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COMPARISON OF SAMPLING METHODS BY WATER INJECTION

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SUMMARY

At present the only recognised method of comparing or calibrating water-in-oil sampling systems is to measure their response to a known quantity of water injected into the oil flow. This paper explains the basics of water injection and goes on to describe some of the laboratory and field experience of the NEL Automatic Sampling project in its study of sampling devices and methods.

1 INTRODUCTION

Many sampling devices and methods are currently available for the determination of the water content of crude oils. Although the results they produce are often used for fiscal and custody transfer calculations there is no recognised means of calibrating a sampler such as is employed, for instance, in calibrating a flowmeter. Whereas the quantity of oil transferred can be measured to within small and known uncertainties, the quality of the oil is established to perhaps a lesser degree. The problem of water content measurement is admittedly a complicated one, involving many factors; variations in homogeneity both spatially and temporally in the pipe from which the sample is taken, isolation and collection of the sample, storage of the sample and then the chemical analysis. The most popular, and essentially the only, method of checking the performance of a sampling system is to subject it to a known water content by water injection as described in section 15 of reference 1 and section 7 of reference 2.

The NEL Automatic Sampling Project, which is sponsored by a consortium of sixteen oil concerns, has a remit to study and improve automatic water-in-oil sampling devices and methods. Some of the techniques and findings of the project are given in references. 2 to 8. The project has relied heavily on water injection techniques in both laboratory test facilities and in field installations. The following sections describe the ways in which water injection was effected in both cases and how successful those methods were. Because the work was commercially funded, however, only selected general findings can be presented in this paper.

2 PRINCIPLES OF WATER INJECTION

Proving a sampling system by water injection involves producing a known water content by injecting a metered supply of water into a metered flowrate of oil and adding it to the existing background water content. In principle it would seem that the water content derived from the sampling system need only be compared to the known water content in order to ascertain the performance of the sampling system. In practice it is far from being so straightforward; what about the homogeneity of the injected water in the oil? what is the water droplet size? what is the background water content and did it vary during the test? These, and a host of other problems, complicate the method.

2.1 Water Injection Requirements

References 1 and 2 specify the equipment and the arrangement that should be employed in water injection tests. These are:

(a)Suitable connection valves, strainer, pressure gauges, and piping.

(b)A flowmeter capable of measuring the injected volume of water during a test with an uncertainty of less than +/- 2 per cent.

(c)A flowmeter capable of measuring the volume of oil flowing during a test also with an uncertainty less than +/- 2 per cent.

(d)Location of the water injection point as far upstream of the sampling point as possible so that the water will traverse all the pipe fittings etc expected to produce the required degree of mixing.

(e)The water injection flow rates should be between 1.0 per cent and 5.0 per cent of the crude oil flow during the test. Note, however, that if for operational reasons the water injection flow rates have to be less than 1 per cent then the measurement of injected water quantity and the accuracy of the laboratory analytical procedure become critical in the assessment of the sampling performance.

(f)The water injection point should be at the bottom or the side of the crude carrying pipe line and the velocity of injection should not exceed 130 per cent of the crude pipe line velocity.

2.2 Testing Procedure

Having installed and checked all the equipment as indicated above the following procedure should be adopted in the proving tests:

(a)Select a time when the pipeline conditions can be held steady.

(b)Arrange to conduct the test at the worst conditions expected during normal use of the sampling system, ie using an oil with the lowest viscosity and the lowest density from the normal range of oils used. Adjust the oil flowrate to the minimum pipeline velocity normally encountered.

(c)Once stable conditions are obtained and the sampler system has been purged, operate the sampler for at least one hour to obtain the 'before' baseline water content of the oil.

(d)Start water injection as described above and continue for at least one hour. After allowing time for the lag between water injection and arrival at the sampling point, begin to take the 'with water injection' sample. Note that at low flow rates the injected water may move at a slower velocity than the crude oil and sampling into the test receiver should therefore be continued for some time after the end of the expected passing of the dry oil.

(e)After ceasing to inject water, continue to sample for a further hour to obtain the 'after' baseline water content. The difference between the 'before' and 'after' baseline water contents should not exceed 0.1 per cent.

(f) In all the 'before', 'with water injection' and 'after' sampling, normal procedures for sample handling, mixing and analysis should be performed.

2.3 Calculations

The deviation between the average water content in the test sample minus the baseline water content, and the average water injected should be calculated from the following formulae:-

$$W_{dev} = (W_{test} - W_{base}) - W_{inj}$$

where:

W_{dev} is the deviation of the percentage water in the samples from the average injected water.

W_{test} is the percentage of water in the test sample.

W_{base} is the average percentage of water in the baseline sample before and after the test.

W_{inj} is the percentage of water injected into the oil and:

$$= \frac{W}{V} \times 100$$

W is the total volume of the injected water (cubic metres)

V is the total volume of the oil and water that passes the sample point during the period when the sampler is in operation collecting the 'with water' sample (cubic metres).

2.4 Ratings for Sampler Performance

References 1 and 2 describe how a measure of a sampler's performance can be obtained by evaluating

$\frac{W_{dev}}{W_{inj}}$ within one of four ratings:

A	less than	+/- 0.05
B	greater than but less than	+/- 0.05 +/- 0.10
C	greater than but less than	+/- 0.10 +/- 0.15
D	greater than	+/- 0.15

Note that these ratings only apply to injected water concentrations of 1 per cent or more. Also note that the value of W_{base} as a percentage of V changes when the water is injected. However, if W_{base} is less than 0.1 per cent the rating W_{dev} changes by less than 0.001 W_{inj}.

