted to prevent test fluid flowing back through the air supply line.

A critical flow nozzle was used to ensure that a constant mass flowrate of air within 0.3 per cent was supplied, provided the upstream pressure and temperature were maintained constant.

Air temperature and pressure were monitored using a platinum resistance thermometer and Texas Instruments pressure gauge respectively.

Each meter was thoroughly flushed and a mid-range flowrate set with no air injected. The meter was zeroed and an initial test point was undertaken. An air flowrate of approximately 2 per cent by volume was set using the air regulator and the air flow stopped. The meter was purged of air and the liquid flow stopped. The test point was started by simultaneously starting the liquid and pre-set air flowrate and stopped by closing both flows simultaneously when the weightank was full. This method was repeated with air percentages up to 4 per cent by volume.

None of the meters performed satisfactorily. Two of them ceased to operate on introduction of the two phase flow. One further meter gave a spread of results of 3 per cent but the density readings during the test points fluctuated by 10 per cent. The remaining meters gave calibration errors of up to 58 per cent.

No correlation could be found between volume of air and K-factor error.

GAS TESTS

These tests were carried out in the Gas Flow Measurement Laboratory at NEL using air.

This set of tests can be split into two distinct sections: low and high pressure. Three meters had been supplied with 18 bar max pressure flanges and were tested at pressures of 15 bar across a flowrange 0.1-1.0 kg/s. Three meters were supplied with flanges capable of withstanding high pressures. These were tested at 60 bar over a flowrange of 0.1-2.0 kg/s. Two meters were not tested in air at the manufacturers' requests.

Of the three meters tested at low pressure, one gave results having a repeatability of 15 per cent. The remaining two exhibited linearities of approximately 0.6 per cent greater than was achieved from liquid tests and repeatability of, in one case, 1 per cent greater than in liquid tests. In both these cases this related to a 10 per cent calibration shift in the K-factor results.

In the high pressure tests one meter failed to operate. The remaining two meters displayed linearities of 1.5 and 1.3 per cent and repeatability of ±0.3 per cent greater than their respective liquid tests.

Fig. 14 illustrates a low pressure test with zero set at 15 bar and zero set at ambient pressure. This shows a typical result in the difference in repeatability depending on the pressure at which the meter's zero is set.

Fig. 15 shows a high pressure test result where the meter was zeroed at both 60 bar and ambient pressure and the results are similar, in this case.

LPG TESTS

Six meters were sent to NMI in The Netherlands for testing at the Shell Pernis plant using LPG to give an extreme value of density.

The meters were all reconfigured to standardise the pulse outputs allowing calibration by a compact meter prover.

Fig. 16 illustrates a typical meter calibration where the LPG results have been re-calculated and superimposed onto a graph of the previous test liquids. There is a shift in K-factor of approximately 0.5 per cent. Overall the LPG results produced linearities of 0.05-1.0 per cent and repeatability of similar order to those of the respective meters in other liquid calibrations.

CONCLUSIONS

From the results found the meters can be separated into four groups.

- One meter performed within the manufacturer's specification in all test phases.

- Two meters performed to the manufacturers' specifications after initial teething problems had been overcome.

- A further two meters, although not meeting the manufacturers' specification, indicated that the specification could be obtained with further upgrading.

- The remaining three meters provided erratic test results throughout the test series.

It is obvious from the above that while a minority of manufacturers' meters perform satisfactorily, the majority showed significant room for improvement.

It is encouraging to note that since the inception of this project many manufacturers have come into the market with new products and most of the manufacturers whose meters were tested in this report have already developed new meters or upgraded the meter electronics.

TABLE 1.

Nominal temperature	13°C		20°C		45°C	
Meter Ref	NEL °C	Meter °C	NEL °C	Meter °C	NEL °C	Meter °C
1	12.18	10.60	19.95	19.00	45.29	44.50
2	12.24	11.22	19.86	18.96	46.14	45.24
3	12.75	N/A	19.94	N/A	45.34	N/A
4	12.29	12.70	19.96	20.10	45.10	43.90
5	12.34	13.30	19.93	21.00	44.69	N/A
6	12.74	12.60	20.16	20.00	45.74	45.00
7	12.39	15.00	20.04	23.00	44.91	47.00
8	12.85	14.10	20.40	21.20	46.28	44.50

