THE NEL SAMPLING PROJECT

by

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INTRODUCTION

Water is present in crude oil flowing from most sub-sea wells and may account for up to 30 per cent of the volume produced. With oil now costing $30 a barrel both fiscal authorities and the operators need to know the exact composition of the crude oil they produce, sell and buy. An under- or over-estimation of 1 per cent, for example, in measuring the water content of a crude carrier's cargo represents a cash value approaching half a million pounds. It is impossible to separate the water in bulk for measurement purposes so reliance is placed on accurate analysis of small samples taken from the crude as it flows through a pipeline. As every part of the sample taken has to represent perhaps 5 million parts of the bulk cargo, it is obviously important that the sample taken be as representative of the cargo as possible.

To study the aspects of representative sampling and to improve present sampling methods, a consortium of 14 organisations concerned with fiscal custody and transfer of crude oil are sponsoring an on-going research programme at NEL. Using a unique two-component test facility, NEL has studied the performance of both proprietary and NEL-designed sampler systems under a variety of conditions. Quantitative measurements of the sampler's

performance and high-speed photographic techniques of their operation have identified certain areas where the samplers can be improved. The demand to perfect these samples is so great that a larger and more comprehensive test facility is being built at NEL to continue the work well into the late 80s.

A BRIEF HISTORY OF SAMPLING RESEARCH AT NEL

In the early 70s the price of crude oil was such that little attention was given to the accuracy of samplers. The rapid escalation in oil prices in the mid 70s changed this attitude however. At this time the newly formed Department of Energy became involved with the fiscal aspects of measurement in the North Sea and asked the NEL to evaluate a number of automatic samplers in current use in the North Sea. This work subsequently expanded into examinations of vertical sampling, mixing affects of bends and jet mixing.

A wealth of experience and the build-up of a comprehensive test facility at NEL resulted from this work. A closer liaison with the oil industry through IP and ISO committees was also established and at the conclusion of the Department of Energy's programme, an industrial consortium was formed to continue the work. This consortium, made up of the 14 members given in Table 1, has sponsored phases one and two of a continuing research project on automatic sampling. A third phase will soon be commencing for the period 1984/85.

BENEFITS OF A LABORATORY-BASED RESEARCH PROGRAMME

Rarely can a laboratory simulation be used to totally analyse a particular phenomenon; in most cases it is good practice to supplement laboratory data

with field data before drawing any conclusions. Several advantages are possible with laboratory simulations, however, and in the case of automatic sampling, these are described below.

a Reduced Costs

One method of studying the effect of pipe geometry or sampler operation on sampling accuracy is to measure the response of a sampler mounted in an actual on-stream pipeline and inject a known flowrate of water. This obviously involves a lot of expense in that normal operation of the pipeline is suspended and the injected water must be separated from the oil after the tests have been completed. Even for small refineries, ship discharges or production platforms, typical costs will run into thousands of pounds per hour of testing. The major advantage of such an expensive exercise is that the measurements are made on real crude oil in an actual field installation.

The use of a small-scale laboratory test facility as used at NEL is, by comparison, very cost effective. The cost of a new 200 mm diameter test facility being built at present, for instance, will cost about £40,000 and require a staff of only two to operate. Typical running costs for such a facility will be in the order of £1000-1500 per week.

b Better Control of Variables

If a field installation is to be used then the possibility of the background water content varying during a test run must be taken into account. The lack of precise measurement and control of both oil and injected water flow-rates brings a large degree of uncertainty into the exercise. Further,

control over tanker discharge flowrates is unlikely to be possible when refinery programmes, shipping schedules etc have to be taken into account.

In a laboratory environment, however, not only can the individual oil and injected water flowrates be controlled accurately, but the way in which the mixture is conditioned can also be controlled in a known and repeatable way. In the NEL test facility, for instance, the water droplet size and water concentration profile can be controlled and determined in a precise and repeatable way. Also, the water concentration, mainflow velocity and physical and chemical characteristics of the fluids can also be set to suit the particular requirements of the test.

