Hydraulics Research
Wallingford

THE EVALUATION OF THE MEX-3DC SILT SENSOR

T N Burt
E A Delo
P R Kiff

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Registered Office: Hydraulics Research Limited,
Wallingford, Oxfordshire OX10 8BA.
Telephone: 0491 35381. Telex: 848552

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ABSTRACT

The measurement of the suspended sediment concentrations in rivers, harbours and tidal basins is often a crucial part of a hydraulic engineering study. Prediction of the rate of siltation of fine sediment from the water can only be computed if the concentrations of sediment in suspension are known over a period of time, typically in the order of months. Accordingly, there has been a demand for reliable suspended solids sensors which are capable of being used in field situations as remote monitors.

In situ field measurement of sediments in suspension is acknowledged to be a very difficult process. Most popular optical methods suffer from combinations of the following problems:

1. Degradation of optical surfaces by biological and chemical contamination
2. Influence of ambient/sunlight effects
3. Temperature effects
4. Power consumption
5. Reliability of lamp sources
6. Permanent sealing
7. Corrosion

This work was done to establish the field performance of a recent introduction to the sensor market. This report describes the evaluation of the MEX-3DC Suspended Solids Meter manufactured by EUR-Control. Evaluation took the form of a laboratory investigation of the long gap sensor's stability, and responses to temperature, formazin and mud suspensions, and a field trial in which the sensor was deployed with an appropriate logging system at Grangemouth on the Firth of Forth.

The instrument appeared reliable and consistent in output and has the advantage of being well suited to waters where very rapid algal or marine contamination results in the need for frequent site visits to clean sensors.

The comparative field trial of the MEX-3DC sesnor with a Partech sensor at Grangemouth indicated that the two instruments gave broadly similar patterns of suspended sediment concentrations with time. However, the concentrations recorded by the MEX-3DC sensor were always between 0.1-0.6g/l higher than those given by the Partech. This corresponded to differences expressed in terms of the Partech concentrations, of between 100-300%.

The PEC envirolog was chosen for is simplicity, low cost and availability. There are other more suitable data loggers e.g. Golden River or DRS which are recommended for future applications.

The short gap sensor should be evaluated which will enable higher concentrations (0.5g/l) to be measured and a further field trial is recommended.

We will not, however, be developing this instrument. The development work done for this project centred on the field data logging method; we have concluded that the logger is not satisfactory.

The sensor has recently been deployed on one overseas contract and is performing satisfactory. The disadvantages are cost, long delivery, and U.S.A. sourcing. It is a matter of judgement which type of instrument to use for which application - this work has enabled us to make a more informed judgement. It will not reduce contract costs in terms of capital investment. It should permit less frequent site visits on field investigations and reduce service costs.

Other contractors will be able to benefit from this work by making available the report to them. Hydraulics Research Ltd are often asked to make recommendations on all types of measurement instrumentation.

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1 INTRODUCTION

The measurement of the suspended sediment concentrations in rivers, harbours and tidal basins is often a crucial part of a hydraulic engineering study. Prediction of the rate of siltation of fine sediment from the water can only be computed if the concentrations of sediment in suspension are known over a period of time, typically in the order of months. Accordingly, there has been a demand for reliable suspended solids sensors which are capable of being used in field situations as remote monitors.

For many years now, Hydraulics Research has used an optical turbidity meter manufactured by Partech Instruments. Although it has performed reasonably well in the past it was recognised that it had a number of disadvantages and was somewhat outdated in the perspective of current technologies.

Therefore, a research project was formulated with the objective of developing a robust and accurate low-power suspended sediment sensor suitable for unattended deployment as a monitor in the field. Initially, it was envisaged that a theoretical appraisal and laboratory tests would be undertaken to investigate the light scattering phenomena of silt suspensions and that a solid state field transducer system would be developed. However, it became apparent in the early stage of the programme that a proprietary transducer had become available which possessed many of the attributes which Hydraulics Research were seeking to achieve, i.e:

a) Solid state emitters and detectors
b) Low power consumption
c) Pulsed operation to eliminate ambient lighting effects

d) Four path ratioing technique to minimise the effects of unequal window fouling.

It was therefore decided not to investigate the proposed angular and wavelength dependencies of light scattering but to purchase and evaluate the new proprietary transducer.

This report describes the evaluation of the MEX-3DC Suspended Solids Meters manufactured by EUR-Control. Evaluation took the form of a laboratory investigation of the sensor's stability, and responses to temperature, formazin and mud suspensions, and a field trial in which the sensor was deployed with an appropriate logging system at Grangemouth on the Firth of Forth.

2 TECHNICAL DESCRIPTION

2.1 General

The EUR-control solid state silt sensor comprises a MEX-3DC suspended solids meter and a RD-120/25 measuring probe. The instrument was identified for deployment at remote sites because of its low power consumption (less than 50mA at 12 volts DC) and "quad gap" principle, which compensates for uneven dirt build-up on the probe window and reduces maintenance. The output signal from the sensor is adjusted by zero and span controls.

The sensor initially obtained with the instrument was a wide gap type which was suited to low concentration measurements typically up to 0.5g/l.

2.2 Operating principle

The instrument uses two light emitting diodes (LED's) and two photodetectors mounted in the measuring probe

(Fig 1). Operating on the four-beam optical transmission principle the MEX-3DC is able to automatically compensate for uneven build-up on the probe windows as well as optical component variations.

Each of the four light paths is sampled with the LED's alternatively on and off while the two photodetectors are operating continuously. When LED 1 is on (see Fig 1), the two photodetectors receive two signals which are different to each other due to the different length of the light paths X1 and X2. Similarly, when LED 2 is on, the path lengths X3 and X4 are different thus causing different signals to the two photodetectors.