Note: Meters 3 and 5 not tested at all 3 temperatures

TEST METER TEMPERATURE COMPARISO

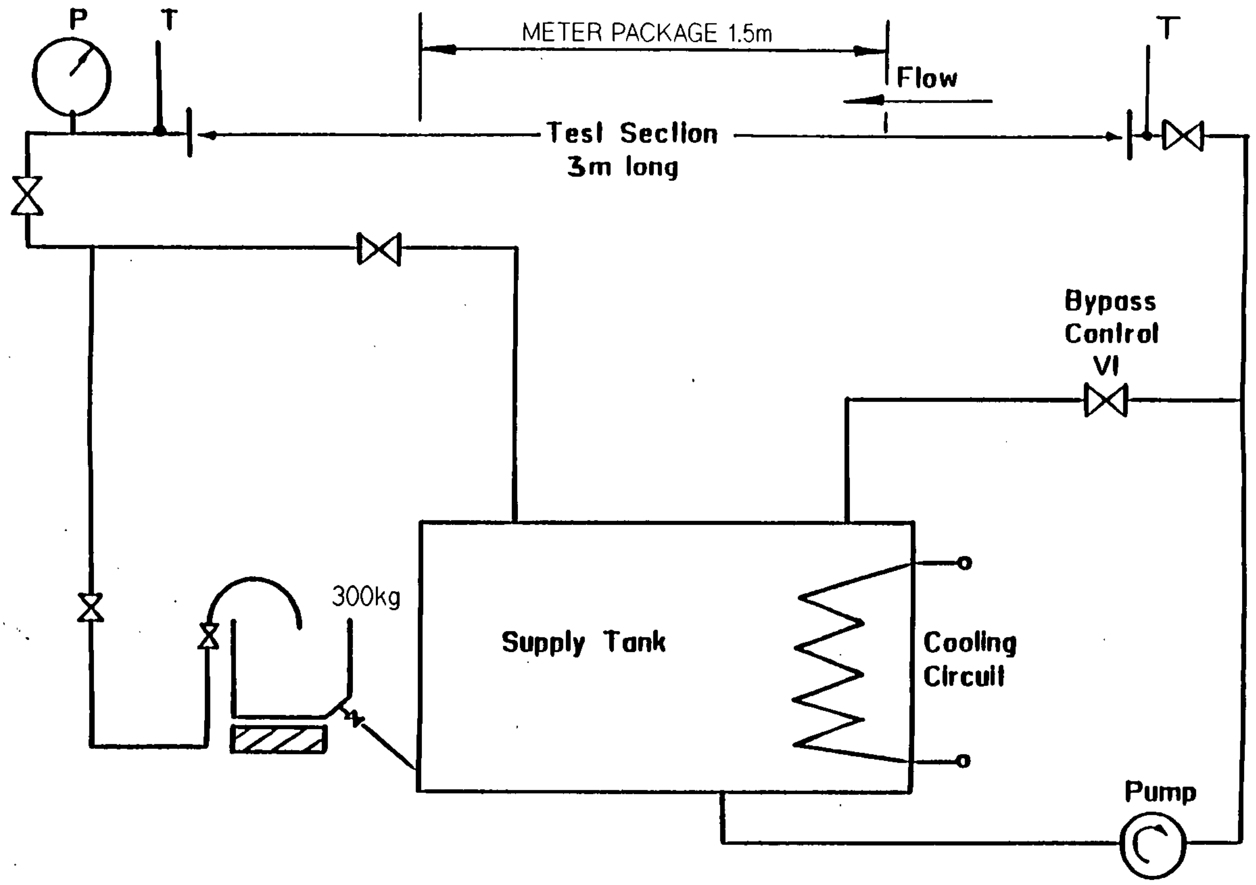

FIG.1. TEST RIG LAYOUT

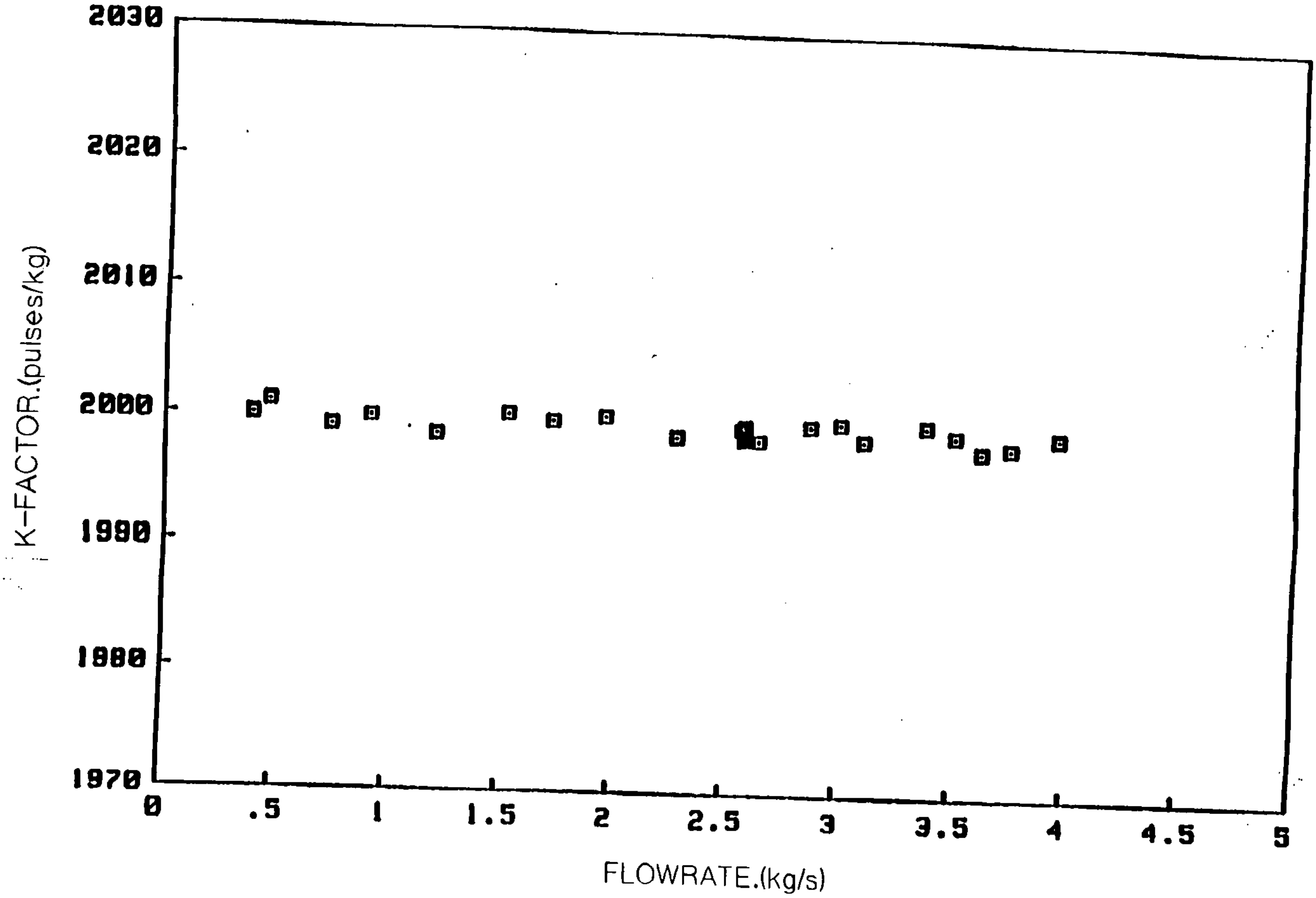