For safety and convenience reasons, it is inadvisable to use a real crude oil in the laboratory but in order to reproduce Reynolds and Weber numbers found in practice, NEL have opted for an odourless kerosine with a viscosity of about 2 cSt at 20°C. Considering the wide range in physical and chemical characteristics of world crudes there is little to be gained by choosing any one crude in preference to another or the kerosine used in the laboratory work. In the North Sea alone the viscosities of the crude ranges from 2-30 cSt and with pipe diameters ranging from 0.3-1.0 m and flow velocities from 1-4 m/s this gives a range of Reynolds numbers of 11 000 to 500 000. The test facility being built at present at NEL can study flows with Reynolds numbers ranging from 50 000-250 000, and so covers the major part of the range experienced in the field. If a different range of Reynolds number, Weber number etc is required, then it is not excessively expensive to change the fluid used in the test facility, some 10 m^3 compared with millions of cubic metres in a field installation.

c Improved Quantitative Measurements

Even in the best of weather conditions there will be problems in installing and using flowmeters and instrumentation in a field installation. Is there a stable power supply available? What about earth loops and is that pump cavitating because someone else is using the process line? Then when you have everything set up, the fire main from which you were to draw water loses pressure.

It would be less than truthful to say that hitches do not occur in the laboratory, but in such a benign, purpose-built environment they are much easier to predict, identify and remove. Further, the life expectancy and calibration of the delicate instruments and data logging equipment will be maintained much longer in the laboratory than in the hostile world of the refinery or tanker discharge quay. A laboratory facility also has the advantage that all parts are readily accessible and in close proximity and in the case of the NEL facility the further advantage that flowmeters can be regularly checked against reference meters in the NEL flow measurement laboratory.

d Possibility of Qualitative Assessments

Many of the fluids suitable for use in a laboratory test facility are optically transparent and this lends itself to qualitative analysis of sampler performance by photographic techniques. In the case of the NEL test facility for instance, the kerosine has the same refractive index as the Perspex used in the construction of the test section and hence no optical distortion occurs no matter what the profile of the kerosine/Perspex interface. Microflash still photography and high-speed cine photography

have both been used in the NEL facility to determine the trajectories of water droplets about and through the samplers under test. This information has been invaluable in helping to explain some of the quantitative results obtained in the research programme.

THE NEL TEST FACILITY

For a laboratory test facility to provide a useful tool in sampling research it must meet several important specifications as described below.

a Mainline flowrate range. Sampler response is very dependent on the mainline flow velocity so any test facility must be capable of producing as wide a range of flowrates as possible.

b Water concentration. The water content of crude oils varies considerably so any research facility must be capable of producing a range of oil/water mixtures of known and controllable concentrations.

c Water conditioning. Some mixing device must be installed in the test facility to produce water droplets of various known and repeatable sizes.

d Water separation. Having injected water into the oil flow, some means of separating it must be employed if continuous operation of the facility is to be achieved, ie if the water takes time to settle and separate from the oil, then only a 'once through' mode of operation may be possible with 'before' and 'after' tanks required.

e Cooling. If continuous operation is envisaged then some form of heat exchanger may be required to cool the recirculating flow.

The facility used up to the present time for all the sampling research performed at NEL was based on a 100 mm diameter test loop with a maximum flow velocity of 1 m/s. A new larger and more up-to-date facility with a 200 mm diameter test section is presently being built to replace it and this will be capable of mainflow velocities up to 2.5 m/s. A schematic of the new facility is given in Fig. 1.

In normal operation oil is pumped around the circuit by pump 'A', a variable speed unit capable of 7–70 ℓ/s flowrates at a discharge pressure of 300 kN/m^2. After a long straight 100 mm section the flow passes through a calibrated turbine flowmeter before doubling back on itself at 'B' and entering a diffuser section into the 200 mm diamter test section. Fig. 2 is a schematic of one of several configurations of the test section which is basically a modular Perspex block construction incorporating various elements.

Water, from a calibrated metered supply, is injected into the test section immediately upstream of a mixing device. In the figure a special orifice mixer is shown which, by virtue of the various mixing velocities it produces through its choice of orifice sizes, can give known and repeatable water droplet sizes. Other proprietary devices could also be installed if required, or the mixing device could be removed entirely if the dynamic loop was to be used (see later).