Each of the signals passes through a single logarithmic converter to linearize the absorption function. Each phase of the measurement is corrected for ambient light by sampling the signals with both LED's off and feeding the "offset" correction back to the logarithmic converter.

3 LABORATORY EVALUATION

3.1 Introduction

The output of the MEX-3DC, was a 0-5V DC signal which was monitored for the purposes of these laboratory tests using a digital volt meter (DVM) and a chart recorder.

To set the instrument up, the zero was fixed by placing the shielded probe in particle free water and adjusting the output to zero using the ZERO potentiometer. The reading of the potentiometer was 6.16 (± 0.5%) for all the tests. The SPAN was set to the maximum 5V with a 1000mg/litre suspension of

Kaolin or 1000ppm formazin equivalent. All the setting-up procedures were made using the 30 second time response to minimise the fluctuations in the DVM and instrument digital readouts. The variations in the readouts with sediment in suspension were sufficient to make it very difficult to gauge by eye a mean value at the minimum time response. Because of this, use was made of the chart recorder to record the output and interpret a mean value.

When high sediment concentrations were being measured ($>$ 400-600mg/l) the instrument automatically switched from the half depletion mode to full depletion. This indicated that the concentration was too high. In practice the output scatter is considerably increased in full depletion and a different calibration slope is obtained. At the change over point, the half/full light flickered.

3.2 Stability

Short-term stability was defined as "warming-up" time. With the recorder having being switched on for 30 minutes (to ensure it has no effect on the warming-up period) the MEX-3DC was switched on with the head in a mud suspension (240mg/l). After 20 seconds, the output had reached over 95% of its maximum value. The maximum value was reached after about 2 minutes. The averaging period for the signal had been set to its minimum value of 1 second.

With a 30 second period over which the signal was averaged, the maximum value was not reached for some 5-10 minutes.

Long-term stability was only possible to ascertain in terms of zero drift. No detectable zero drift was found up to 24 hours. Attempts to determine drift in output with a suspended sediment proved inconclusive as it was impossible to keep a sediment in suspension with constant concentration and size distribution.

3.3 Temperature response

The effect of raising the temperature from 5° to 35°C was investigated using both a formazin suspension with a solids concentration equivalent to 700mg and a particle free water. No change in the reading was recorded for the particle free water thus indicating a stable zero value. The change recorded for the formazin suspension was of the order of a 2% increase as the temperature was raised by 30°C. This could have been due to a change in the size distribution of the formazin suspension with the continuous stirring necessary.

3.4 Response to particle/floc size distribution

As in all sensors based on the extinction of visible or near visible radiation, the output is proportional to the cross-sectional area of the particles in suspension (Fig 2). Under the laboratory conditions, the sediment tested was kept in suspension by a magnetic stirrer in a cylindrical vessel. The degree of shear, and therefore the size of the flocculated fine sediment, will depend on both the stirring speed and the orientation of the probe.

Output signal scatter was noticed on some occasions and a curious and unexplained phenomenon also occurred which is shown in Figure 3. With a constant stirring speed and a fixed probe orientation a cyclical variation in chart signal frequency and amplitude was noted. Assuming no electronic cause, the implication was that the floc size was changing over a 90min cycle. Variation in amplitude had been noted to coincide with flocculating conditions (in this case there was 300mg/l sediment in sea water) but the frequency oscillation is puzzling. This phenomenon was observed in both the shielded and unshielded probe but the unshielded probe showed the effect to a greater extent. This may have been due to an orientation effect of the asymmetrical crystals aligning in a preferred direction in the flow and showing "optical birefrigence". This however is unlikely to occur in natural suspensions.

The diameter of the infra-red beam (wavelength 880nm) is unknown but presumably must be very small if the effect of floc size is causing the scatter. Some of these effects have been noted in the Novosina Analyte, an infra-red back-scatter suspended solids meter.

3.5 Response to formazin

Formazin is an organic crystalline solid which is precipitated in solution by mixing two reagents and is the basic standard used in turbidity measurements. It has a uniformly sized structure and gives a reproducible optical density reading in both transmission and reflection turbidimeters. Its density is significantly less than that of silica based sediments and so a turbidity standard of say 1000ppm does not contain 1000mg solids. It is also white in colour (in bulk) and thus absorbs less radiation.

The formazin calibration with a possible maximum of 1000ppm was found to be a slight curve (Fig 4).

3.6 Response to mud suspensions

Three mud suspensions and a Kaolin suspension were tested and their calibration curves derived. The SPAN control was set to give a 5V output with a 1000mg/l Kaolin suspension. This was an approximate figure as the MEX was in the full depletion mode.

Other mud samples covered the range of types that are commonly tested. A dark-brown mud, a red-brown and a grey mud (Hong Kong). As these samples were bed sediments, not suspended material, all were sieved to remove the > 38 µm fraction and the calibration curves are shown in Figure 5. It can be seen that the colour of the mud has a significant effect on the calibration and on the maximum concentration that can be measured. The darker the mud, the higher the output for a given concentration. The size distributions of the muds are not significantly different (Fig 6). The standard Partech visible light transmission turbidimeter does not show this effect to any extent. It is suspected that instruments in which radiation scatter plays a significant part in the output are more subject to this phenomenon. The Novosina Analyte also measures backscattered infra-red radiation and exhibits a similar effect. Further work is necessary if the true reason for this effect is to be established.

An additional calibration was obtained from the Hong Kong mud with a maximum of 500mg/l for both shielded and unshielded configurations (Fig 7).

4 FIELD TRIAL

4.1 Introduction

Field trials of the MEX-3DC silt sensor and data logging system were carried out first in October 1986 and subsequently for a longer period starting in February 1987 and ending in April 1987. The site for the field trials was in the River Forth at Grangemouth docks where a Partech silt monitoring system was already installed. This enabled a direct comparison to be made between the two systems.