Sampling systems with a Rating A meet the highest requirements, but Ratings of B, C, or D denote a lower performance and consideration should be given to implementing possible improvements in the sampling system.

3 THE NEL LABORATORY TEST FACILITY

At first glance it may seem easier to conduct water injection tests in a laboratory facility than in the field; costs are reduced, there is better control and repeatability of the variables, there is the potential for improved quantitative measurements and transparent pipework can make even qualitative assessments a possibility. However, all is not that simple. For safety and convenience reasons, crude oil cannot be used in the laboratory. Hence, to reproduce the Reynolds and Weber numbers of north sea crudes (2 to 30 cSt viscosity, 0.1 to 1.2 m diameter pipes, 1 to 4 m/s velocity) in a 200 mm diameter laboratory a lighter, 2 cSt kerosine type oil must be used. This means it is easy to separate the water from the kerosine after use, but makes it difficult to produce an homogeneous mixture of water and kerosine at the point of sampling. Much development went into the design of the NEL sampling facility water injection section to overcome this problem.

3.1 Description of the NEL facility

A schematic of the NEL test facility is shown in fig. 1 and a full description given in references 3 and 4. In normal operation kerosine is pumped around the circuit by a variable speed pump capable of 50 l/s flowrate and imparting an energy rise of 220 J/kg. After a long straight 100 mm section the flow passes through a calibrated turbine flowmeter before doubling back on itself and entering a diffuser section into the 200 mm diameter 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. A gantry is available so that the test section can be mounted vertically for upward or downward flows tests.

The sampler to be studied 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. Alternatively, a sampling scoop tube can be inserted in the test section to collect and divert flow into a by-pass loop. A range of small pumps and connection configurations are available for the study of external or by-pass cell samplers.

The water/kerosine mixture in the main flow is then conveyed via a flexible hose into an inlet ring 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 the largest water droplets to settle downwards for collection and transfer to settling tanks before re-injection. The oil is collected from the top of the tank and returned via a flexible hose to the main circuit and the pump inlet. The height of the inlet and outlet in the main separation tank can be adjusted to cater for different levels of fluid and also to achieve the best water separation characteristics. If required, a coalescer filter can be brought into the circuit to 'polish' the kerosine and remove any fine water droplets before recirculating to the test section.

It is interesting to note that the test facility can also be run without water injection in a closed loop mode. In this case the separation tank and the coalescer filter are shut off and a measured mixture of water and kerosine constantly recirculated in the loop. The volume abstracted by the sampler is made up by a small feed tank and the small change in water concentration calculated accordingly.

As mentioned above, one of the most difficult parts in the design and operation of the facility was the water injection system. Only after extensive research was the final arrangement decided. Water, from a calibrated metered supply, is injected into the kerosine flow through a water injection section shown as shown in fig. 3. The five nozzles, their jets, feed pipes and annular water gallery are all designed to ensure each nozzle delivers equal water flows into equal cross-sectional areas of the test section. Immediately downstream of the injection section a twin plate arrangement with holes of variable area is installed as shown in fig. 4. Each of the two plates has five square orifices. A cam system is used to slide the plates relative to each other in such a way that the overlap of their orifices produces a square orifice infront of each of the five water injection nozzles. Operation of the cam controls the size of each orifice and the smaller the orifice the faster the water and kerosine mixture flows through and the smaller the water droplets produced. In this way, water droplets of a given and repeatable size can be produced. Immediately downstream of the twin plate arrangement a system of baffle plates is mounted to destroy any jets from the orifices.

Before any samplers were assessed in the facility, tests were conducted to check the quality of the water mixture produced. Firstly a NEL design of sampling scoop tube (see reference 4) was traversed across the vertical diameter of the test section to measure the limits of flow velocities and droplet sizes that could maintain an homogeneous mixture at the sampler position. Secondly, the same scoop tube was used to divert a portion of the main flow through a special droplet sizing section as shown in fig. 5. Short duration flash photography was used to 'freeze' the motion and give photographs from which droplet sizes could be measured.

3.2 Testing procedure and Calculations

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 and setting the sampling pump speed to give the required sampling rate. After allowing time to purge all the sampling system with neat oil, the water injection pump is started and sufficient time allowed to establish stable conditions before samples are collected for analysis.

Because the laboratory facility is mainly used to study the operation of samplers and the sampling system, tests are usually shorter than the one hour recommended in references 1 and 2. For this, and operational reasons, the tests conducted in the laboratory facility are conducted on a volumetric flowrate basis and not on a total volume basis as described in references 1 and 2. W_{inj} is determined directly from the injected water and kerosine flowmeters as:

$$W_{inj} = \frac{\text{Volumetric flowrate of injected Water}}{\text{Volumetric flowrate of injected water and kerosine}} \times 100$$

This is usually calculated to +/- 0.01 per cent volume for volume (v/v) water.

Because the water is injected into water-free kerosine, $W_{base} = 0$.

W_{test}, 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:

$$W_{test} = \frac{\text{Volume of Water in sample}}{\text{Volume of Water \& kerosine in sample}} \times 100$$

This can usually be calculated to better than +/- 0.1 per cent v/v water.

4 THE FIELD TEST FACILITY

The limitations on oil type and pipeline size of a laboratory facility can largely only be overcome by conducting water injection tests in a field installation. An opportunity for such field testing arose when one of the sponsors of the NEL sampling project made available a sampling installation in a refinery. This provided the means to conduct many water injection tests to compare samplers and sampling methods and to study water mixing and water transient behaviour.