The sampler to be examined can be installed in one of the Perspex blocks and positioned any distance downstream of the mixing section and in any orientation. A water micro-injector can be lowered into the flow immediately upstream of the sampler to study the trajectories of the individual water droplets by photographic means.

After passing through the test section, the water/kerosine mixture is constrained into a 100 mm pipe which in normal operation leads through valve 'C' to the diverter valve 'D'. The diverter is only used if a bulk sample is required as an absolute measure of the water content of the mixture flowing in the circuit. To do this the flow is momentarily diverted into the steel measuring cylinder tank where the water is allowed to settle out and the absolute water content of the bulk sample determined.

In normal operation, however, the mixture is conveyed via a flexible hose into an inlet ring 'E' at the bottom of the vertical cylindrical separation tank of 10 m^3 capacity. The whorls of small holes on the inlet ring ensure a uniform percolation of the flow into the tank where it rises slowly upwards, allowing water to settle downwards for collection and further separation via a coalescing filter. The water is passed into a holding tank for further settling before subsequent re-injection into the test section flow. The rising oil in the main separation tank, now without its water component, is collected by an outlet ring 'F' of similar geometry to the inlet ring and returned via a flexible hose to the main circuit and pump inlet through valve 'G'. The height of the inlet and outlet rings in the main separation tank can be adjusted to cater for different levels of fluid and also to achieve the best water separation characteristics. The geometry of the tank is such that screens and different inlets and outlets can be accommodated to achieve the best separation characteristics for any other oils that may be used.

At higher mainline flows and greater water concentrations it may not be possible to separate all the water from the oil as the flow rises in the separation tank. In these cases, to avoid recirculation of water into the test section, the facility can be run in a closed or 'dynamic loop' mode.

In this case valves 'C' and 'G' are closed and valve 'H' opened so that the separation tank is excluded and the flow recirculated only within the dynamic loop. As the volume of the dynamic loop is known, a water/oil mixture of known proportions can be used to fill it before sampling tests begin. The mixture is then circulated for a period to ensure uniformity around the loop before sampling starts. This method of operation requires no separation and can be used when sampling for long periods is required, the volume abstracted by the sampler being made up by a small feed tank and the small change in water concentration calculated accordingly.

EXPERIMENTAL PROCEDURES

All quantitative testing on the facility is based on the fact that a known water concentration is presented to the sampler under test and this can be compared with the water concentration in the resulting sample.

The percentage concentration of water in the test section is determined directly from the flowmeter readings for the incoming water and oil flowrates as below:

$$I = \frac{\text{volumetric flowrate of injected water}}{\text{volumetric flowrate of water and kerosine}} \times 100 = \frac{W_I}{W_I + K_I} \times 100.$$

This can usually be calculated to better than ±0.01 per cent.

The percentage of water in the sample is determined by gravimetric separation of the water and oil components and individual volume measurement in calibrated measuring cylinders or pipettes as below:

$$S = \frac{\text{volume of water in sample}}{\text{volume of water and kerosine in sample}} \times 100 = \frac{W_S}{W_S + K_S} \times 100.$$

The sampling error, E, was then determined from:

$$E = \frac{S - I}{I} \times 100 \text{ per cent.}$$

A positive error would therefore mean the sampler was collecting more water than it should, while a negative error would mean the sampler was collecting less water than it should. Note that whereas I and S express the water content as a percentage of the total water and kerosine volume, E is expressed as a percentage of the water volume only and the difference in magnitude of the two types of percentage must be remembered when comparing values.

The experimental uncertainty in measuring the sampling error, E, was calculated as better than ±5.0 per cent.

The normal practice in performing a test is to mount a given sampler in its desired position and orientation and set the oil flowrate by adjustment of the pump speed. After allowing time to purge all the sampling system with neat oil, the water injection is started and sufficient time allowed to establish stable conditions before samples are collected for analysis.

SOME RECENT FINDINGS IN THE NEL SAMPLING PROJECT

All data and results obtained from the sampling project are of course

available only to the sponsoring organisations of the research programme and only generalities can be discussed here.