The existing Partech system consisted of two 0-1000ppm range sensors calibrated to 2000ppm, one positioned 0.3m above the bed and the other at the lowest astronomical tide level (LAT). Each was connected to a Rustrak chart recorder. The MEX-3DC sensor was mounted with the lower Partech sensor at 0.3m above the bed.

4.2 Logging system

The MEX-3DC control electronics were packaged in a suitable environmental box together with a small solid state logger - the P.E.C Envirolog. The data logger had a memory capacity of 2KB and was briefed and debriefed using an Epson HX-20 portable computer. Briefing involved programming the logger to record data every 15 minutes and giving it other information such as date, time and type of sensor. Although the logger recorded every 15 minutes the sensor was working continuously and hence eliminated any warm up time problems. The logger, programmed in this manner, was capable of recording and storing seven days of data, after which time, it had to be extracted or debriefed using the Epson computer.

4.3 Calibration

The existing Partech system was calibrated on site using formazin solutions of known concentrations. Bottle samples of river water were taken at the site and the calibrated Partech was dipped into the sample and the reading noted. The bottle samples were later analysed in the laboratory for concentrations of suspended solids and using the formazin calibration curve a relationship between formazin and river solids was found (Fig 8). Also shown in Figure 8 is the laboratory calibration of the Partech using suspensions made up from mud which had been collected from Grangemouth during a previous project study.

Due to difficulties experienced in calibrating the MEX-3DC sensor during the October deployment and in view of the results of the laboratory evaluation it was decided not to calibrate the sensor using formazin. Therefore solutions of known silt concentrations were made up using mud which had been collected from Grangemouth. Before deployment, the instrument was calibrated several times using these solutions and this was found to be repeatable. Although the sensor was designed for measuring low concentrations (typically $<$ 500mg/l) it was known that the suspended solids concentrations at Grangemouth were likely to be in the range of 0-2000mg/l. Therefore, the sensor was repeatedly calibrated over this range and the results from the calibration were better than expected (Fig 9). The instrument was on half depletion mode at 1200mg/l and at 1500mg/l had switched to full depletion mode with an unstable signal.

The calibration was checked on site before deployment and again one month later during a maintenance visit using the suspensions of Grangemouth mud prepared for the laboratory calibration (Fig 10) These two calibrations were similar and exhibited a near linear relationship between suspended solids concentration and output voltage up to concentrations of about 1500mg/l.

4.4 Comparison of Mex-3DC and Partech

The reading from the Partech was recorded every two seconds on the Rustrak chart recorder, an example of which is shown in Figure 11. The MEX-3DC system logged its reading every 15 minutes. It was decided to analyse four days worth of data which were selected to be representative of the whole of the range of possible concentrations. In February 1987 the maximum spring tide occurred on 28/2/87 and the suspended solids concentrations recorded by both instruments on that day are shown in Figure 12. Both instruments picked up the same peaks in the suspended solids although the MEX-3DC sensor recorded consistently higher concentrations. At low concentrations the MEX-3DC gave concentrations about 0.2g/l higher, whereas, at high concentrations it was often 0.5g/l higher than the Partech concentrations.

Figure 13 shows the results from a neap tide day. The two sensors follow the same broad pattern which is one of low suspended solids concentrations with two abrupt peaks at 14.30hrs and 17.30hrs. Both instruments picked up these peaks but once again MEX-3DC sensor was recording concentrations typically 0.15g/l higher than the Partech. Two more days of data were analysed on mid range tides and the results are shown in Figures 14 and 15. In both graphs the MEX-3DC and Partech follow the same pattern although the MEX-3DC is again between 0.1-0.4g/l higher than the Partech. However in Figure 14 the Partech recorded peaks at 11.30hrs and 20.20hrs that the MEX-3DC sensor did not.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. The instrument appeared reliable and consistent in output and has the advantage of being well suited to waters where very rapid algal or marine contamination results in the need for frequent site visits to clean sensors.

2. The natural variation in sediment concentration within the small sensing volume causes a rapid fluctuation in digital readout. This must be smoothed without incurring appreciable delay if a reproducible reading is required within 90 seconds.

3. Calibration with the mud under test will be more necessary than with the Partech type instrument but, with the lower maximum concentration, the calibration curves are essentially linear.

4. The full depletion mode must be avoided unless reduced accuracy is accepted and separate calibration curves are used. The point at which the half depletion mode becomes saturated varies with the colour of the sediment but can be as low as 400 mg/l.

5. The comparative field trial of the MEX-3DC sensor with a Partech sensor at Grangemouth indicated that the two instruments gave broadly similar patterns of suspended sediment concentrations with time. However, the concentrations recorded by the MEX-3DC sensor were always between 0.1-0.6g/l higher than those given by the Partech. This corresponded to differences expressed in terms of the Partech concentrations, of between 100-300%.

5.2 Recommendations

1. The PEC envirolog was chosen for its simplicity, low cost and availability. There are other more suitable data loggers e.g. Golden River or DRS which are recommended for future applications.

2. The short gap sensor should be evaluated which will enable higher concentrations (0.5g/l) to be measured and a further field trial is recommended.

FIGURES.