FIG.2. SATISFACTORY ZERO CALIBRATION

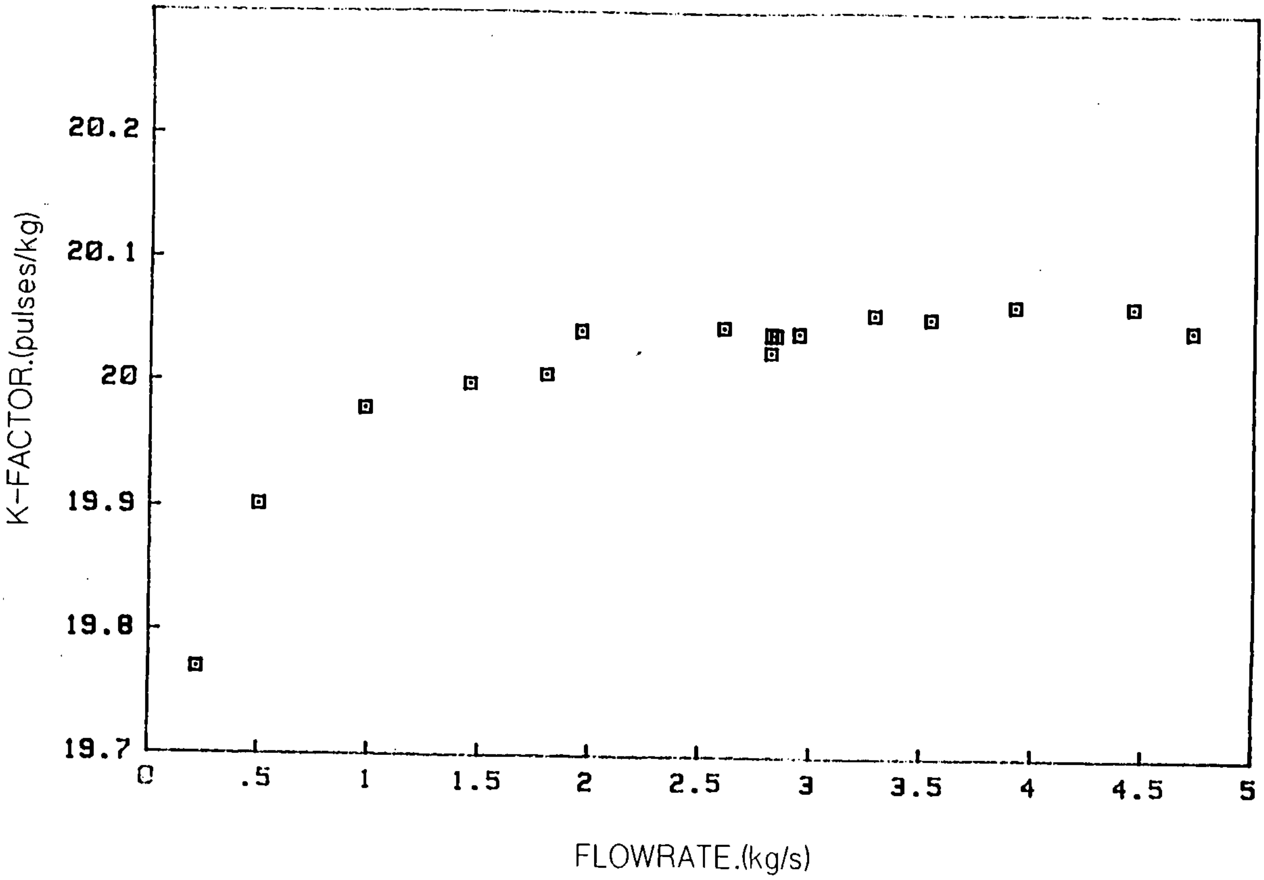

FIG.3. UNSATISFACTORY ZERO CALIBRATION

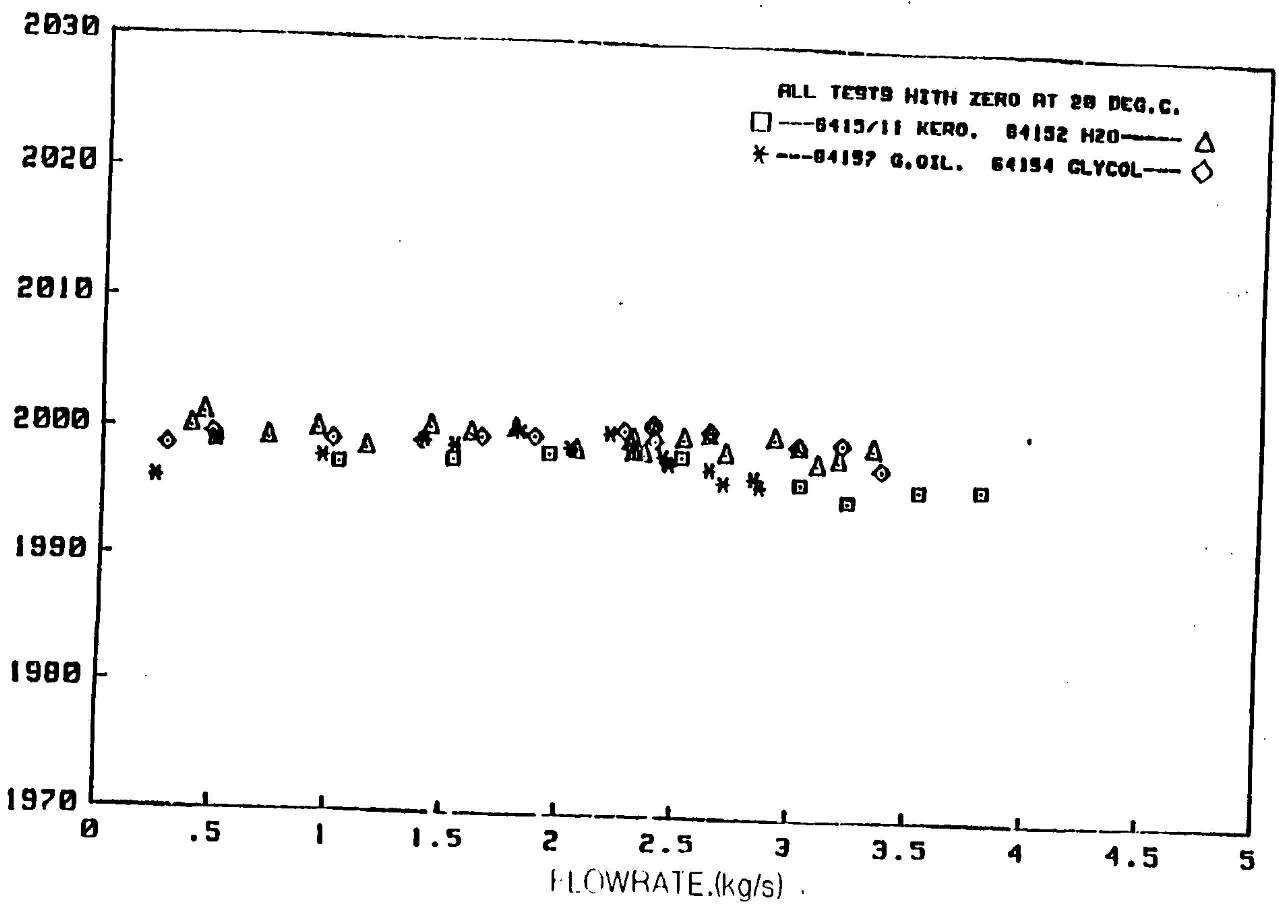

FIG.4. NO DENSITY OR VISCOSITY EFFECTS