4.1 Description of the Field Facility

The field sampling station was located in a refinery at a point where pipe lines running from jetties to the refinery manifolded with headers from a tank farm. In such a location samples could be obtained from tank to tank transfers utilising the tank farm pumps either directly in and out of the jetty head crossover or via the long jetty lines. The sampling station could also be used for sampling from cargoes transferred from ship to shore via the ship's pumps though this was not the best position for such work because of the distance between ship and sampling point. A schematic of the pipe configuration, water injection points and sampling equipment used at the jetty head cross-over during the course of the NEL tests is given in fig. 6.

The sampling station itself was situated on the No. 1 Header about 2 m downstream of the jetty/header manifold. The internal diameter of the mainline pipe at the sampling station was 1.197 m giving a cross sectional area of 1.125 m^2. The approximate hold up volume between injection and sampling points on the direct route down the no. 2 header, crossover via the no. 3 line and up the no. 1 header was calculated as 37 m^3. Hold up between injection and sampling points via the no. 2 header, down the no. 3 jetty line, crossover at the jetty end, return by the no. 2 jetty line and up the no. 1 header was calculated as as 379 m^3.

In the NEL tests two 50 mm (2") water injection points were hot tapped onto the no. 2 header as shown in the figure. Although not strictly in accordance with the recommendations of references 1 and 2, the use of two tappings instead of one was necessitated by the use of the fire main as a source of water. Sea water from the refinery fire ring main was piped to each injection point by a 50 mm (2") fire hose via a non-return valve and a ball valve mounted on the pipe. Both injection point hot taps were trepanned to a nominal 50 mm (2") diameter inlet hole.

It can be seen from fig. 6 that the sampling station had provision to mount an in-the-line sampler directly in the pipe wall, and also to mount an external cell sampler in a by-pass loop supplied from a NEL design of scoop tube inserted into the main line. The by-pass loop also had a water-in-oil monitor working on the capacitance principle which was used to monitor the passage of water transients through the sampling station.

The sampling station was provided with a multi-point profiling probe as described in section 6 of reference 1. Profiling tests were conducted before each water injection test and it was found that in all cases the vertical water concentration profile was well within the limits specified in reference 1.

All instrumentation, computers, data loggers, water analysis equipment etc. was housed in a 'Portacabin' adjacent the sampling station. A Commodore PET computer monitored all 4 flowmeters and the Capacitance cell output and recorded them on disc and gave a hard copy both as a print-out and on a chart recorder. During some of the tests the output from the capacitance cell was logged digitally on an Epson PX8 portable computer using the program DATALOG and analysed using the program DATACAL for use in water transient computer simulations described in references 6 and 7.

4.2 Testing Procedure and Calculations

Because of the pipeline size and the quantity of oil concerned, it would have been expensive to measure flowrate using a full bore flowmeter. Total oil transferred during a test was therefore calculated by reading the exporting and receiving tank dip gauges before and after the test and an insertion flowmeter was used to check for any variation of flow during the test. This arrangement had the capability to measure flow to within +/- 2.0 per cent of full flow.

50 mm (2") calibrated turbine flowmeters, together with the requisite upstream and downstream lengths of straight steel pipe, were fitted to each of the seawater lines. The flowmeters were found to correspond with each other when placed in series in the same line at the start and the end of the testing programme. This measurement system had the ability to measure injected flow to +/- 1.0 per cent of full flow.

Several samples were taken both from the by-pass loop and from the centre probe of the profiler before and after water injection to measure the 'before' and 'after' background water contents. All of the NEL tests were conducted on tank to tank transfers and constant background water was obtained either by allowing the tank contents to stand for a long time or by running the tank stirrers for a time before the transfer began.

5 COMPARISON OF WATER INJECTION METHODS

The laboratory and field water injection tests conducted by NEL were directed more to studying sampling instruments and methods rather than proving a particular sampling installation as described and recommended in reference 1. A salient difference between the NEL tests and the recommendations of reference 1 was the shortness of the NEL tests, none of which approached the one hour recommended in reference 1, but this has not affected the validity of the conclusions drawn from these specially designed tests.

5.1 Laboratory Tests

The NEL experience has shown that a laboratory sampling facility can be used to produce repeatable and accurately known flowrates, water contents and droplet sizes for the study and testing of sampling devices and methods. The provision of visual access and high speed photography has proved a useful qualitative tool to assist the studies. The laboratory provides a clean, stable, and controlled working environment in which to conduct test work. It also provides the cheapest, most adaptable and quickest means of performing this work. It is generally accepted that the low viscosity of the kerosine used in the NEL tests and the resulting rapid drop-out of water, gives rise to the most onerous sampling conditions, ie that if a sampler system is shown to work in the laboratory then it is more than likely that it will also work in a field installation.

5.2 Field Tests

Although the laboratory facility has provided a valuable and extensively used tool during the NEL Sampling Project it had several limitations. The most obvious of these were the maximum test section pressure of two or three bar, a maximum working temperature of 40°C and the restriction to a kerosine type oil. It was only by moving to a field installation that these shortcomings could be overcome.