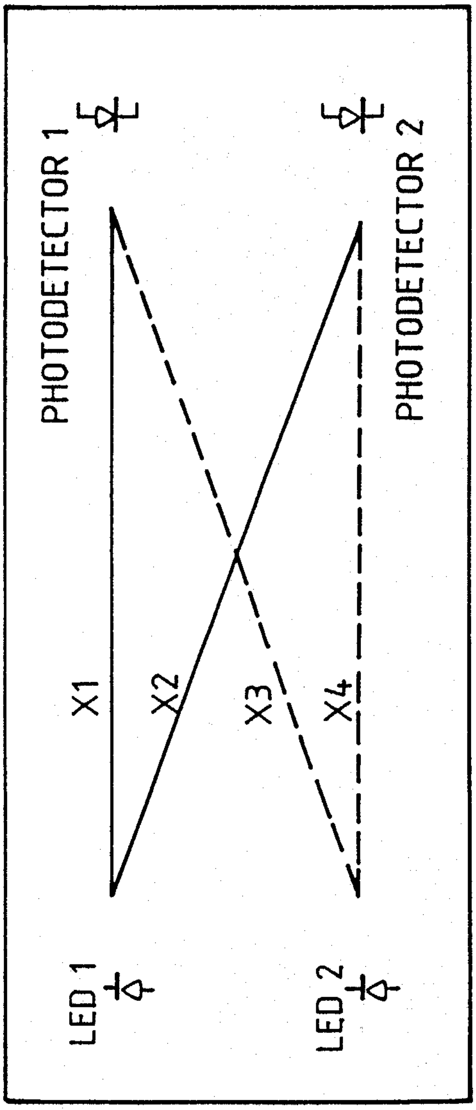

Fig 1 Four-beam light operating principle

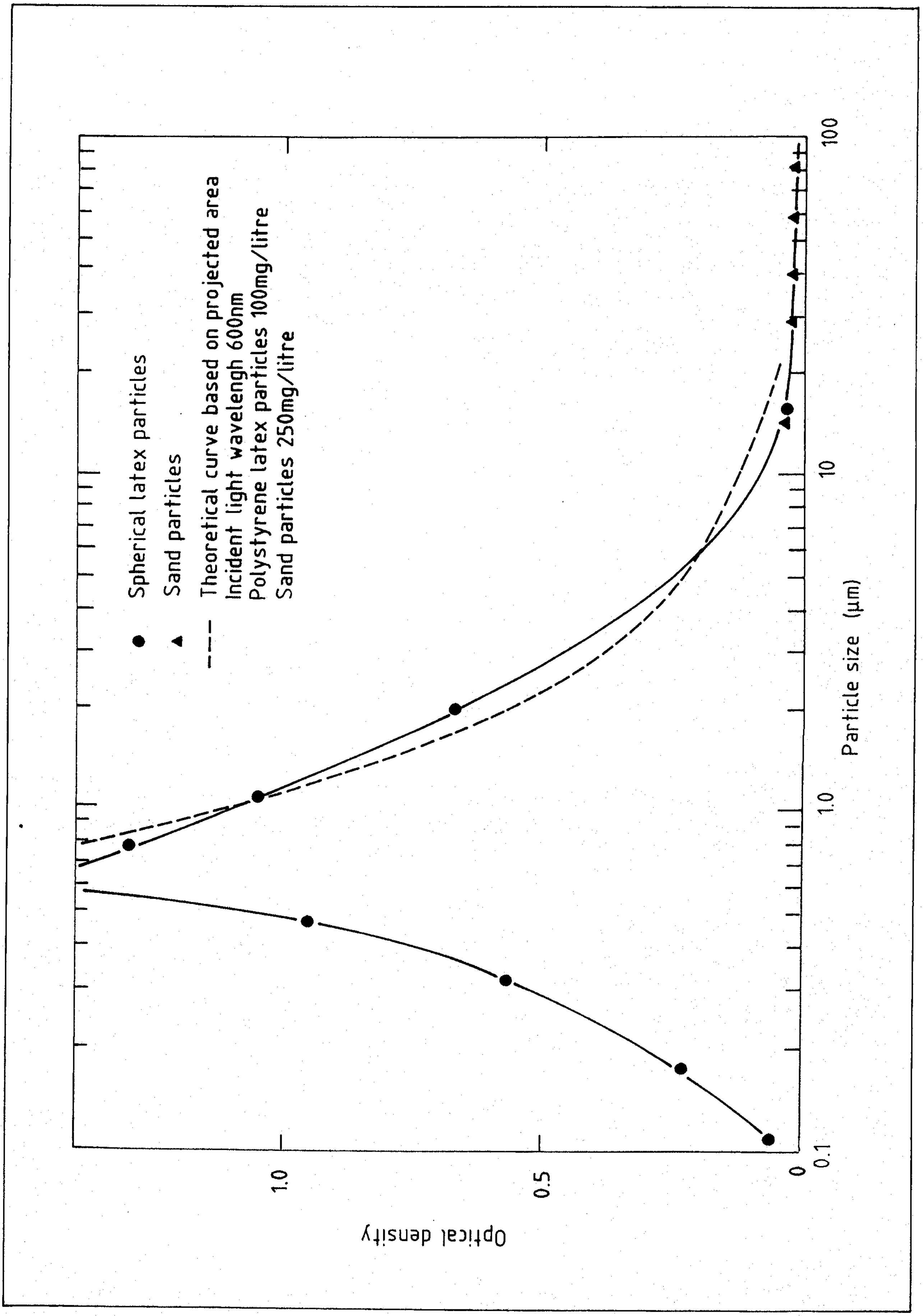

Fig 2 The effect of particle size on optical density