The research programme of phases one and two over the last two years has concentrated on the study of fast loop and proprietary grab samplers using the original 100 mm diameter test facility. During the course of the sampler assessments, much effort has also been devoted to assessing the characteristics of the test facility. For instance, a photographic exercise performed to determine the actual sizes of water droplets obtained at the various mixing conditions found the large droplet setting produced droplets of 0.53 mm diameter with a 95 per cent scatter of ±0.47 mm. Tests were also performed to determine the vertical water concentration profile which confirmed that, but for the lowest mainline flow with large droplet size, the profile was acceptable on the axis of the test section where the samplers were positioned. Checks also confirmed that water was not retained in the kerosine used even after vigorous mixing over a sustained period. All samples were found to separate into their water and kerosine components by simple gravimetric separation within hours of issuing from the sampler.

In order to provide an absolute calibration check on the system, several bulk samples were obtained. In this exercise the total mainline flow was diverted into a holding tank at the same time as the output from the water and oil flowmeters were integrated. The water content of the bulk sample was compared with the water content derived from the flowmeters and found to agree within 2 per cent over several different conditions.

Having confirmed that the test facility produced the required conditions, the programme continued with an examination of samplers themselves. The sampler response in different orientations and as mainline flowrate, water

content, droplet size, grab rate, percentage isokinetic sampling rates etc, were varied, was studied quantitatively and qualitatively. Some salient points which came to light during the test programme are given briefly below:

a Probe Orientation

In general it was found that both the fast loop and grab samplers should be mounted horizontally from the side if the best representative samples were to be obtained.

b Sampling Rate

In general it was found better to sample isokinetically, ie with the same velocity within the sampler probe as in the main flow, when using a fast loop sampler. The high-speed photography indicated that even when the grab samplers were operated at 50 grab/min the flow distortion caused by the grab operation was swept away by the mainflow well before the start of the next operation.

c Water Droplet Size

The work indicated that water droplet diameters exceeding 0.5 mm could produce sampling errors. The use of high-speed photography identified several fluid dynamic phenomena to explain these findings.

d Mainflow Velocity

The results of the work and the high-speed photography identified several

fluid dynamic problems that were affected by the mainflow velocity. Although higher mainflow velocities are desirable as regards adequate mixing of the pipeline contents, the higher velocities can also introduce eddies and turbulence about the sampler probe.

e Design of Sampler

Several strengths and weaknesses of the various samplers were identified and some modifications made to improve their performance. The confidential nature of the research programme and the proprietary samplers means that no comments can be made on any particular design.

f Analysis of Sample

The research identified that, in certain circumstances, inaccuracies could occur in the centrifuge method of water determination. The reason for this was identified as the result of inaccurate graduation markings on certain batches of ASTM centrifuge flasks.

THE FUTURE - THE PHASE-THREE TEST PROGRAMME

The design, construction and commissioning of the new 200 mm test facility will occupy most of the staff effort on the project until January 1985. Only then will the test facility be available for full-time experimental work when the first task will be to check water droplet size, water concentration profiles etc.

The proposed subjects for study are described individually below.

a Statistical Analysis of Pertinent Data

This will include an examination of field sampling data as supplied by member companies to try to identify trends in sampling errors. A point of particular interest for study will be the problem of the 10 000 grab requirement for each tanker unloading.

b Grab Samplers

Further work will be done on proprietary grab samplers in both standard and modified forms. Higher mainline velocities will be used for the tests in the new facility. The effect of water concentration transients may also be studied.

c NEL Fast-loop Sampler Probe

After the promising results of the phase two work with this design of probe, further work will be done in the new facility to assess its peformance over a wider operating range and also when manufactured in different bore sizes. Again, the effect of water concentration transients could also be studied and compared with the grab sampler results of (b) above.

d Secondary Sampling

Using the NEL design of fast-loop probe as standard, studies would be made of the effect of secondary sampling. The effect of water concentration transients on such a secondary sampling system may be examined.

e Flow Conditioning

A brief examination of the effect of pipe bends, proprietary mixers, and a NEL type of jet mixer would be undertaken.

All the above work would be performed in a horizontal test section. The new facility will be capable of mounting the test section vertically, but such an option may have to wait until a later phase in the research project.