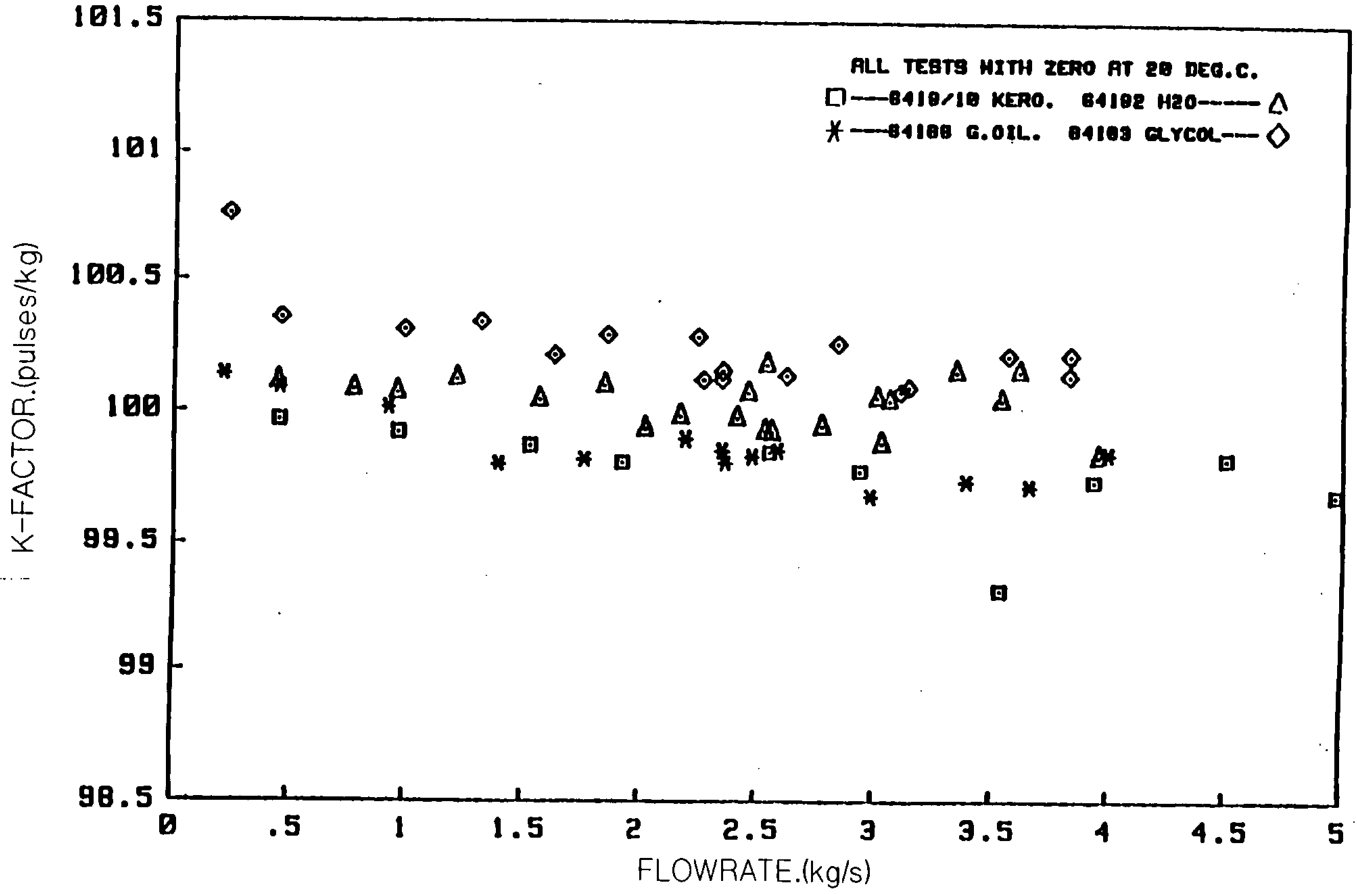

FIG.5. DENSITY EFFECT

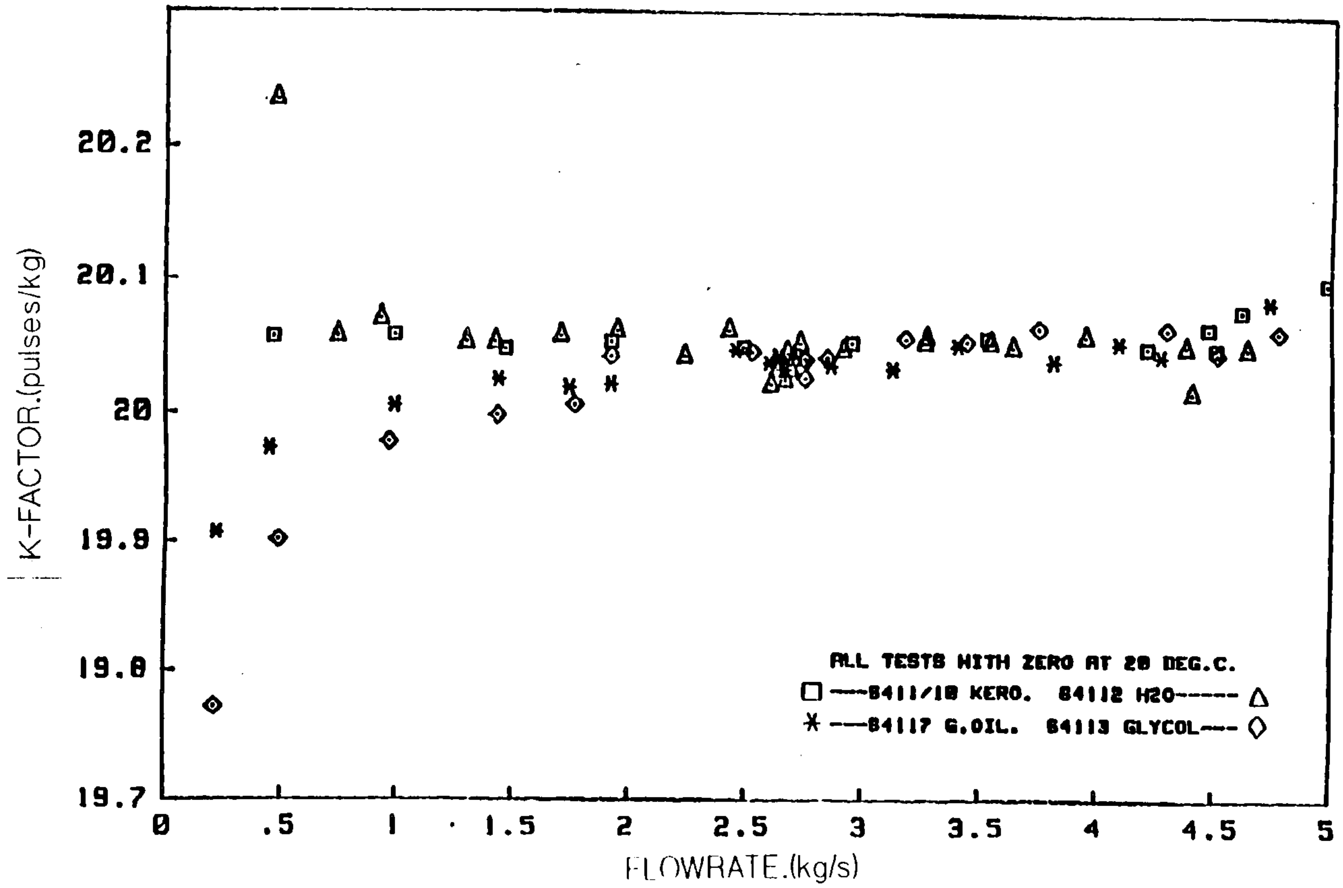

FIG.6. VISCOSITY EFFECT

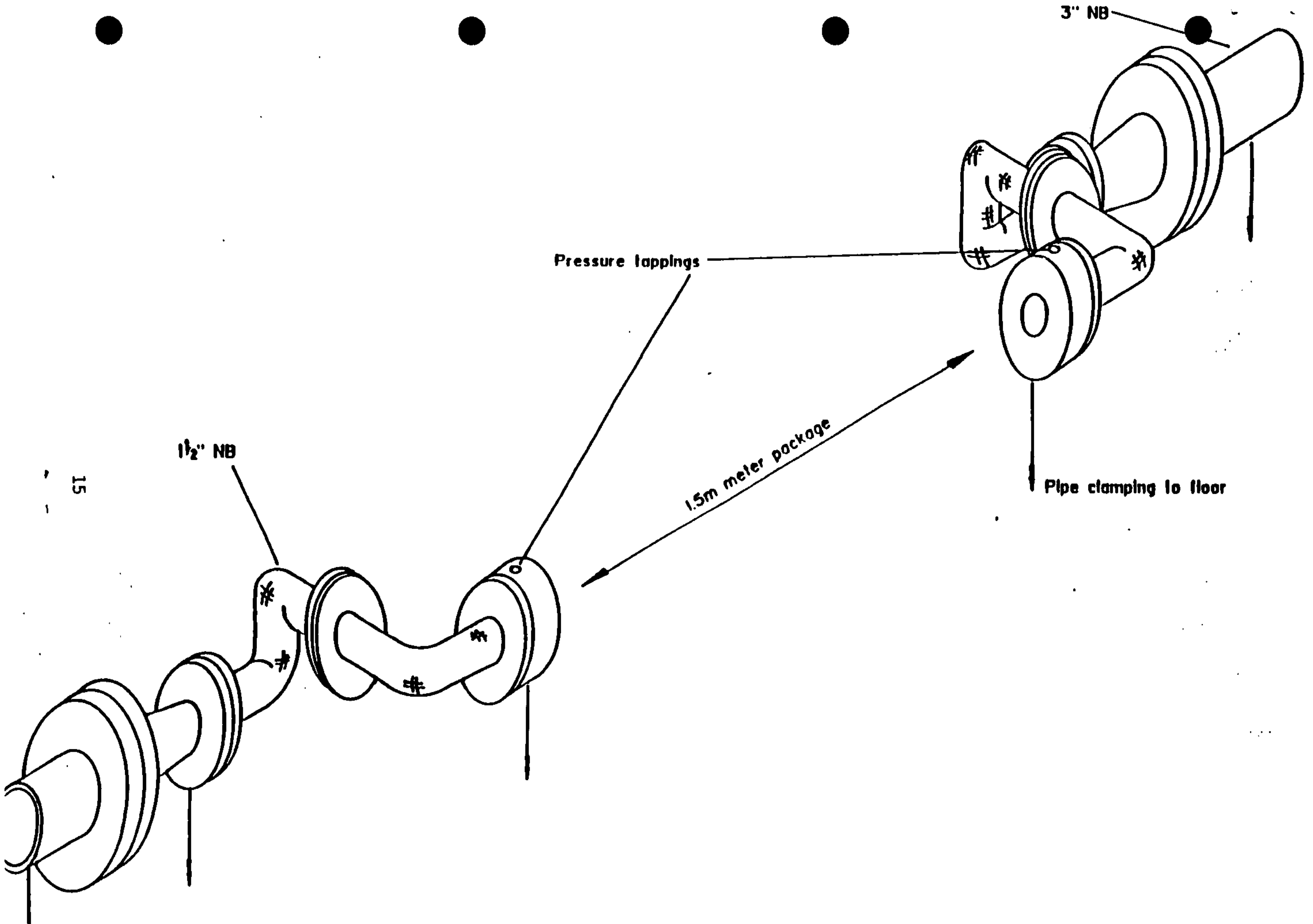

FIG.7. SWIRL EFFECT TEST. PIPE LAYOUT