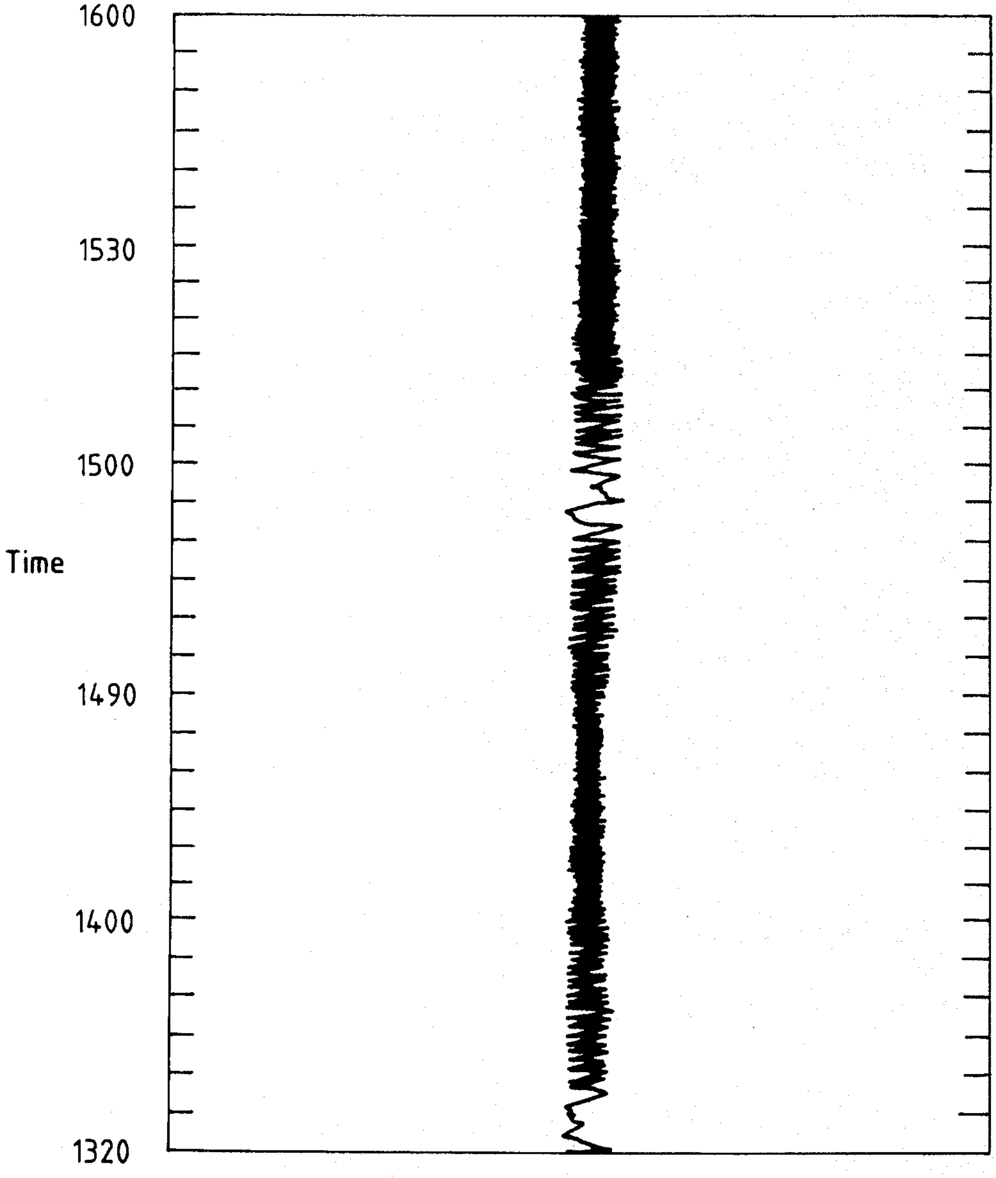

Fig 3 Cyclical variation in output from MEX-3DC sensor

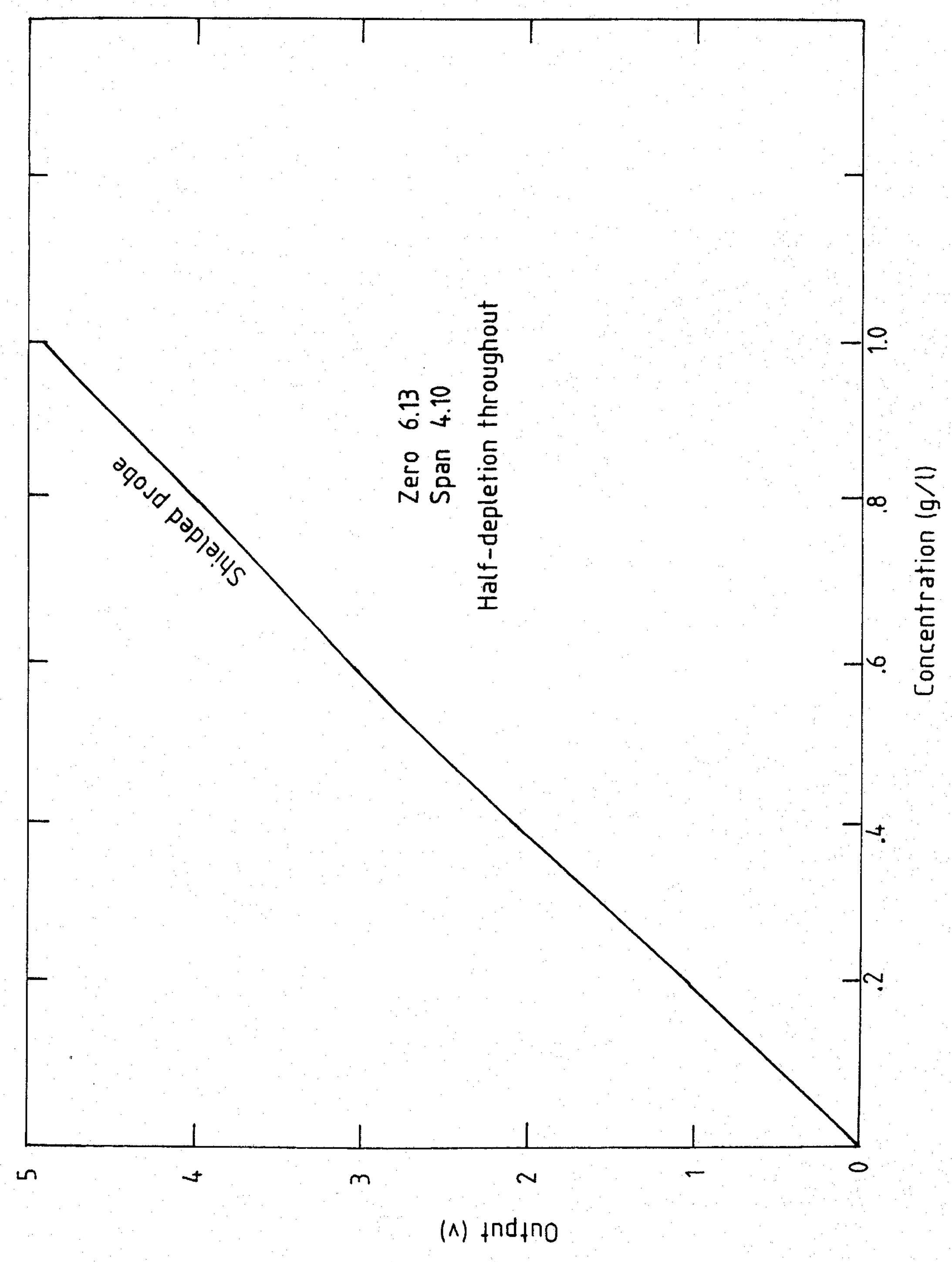