Further, the very strengths of a laboratory facility can also prove to be weaknesses when designing devices and methods for use in a refinery or production platform environments. Operators sitting in the warmth and cleanliness of a cosy laboratory easily forget that the sampling system under test is destined for use in harsher conditions. The laboratory does net experience 150 km/hr winds laced with salt spray or freezing or skin blistering temperatures and spanners with 4m long extensions are never used on the instruments. Only the occasional fleck of rust will make a single circuit of the laboratory facility compared with the sand, straw, rags and wax precipitates found in the field. It is no use designing a system that works perfectly in the laboratory if it does not take these factors into consideration.

On the other side of the coin, however, is the fact that no red faced operations manager will ever enter the laboratory demanding that the test you have just taken three days to set up will have to be postponed indefinitely because someone somewhere has altered shipping times or pipeline export quotas.

5.3 Recommended Water Injection Procedures

The sampler proving procedures outlined in references 1 and 2 work well in a laboratory environment, but can prove difficult in a field application. The recommended one hour duration of water injection is designed to produce a reasonably large sample on which to conduct water content analysis. However, the problem of maintaining a uniform flow and constant background water over that period can be difficult to ensure.

It is also of interest to note that when the recommended uncertainties of +/- 2 per cent in water and oil flow and the minimum shift of 0.1 per cent v/v water in background water content are taken into consideration, then the uncertainty in measuring the rating is of the same order as the +/-0.05 for the class A rating.

6 CONCLUSIONS

The experience of the NEL Sampling Project with water injection has shown that:

(1) Water injection in a laboratory test facility can be a cheap, adaptable and accurate tool in the study and evaluation of sampling devices and methods. The use of low viscosity kerosine most likely gives a 'worst case' situation for sampling, but;

(2) A sampling device or method developed in the laboratory facility should always be proved in a field installation by water injection techniques to evaluate the problems of high pressure, temperature and dirty and viscous crudes that cannot be simulated in the laboratory.

(3) The recommendations described in DIS 3171 can be difficult to obtain in the field, particularly those of length of test, measurement of oil flowrates and constancy of background water.

(4) The DIS 3171 recommended uncertainties in oil and water measurement and limits on the constancy of background water can give rise to an uncertainty in the measurement of the rating of the same magnitude as the 'A' rating. Hence, if a valid 'A' rating is to be given to a system, then the uncertainties in the associated measurements must be less than those recommended in the DIS.

ACKNOWLEDGEMENT

This paper is published by permission of the Director, National Engineering Laboratory, Department of Trade and Industry, East Kilbride, Glasgow.

LIST OF FIGURES

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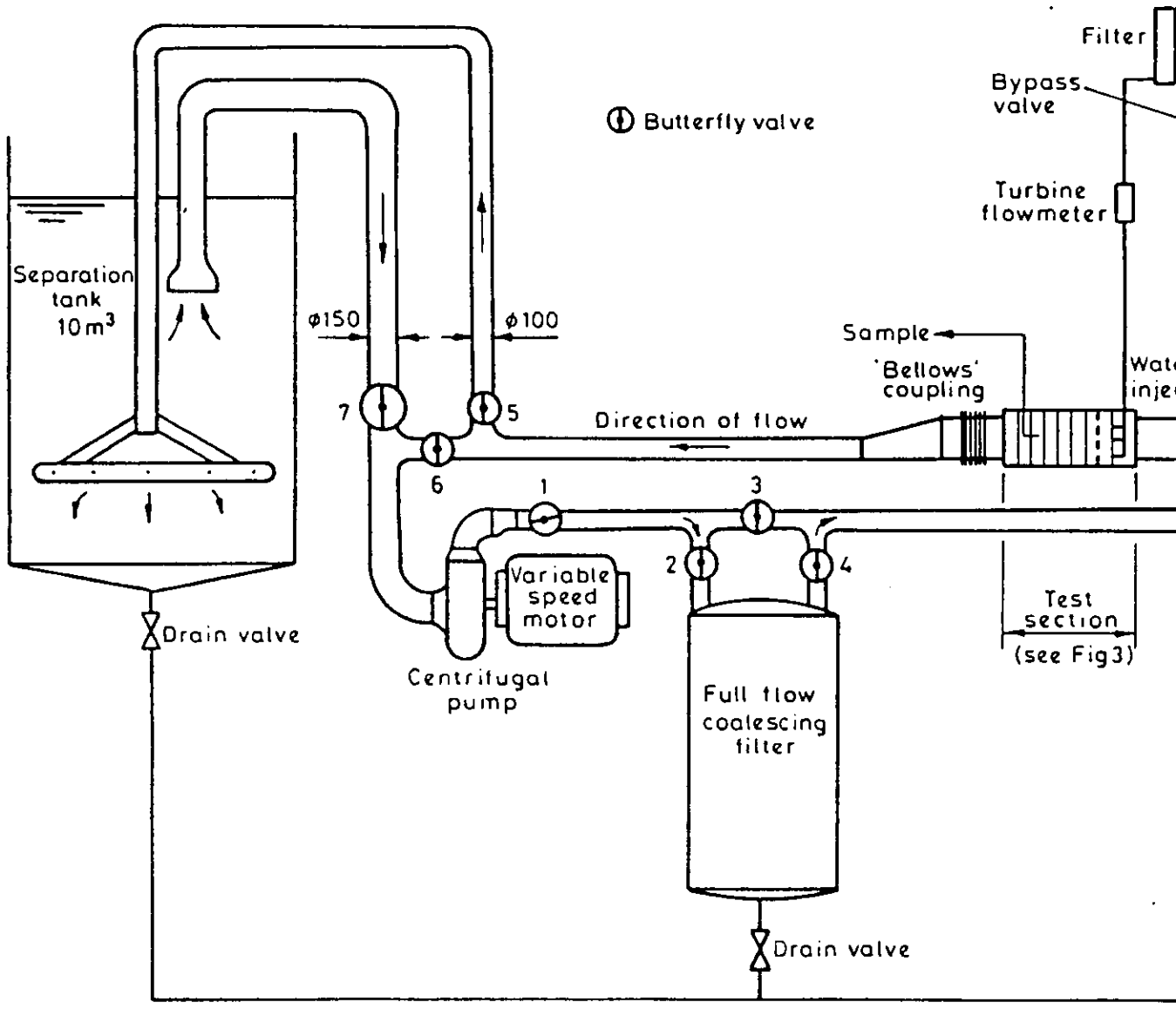