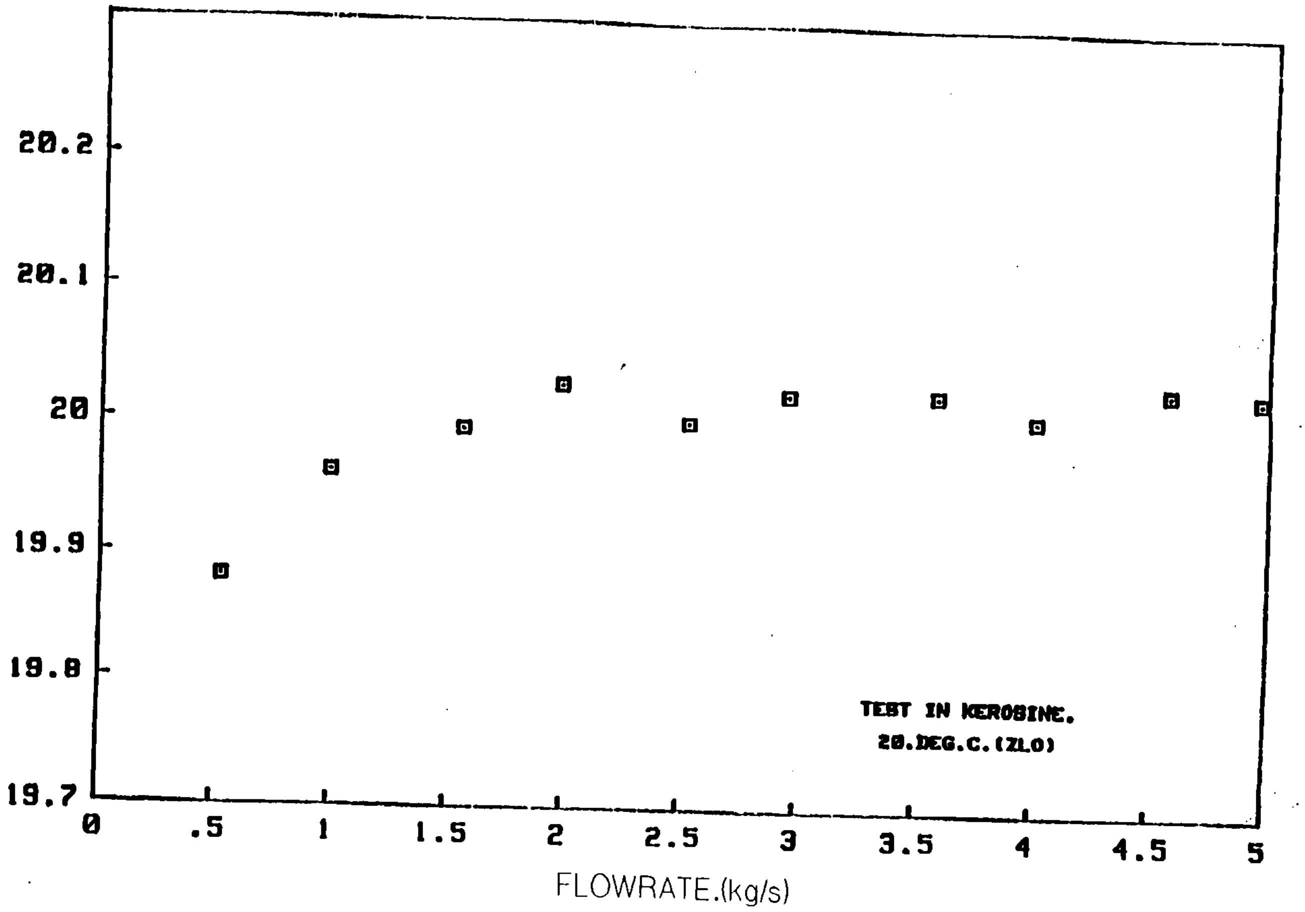

FIG.8. ZERO DRIFT DURING SWIRL TEST

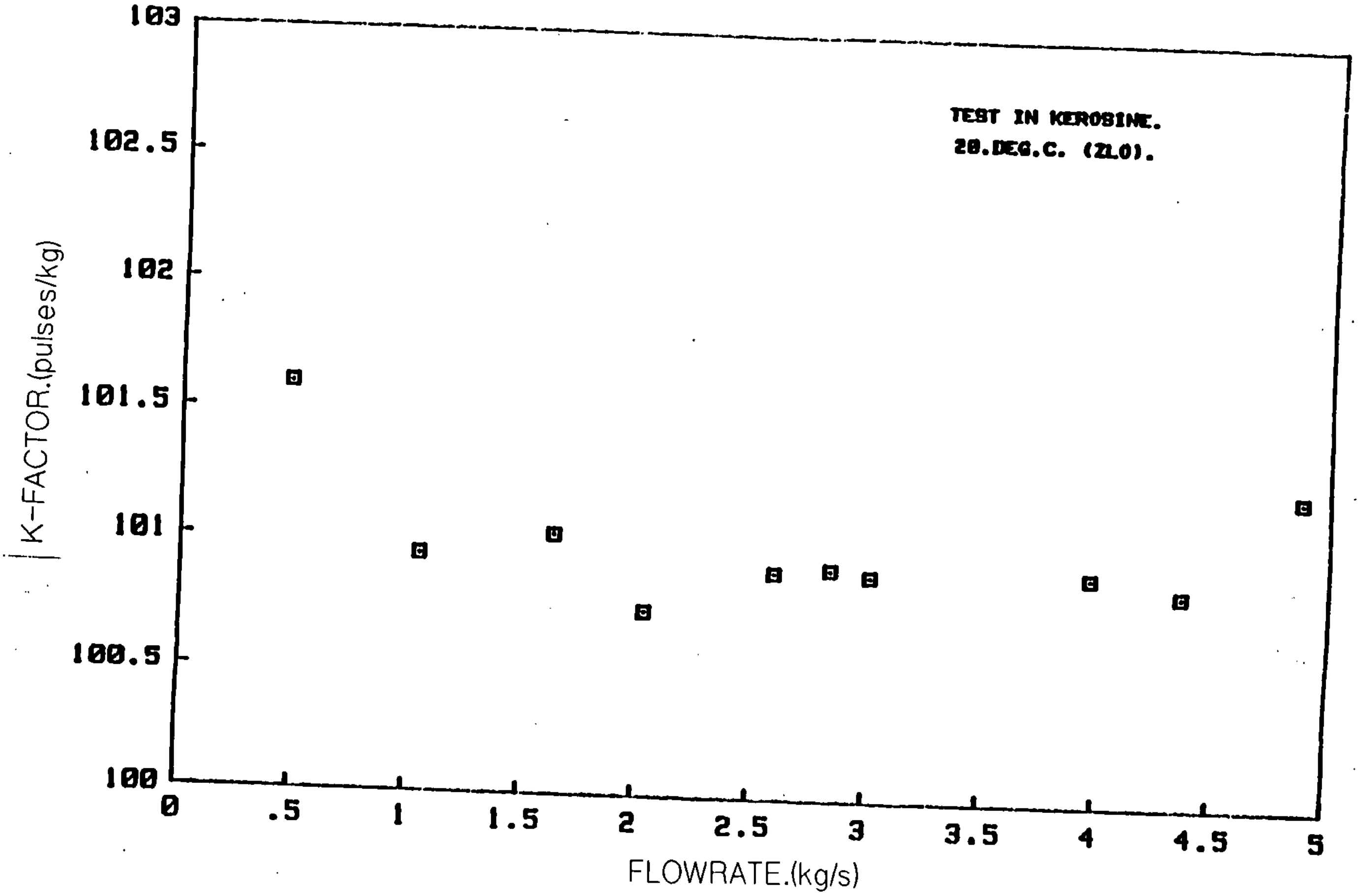

FIG.9. ZERO DRIFT DURING SWIRL TEST

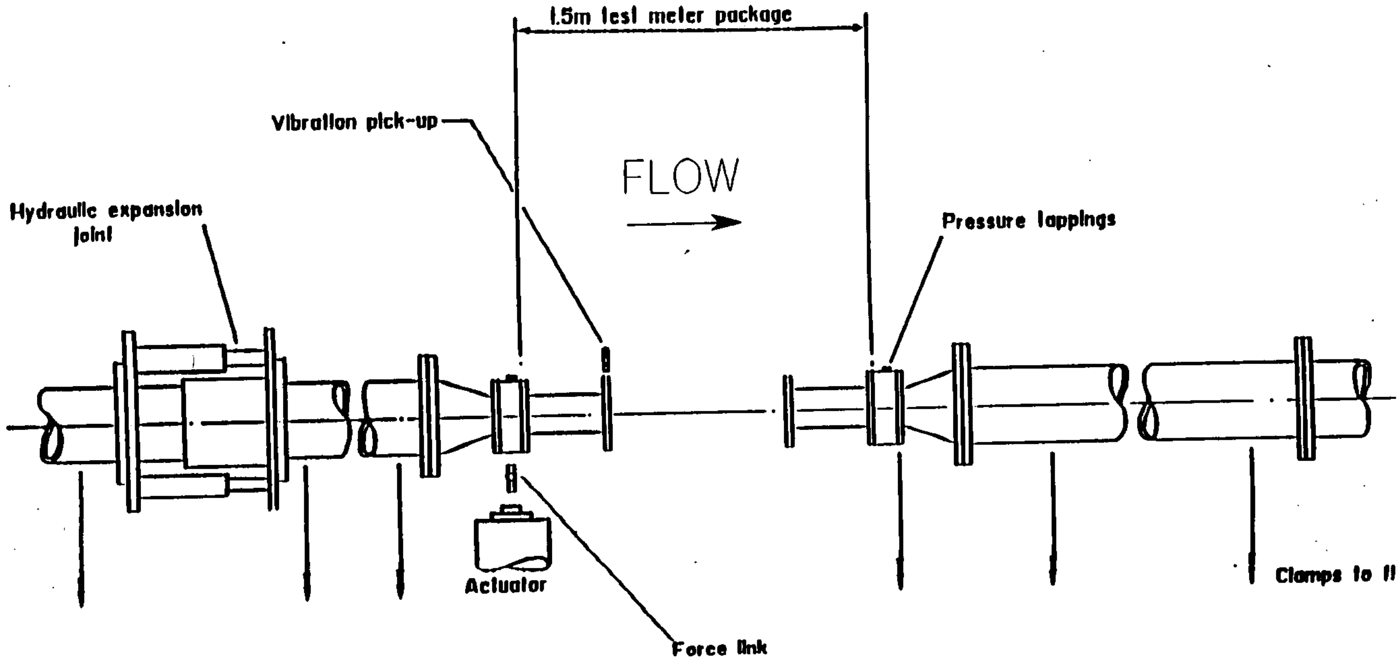