Fig 4 Calibration curve of MEX-3DC sensor with Formazin

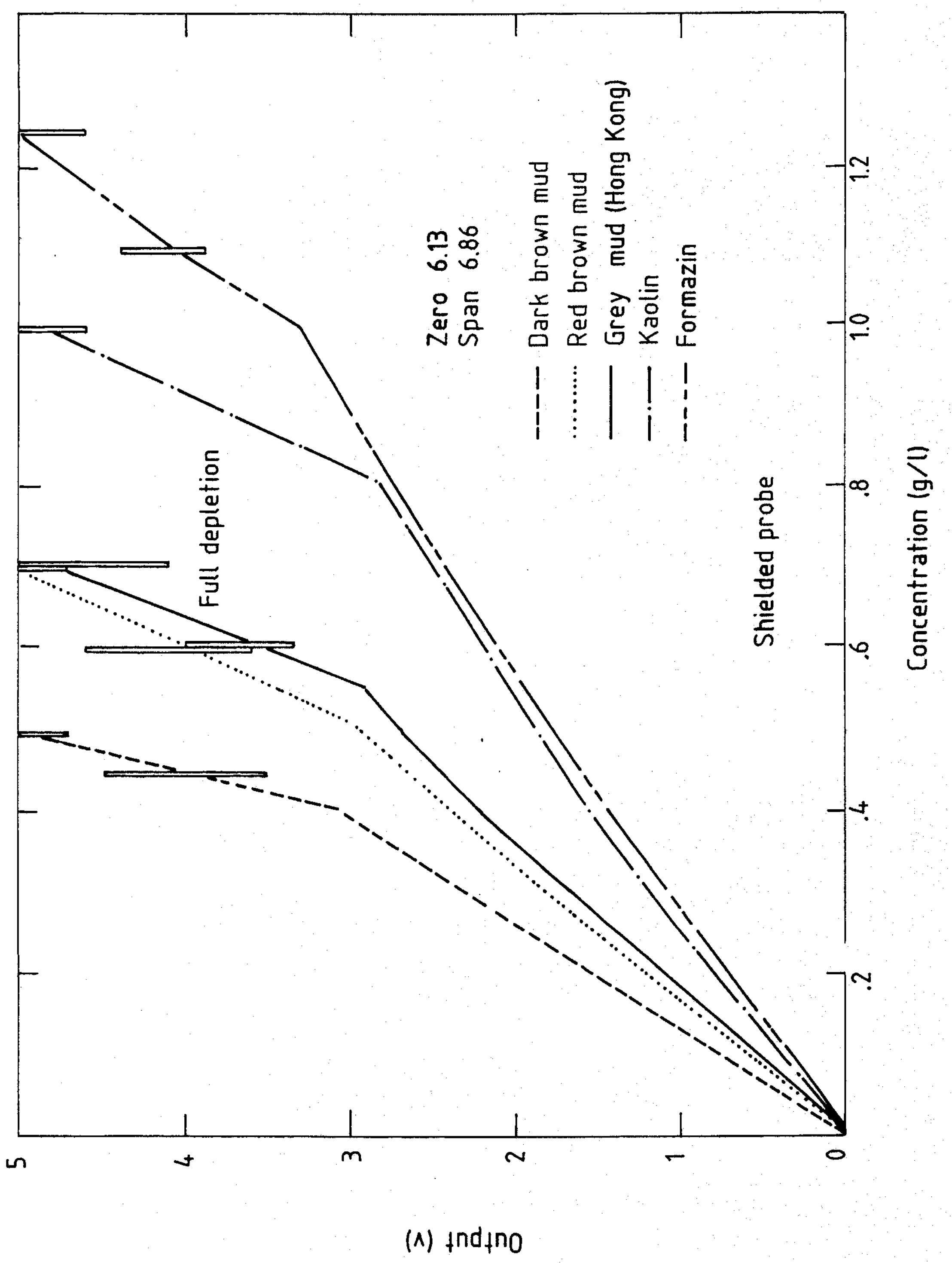

Fig 5 Calibration curves of MEX-3DC sensor with sample muds