Fig 1 The NEL 200mm Laboratory Test Facility

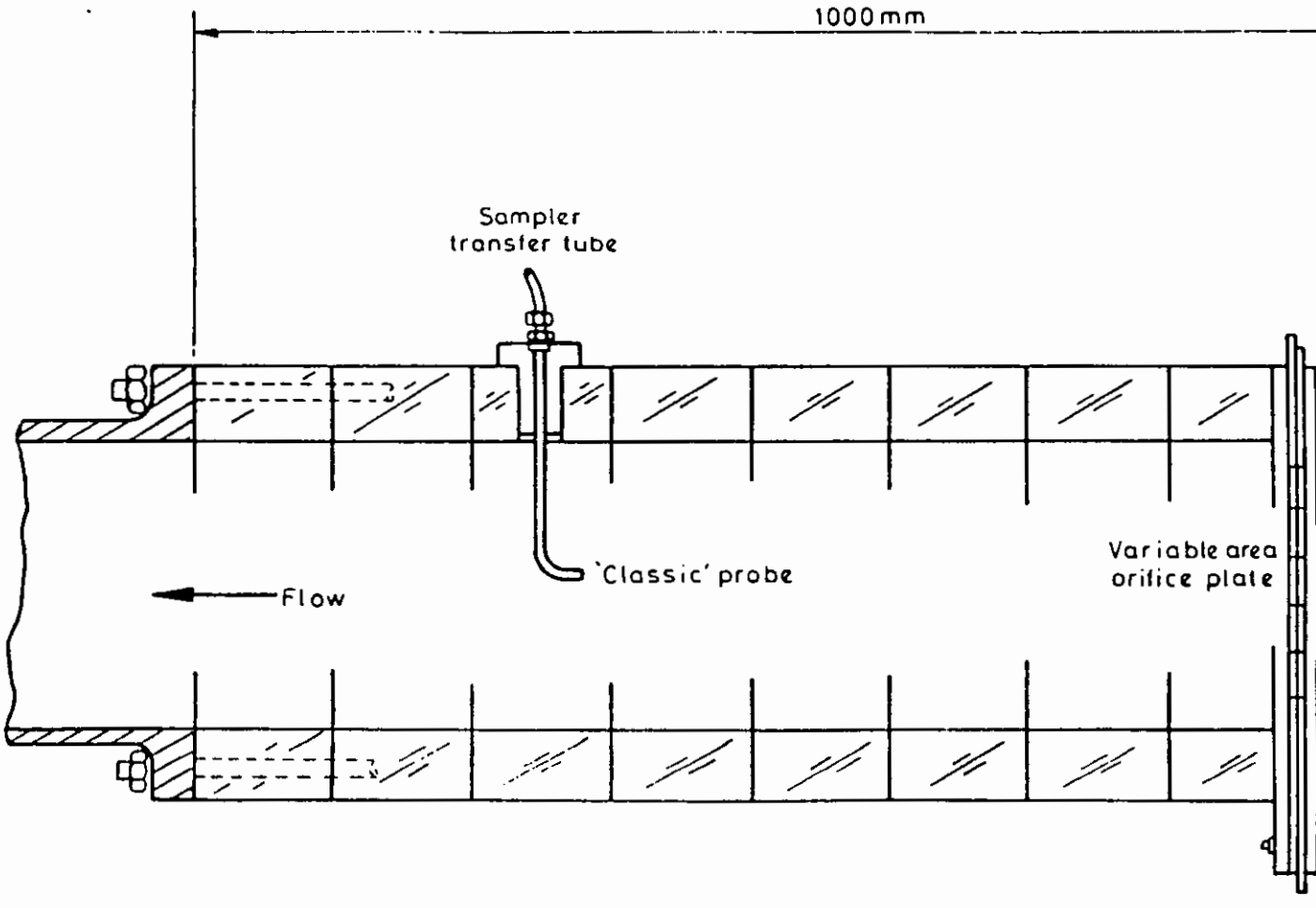
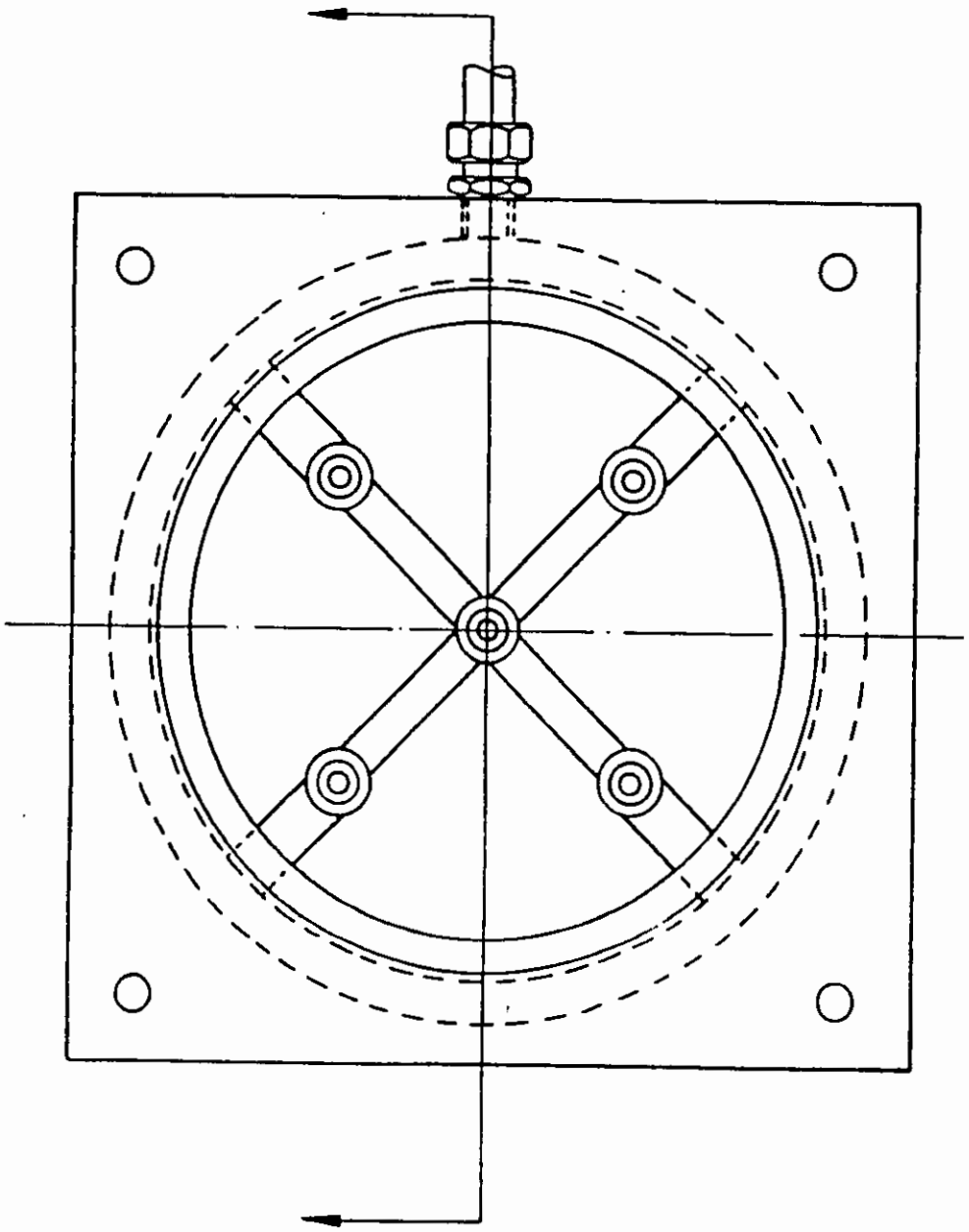