TABLE 1

MEMBERS OF THE NEL AUTOMATIC SAMPLING RESEARCH CONSORTIUM

Amoco (UK) Exploration Co
BP International Ltd
Britoil plc
Chevron Petroleum (UK) Ltd
Department of Energy
Department of Trade and Industry
ELF UK plc
Esso Engineering (Europe) Ltd
Marathon Oil UK Ltd
Mobil Oil Company Ltd
Norwegian Petroleum Directorate
Occidental Petroleum (Caledonia) Ltd
Shell UK Oil
Union Oil Company of Great Britain

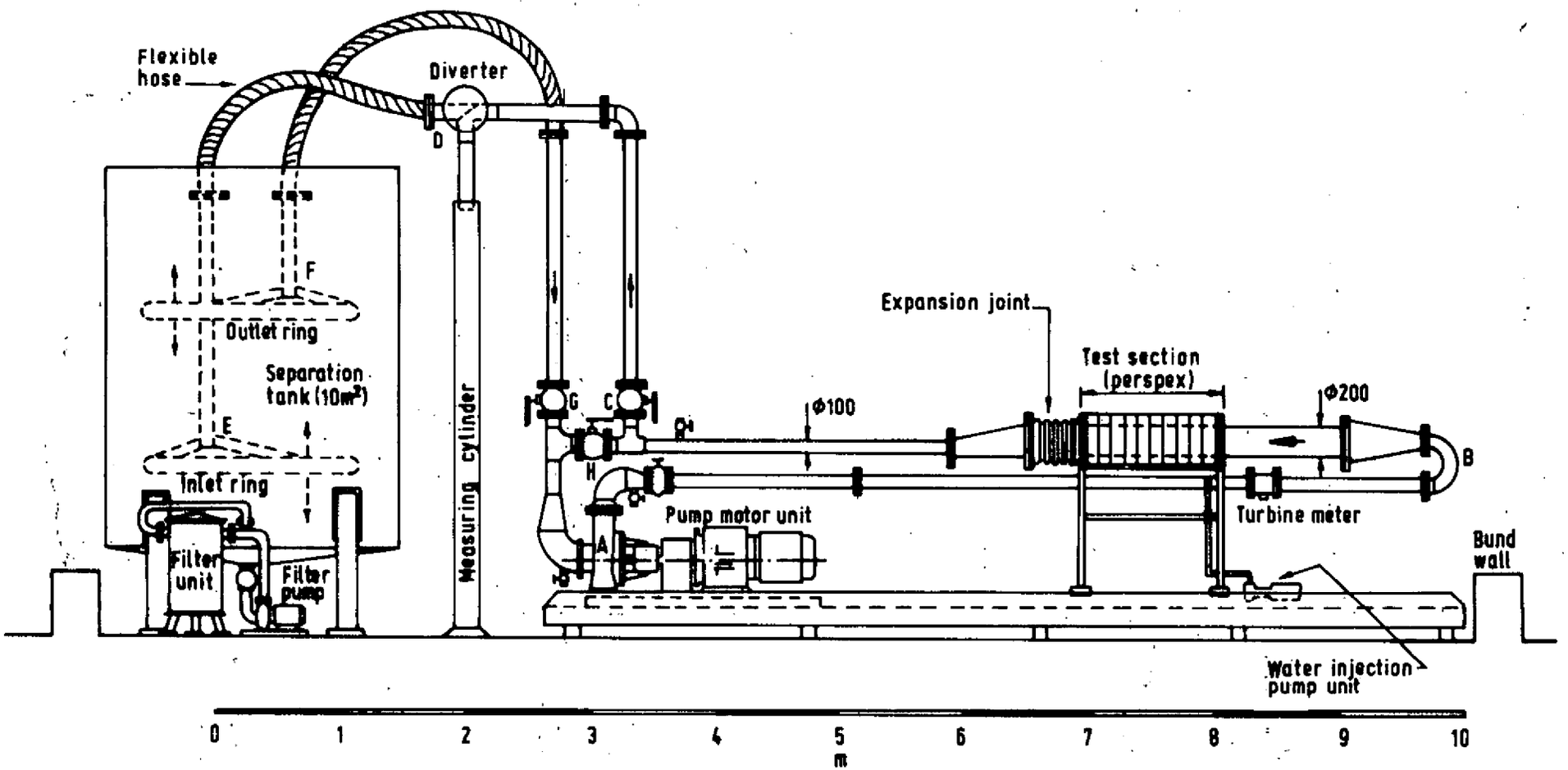
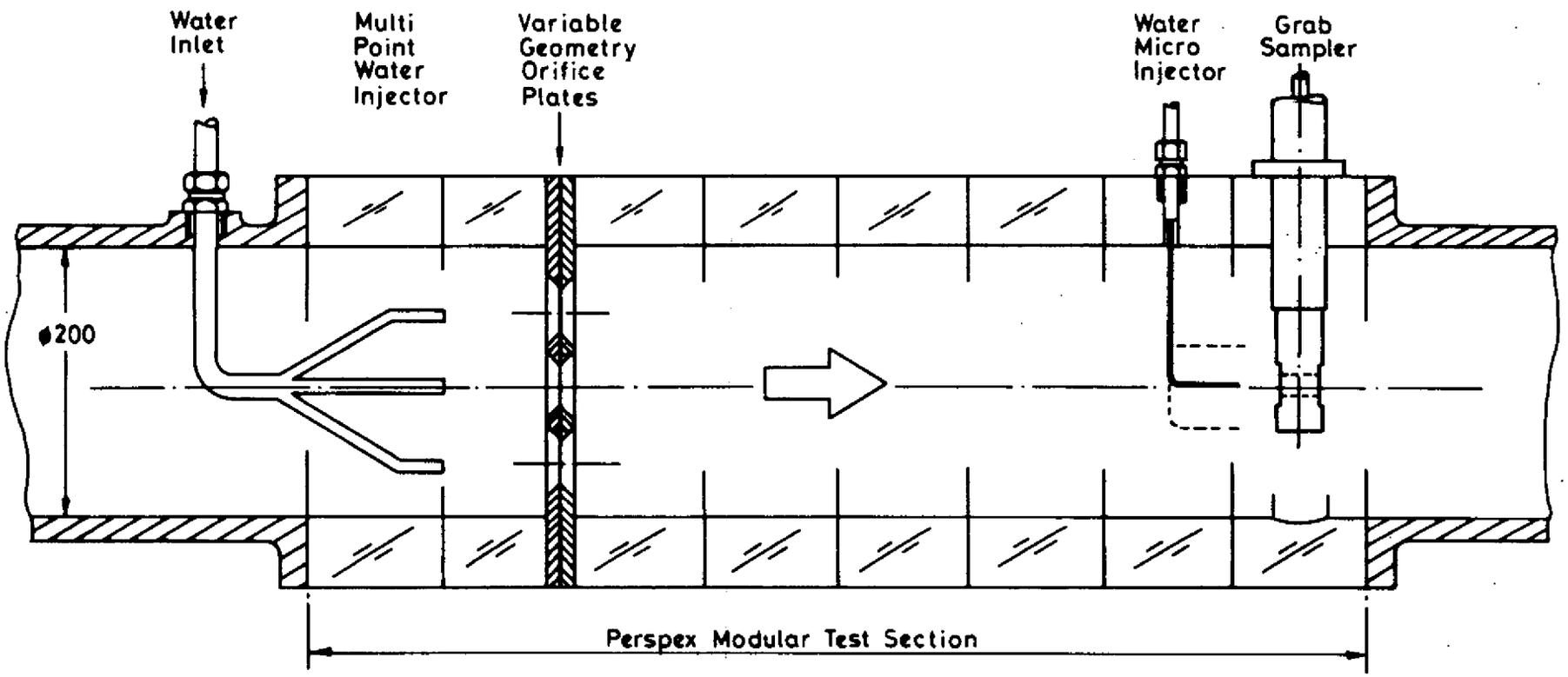


Fig 1 Schematic of 200mm Sampling Facility



Scale 5:1

Fig 2 Schematic of Test Section with Grab Sampler Installed

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.