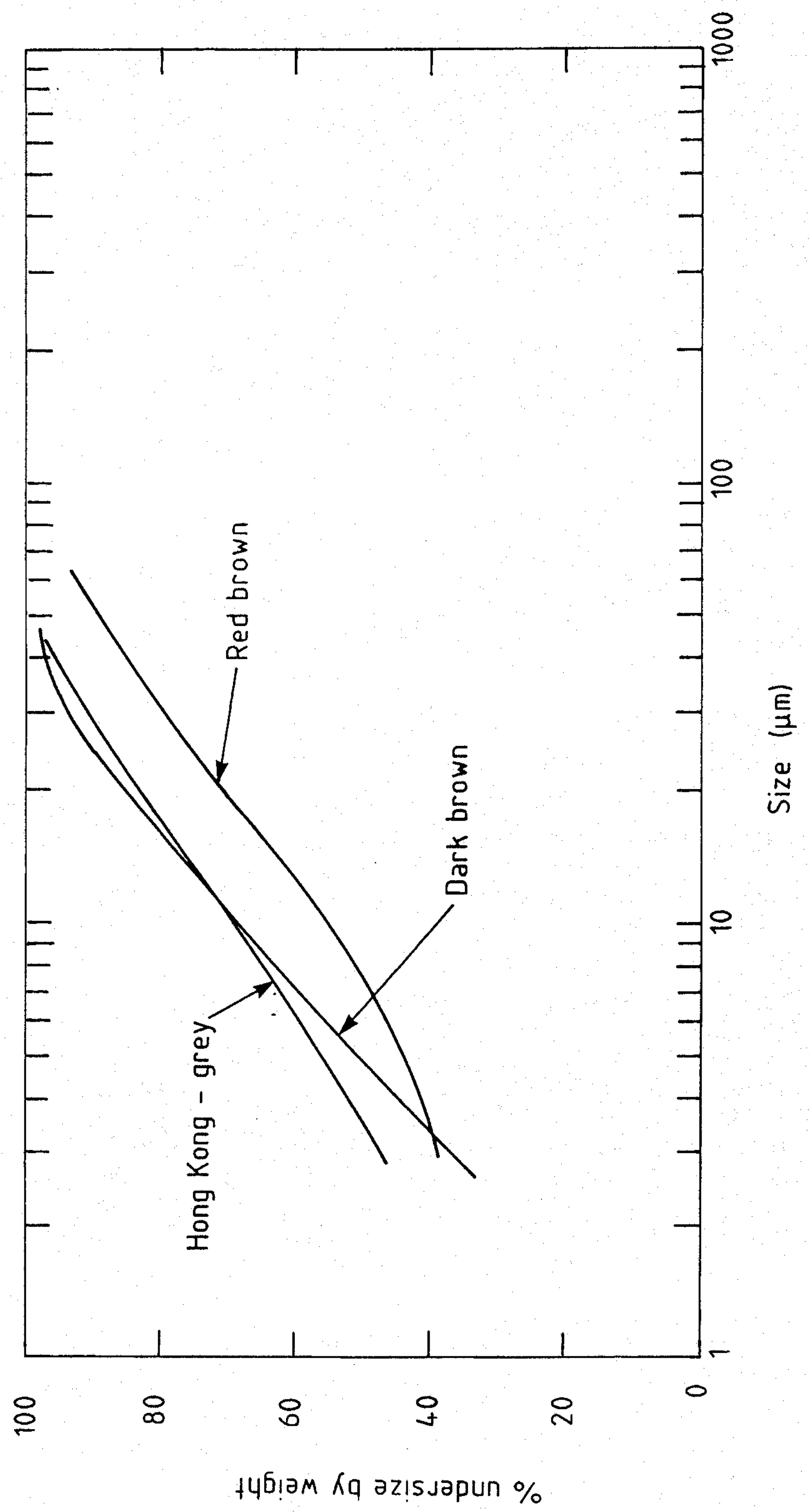

Fig 6 Particle size distribution of sample muds

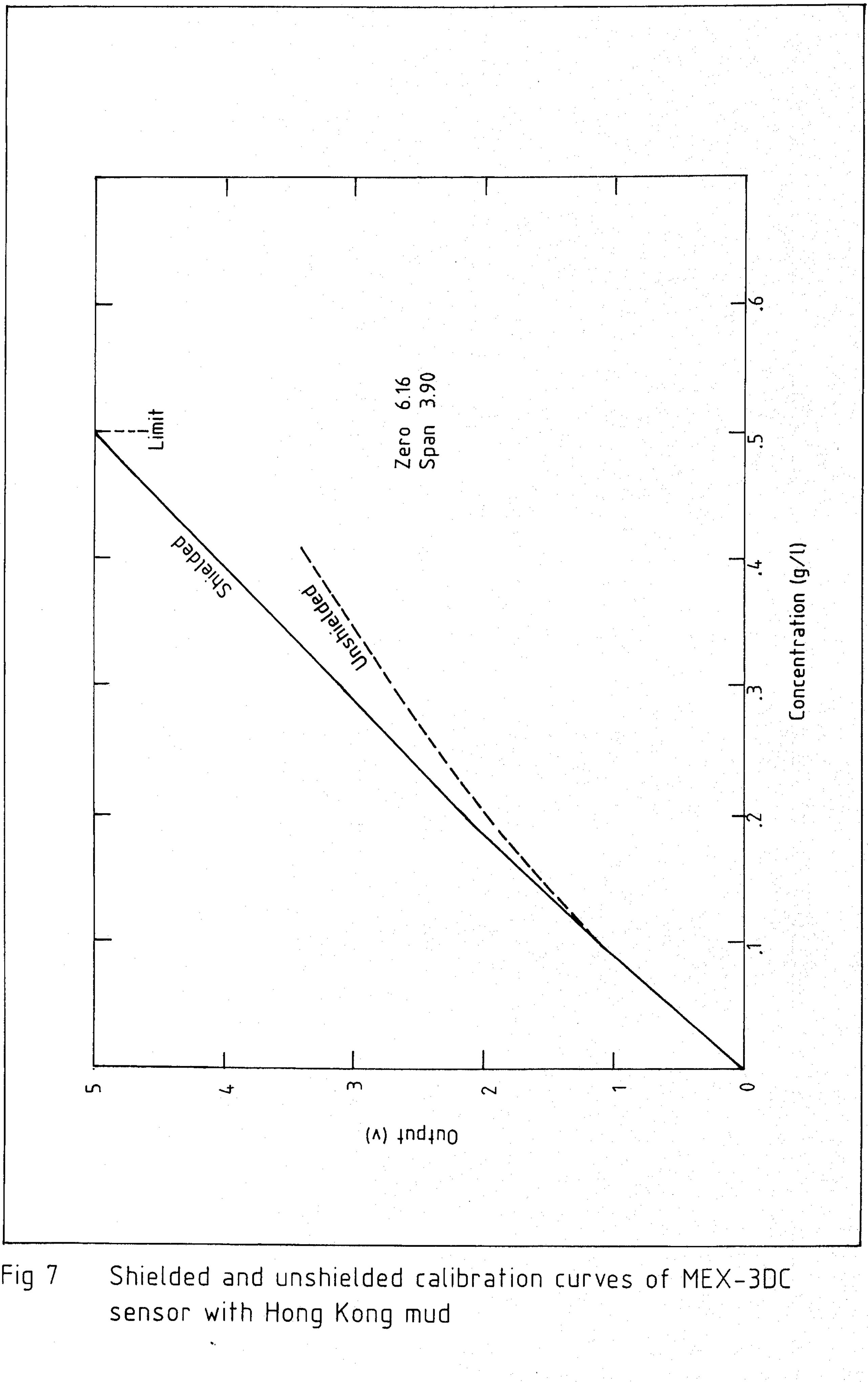

Fig 7 Shielded and unshielded calibration curves of