Fig 2 The 200mm Test Section



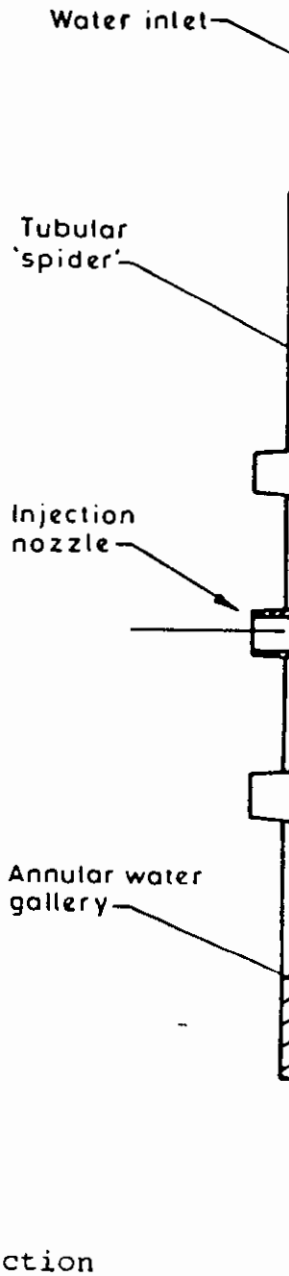


Fig 3 Water Injection Section

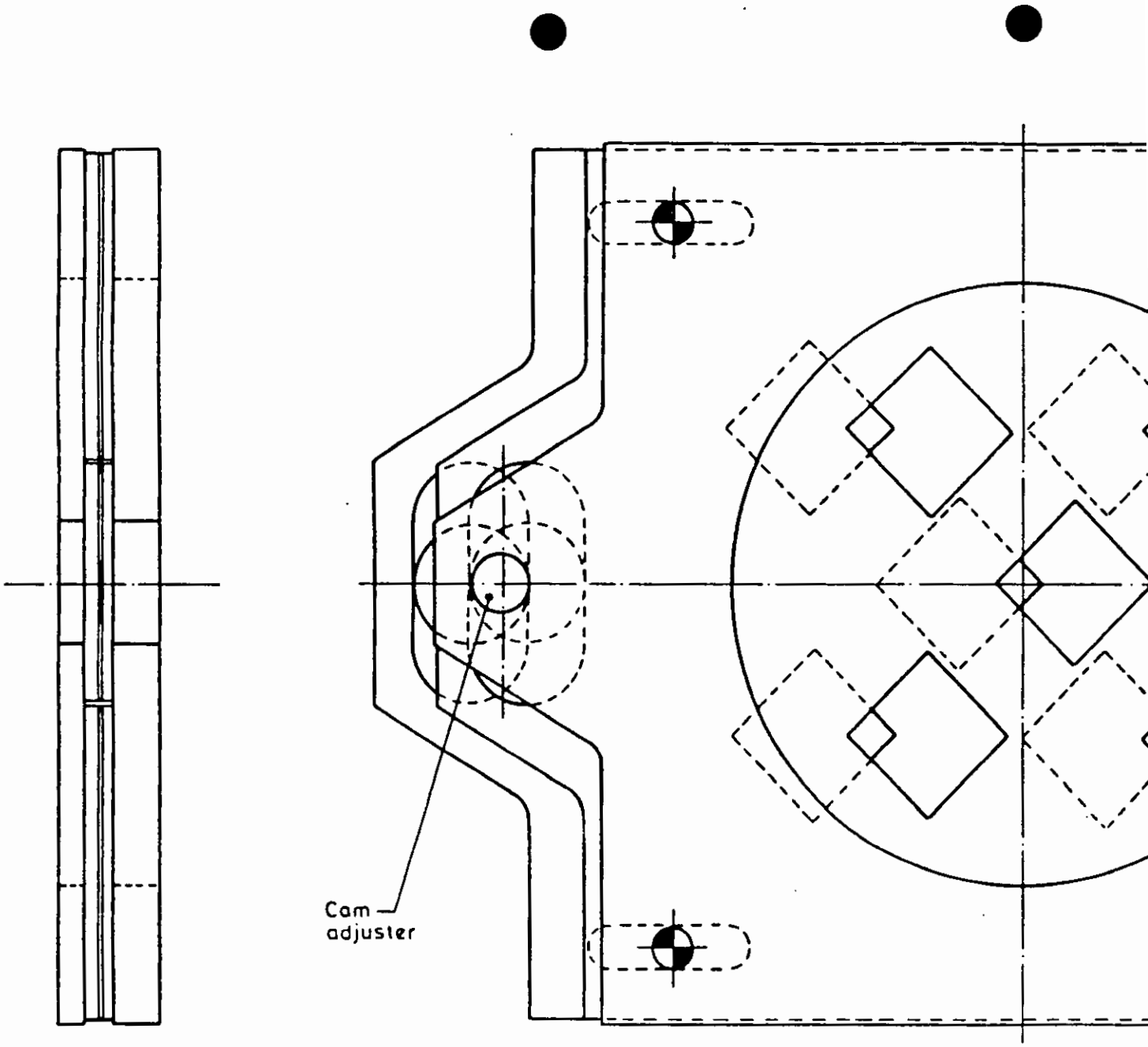


Fig 4 Variable Area Orifice Plate