FIG 10 VIBRATION EFFECT TEST. PIPE LAYOUT

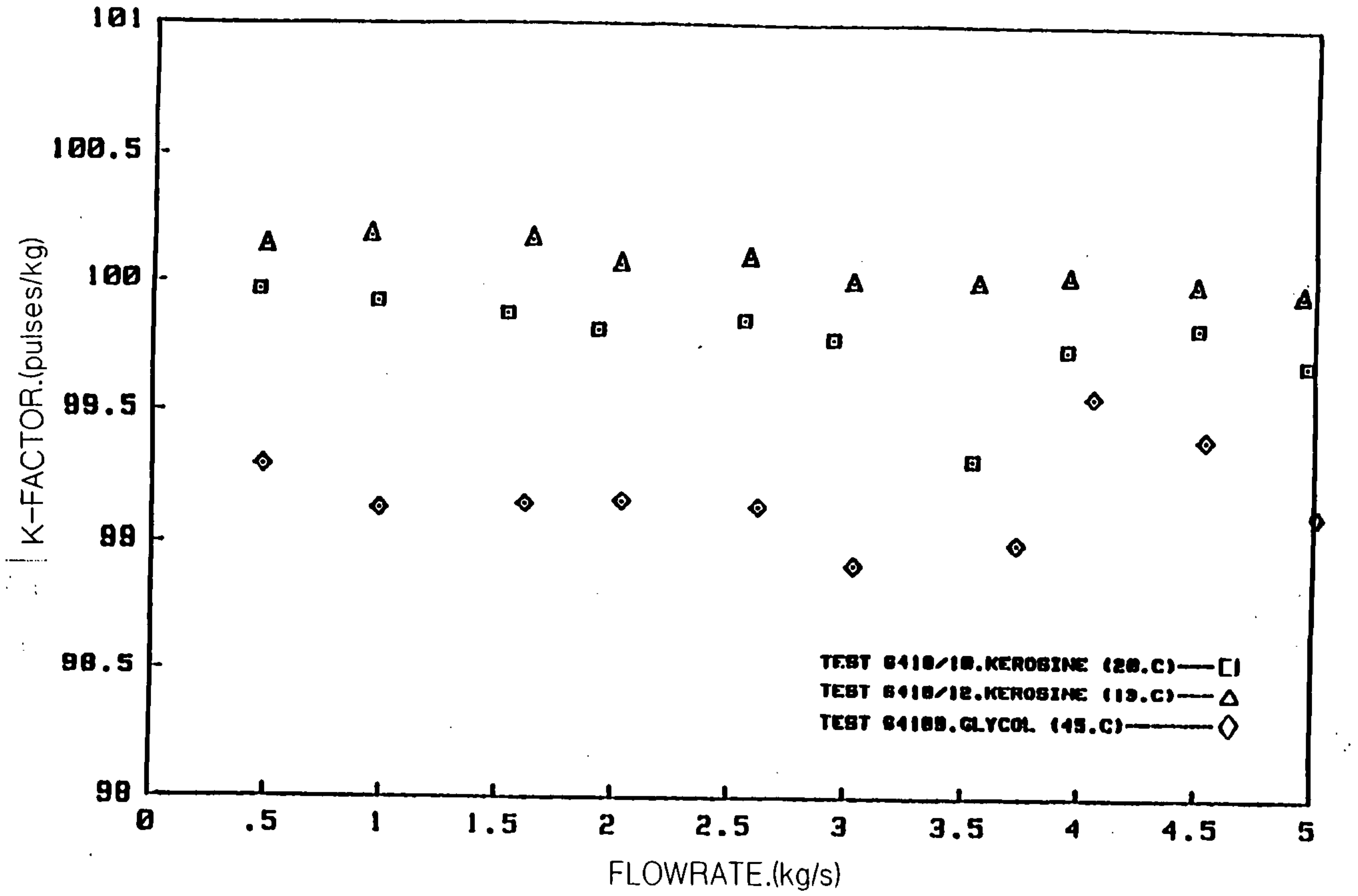

FIG.11. POOR TEMPERATURE EFFECT CALIBRATION

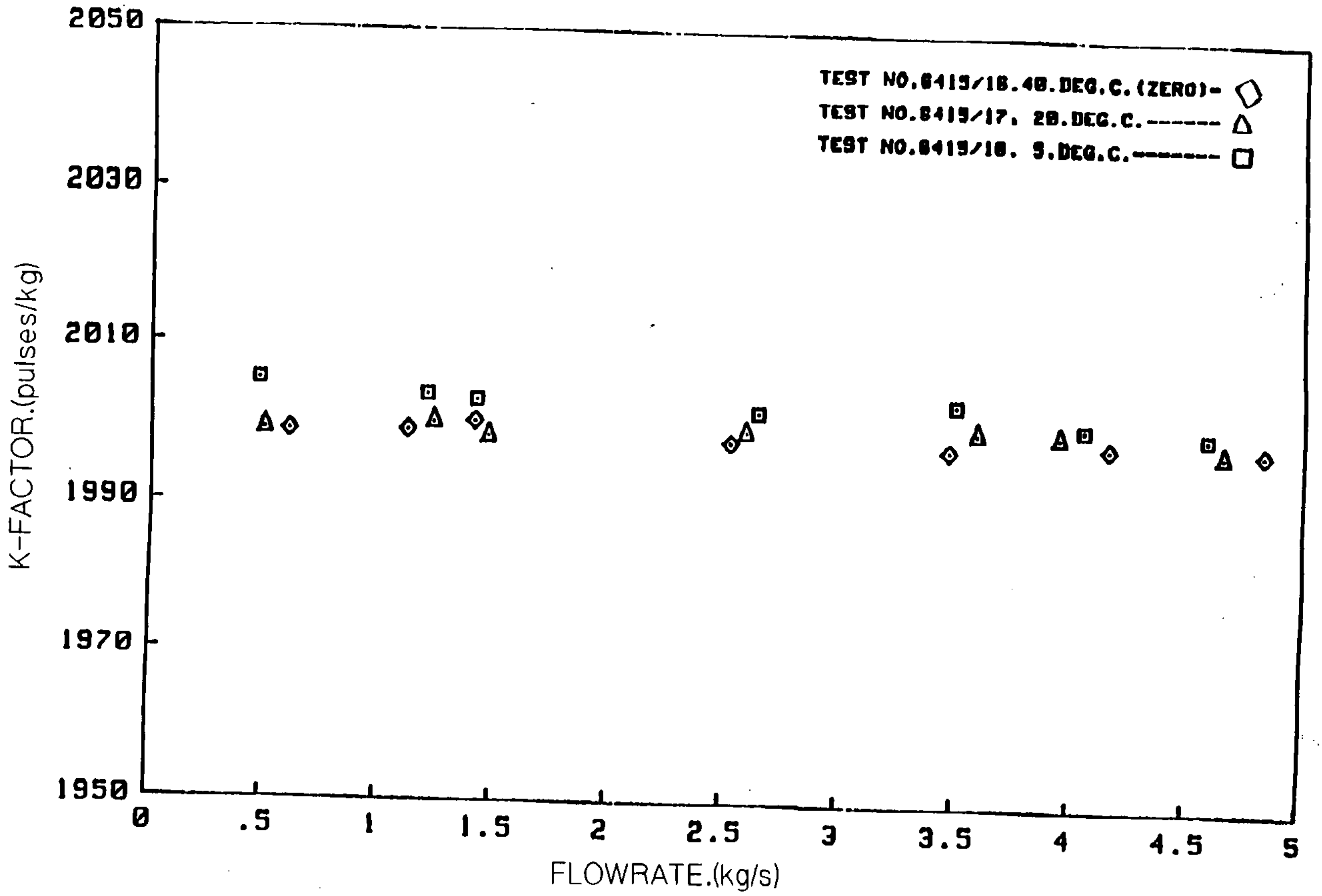

FIG.12. GOOD TEMPERATURE EFFECT CALIBRATION

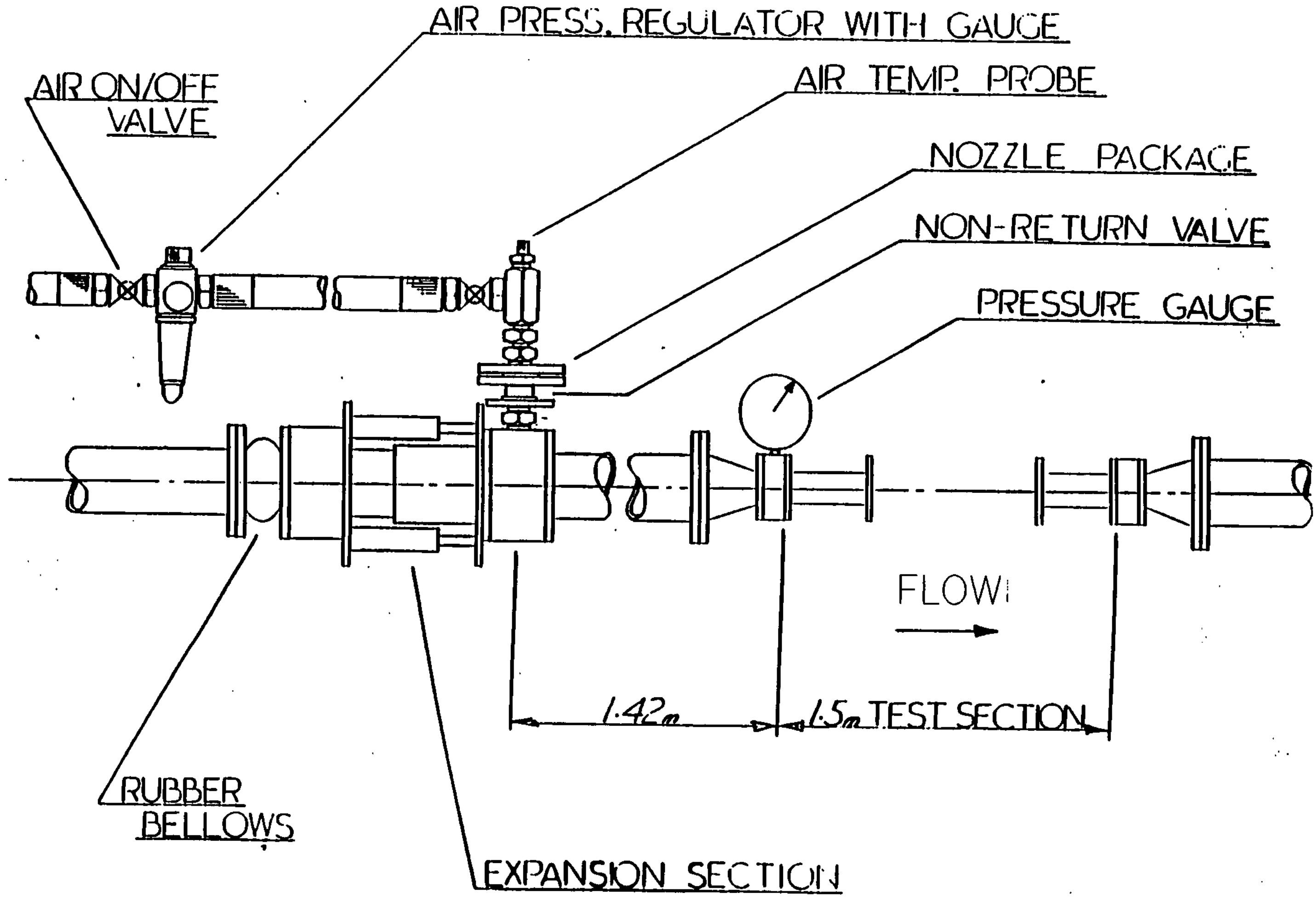

FIG.13. AIR ENTRAINMENT TEST. PIPE LAYOUT

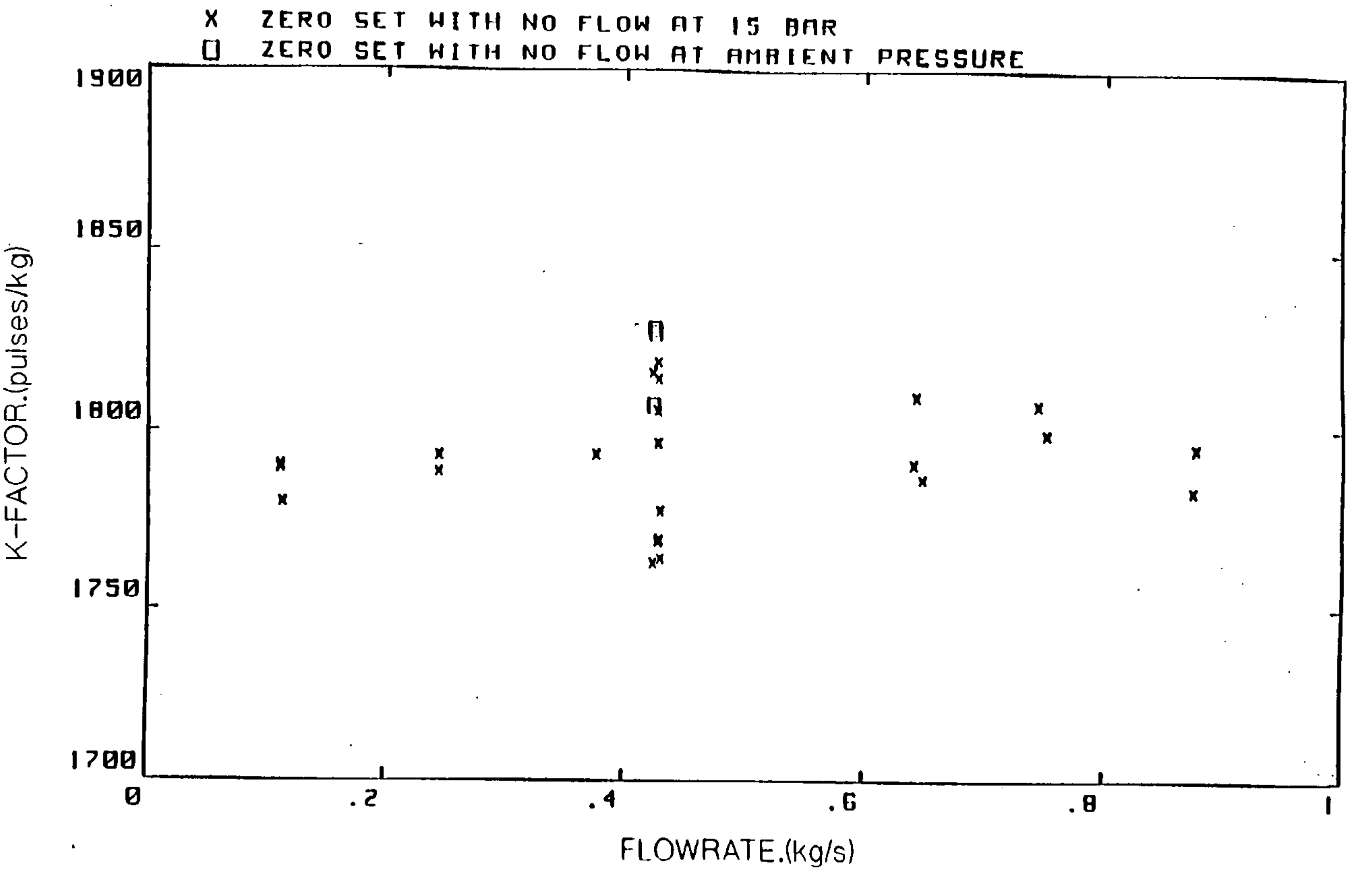

FIG.14. LOW PRESSURE GAS TEST RESULT