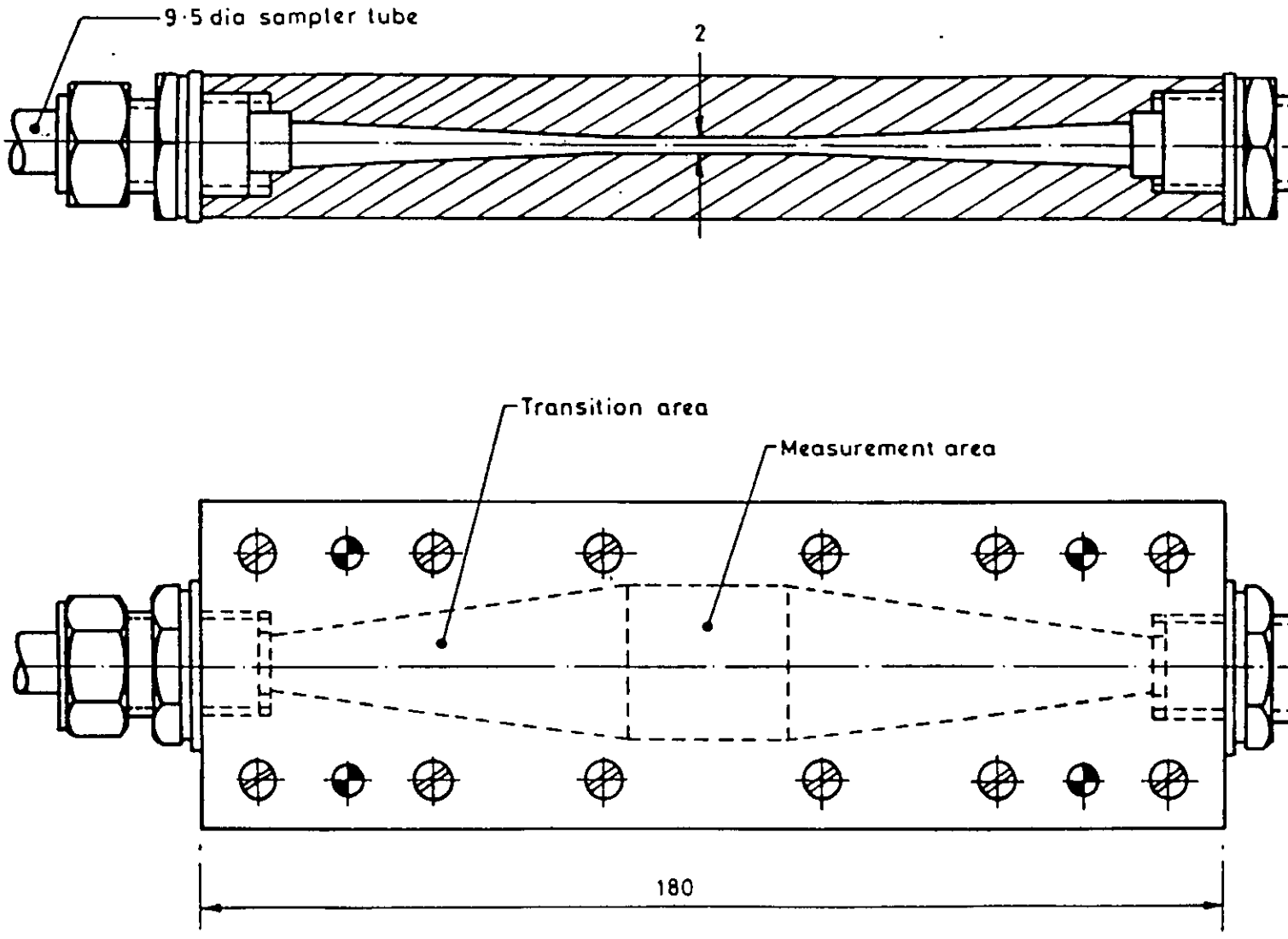


Fig 5 Droplet Sizing Section

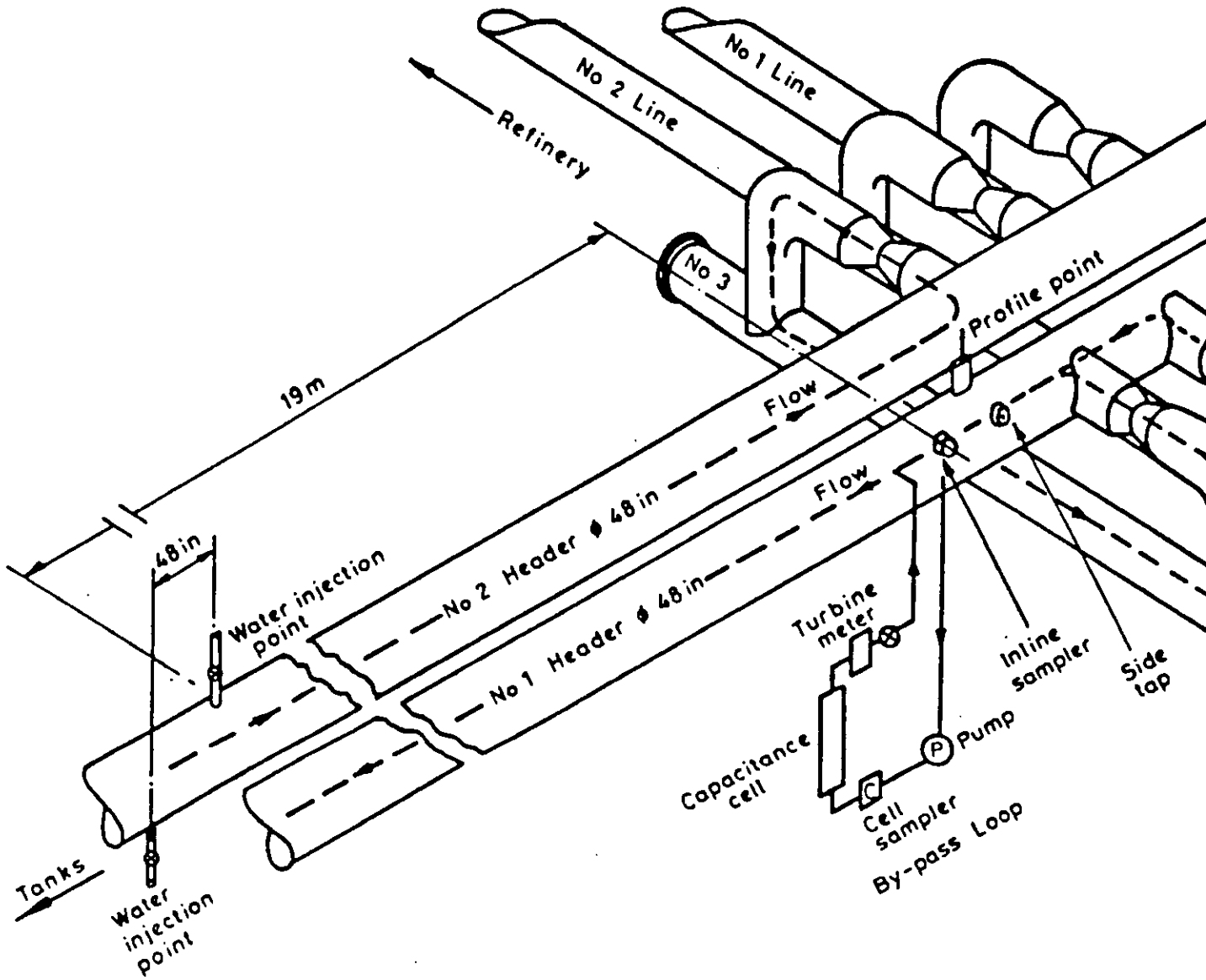


Fig 6 Schematic of Field Sampling Station