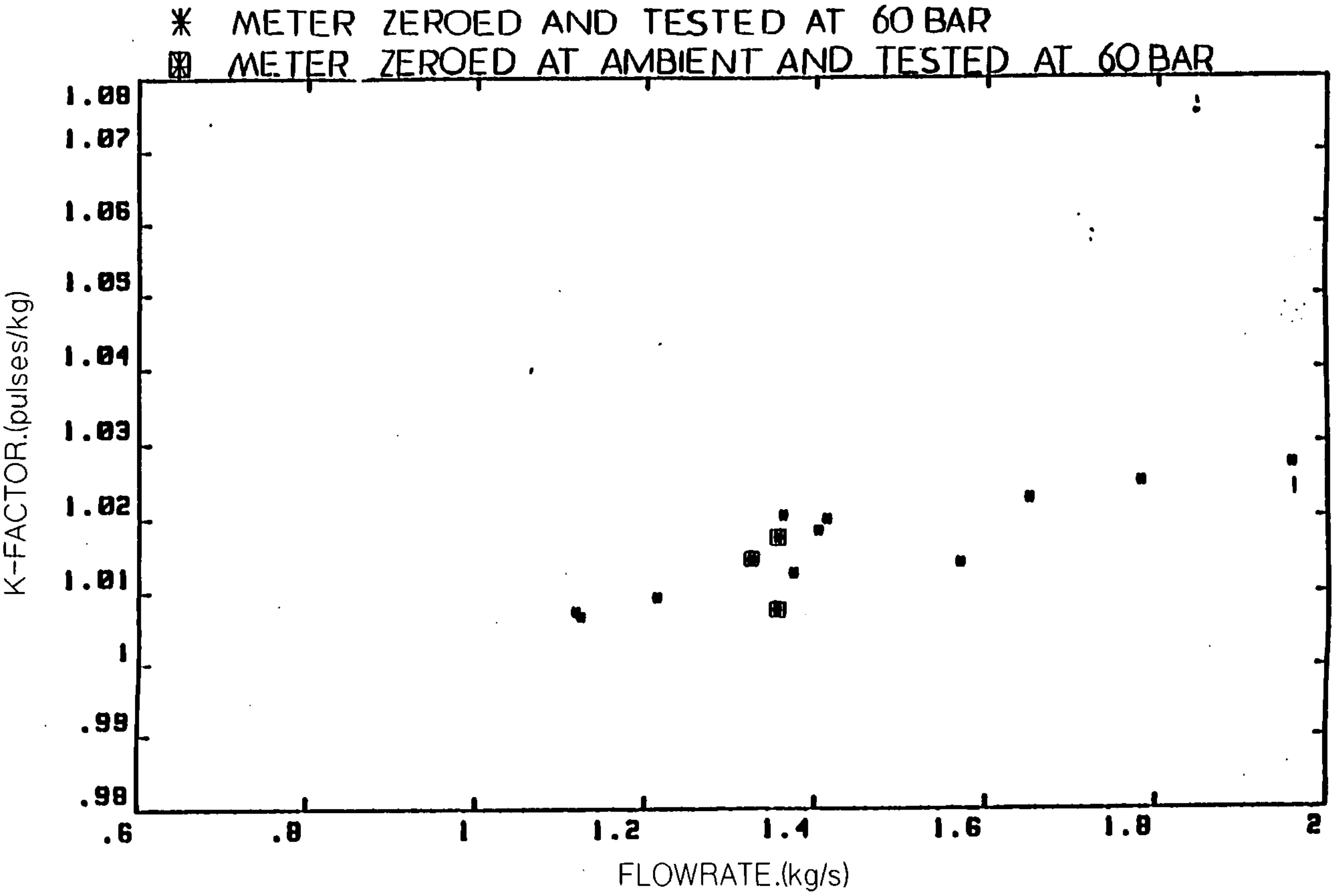

FIG.15. HIGH PRESSURE GAS TEST RESULT

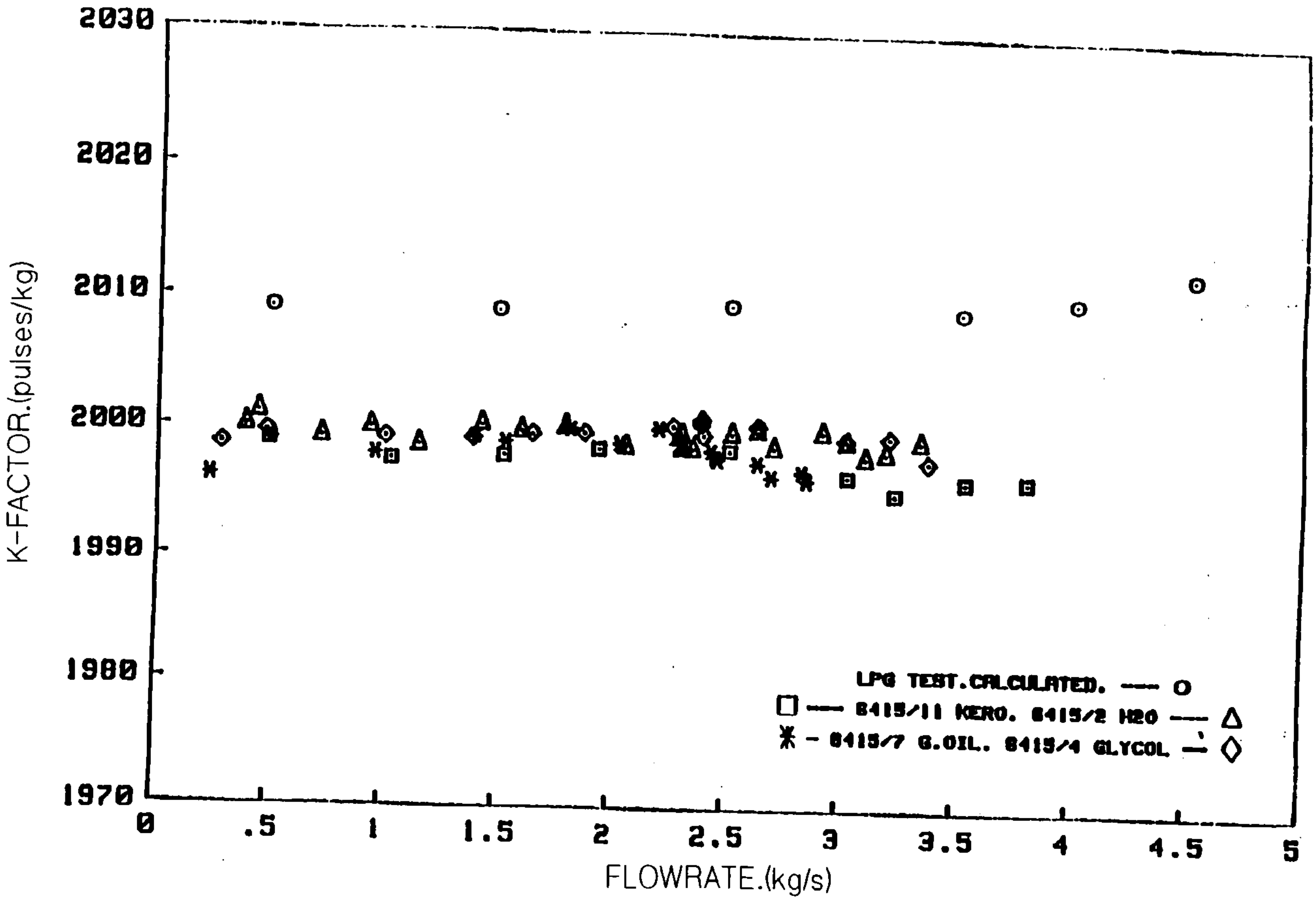

FIG.16. LPG AND LIQUID TEST RESULT

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.