MEX-3DC sensor with Hong Kong mud

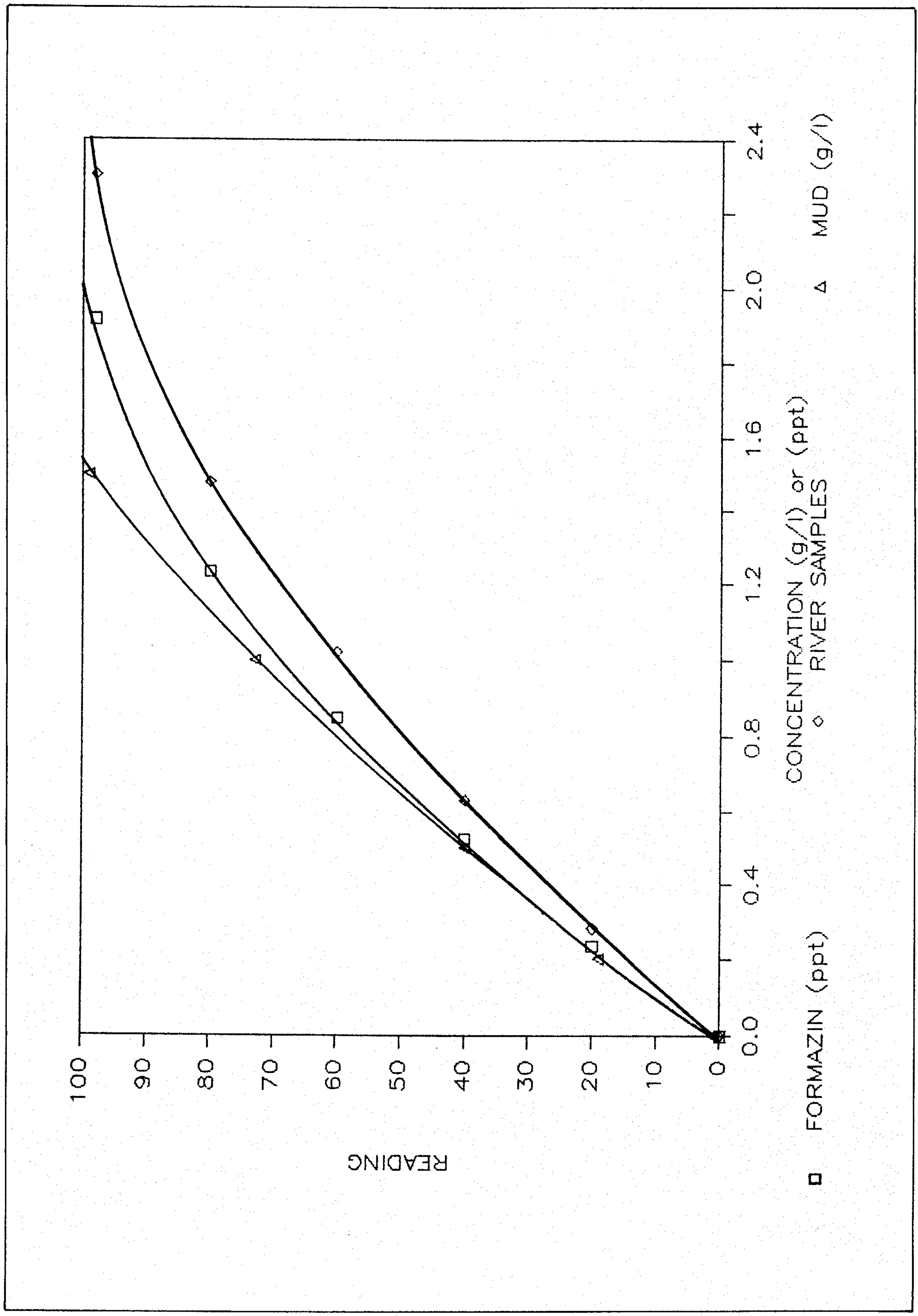

Fig 8 Calibration curves of Partech sensor with formazin, river solids and Grangemouth mud

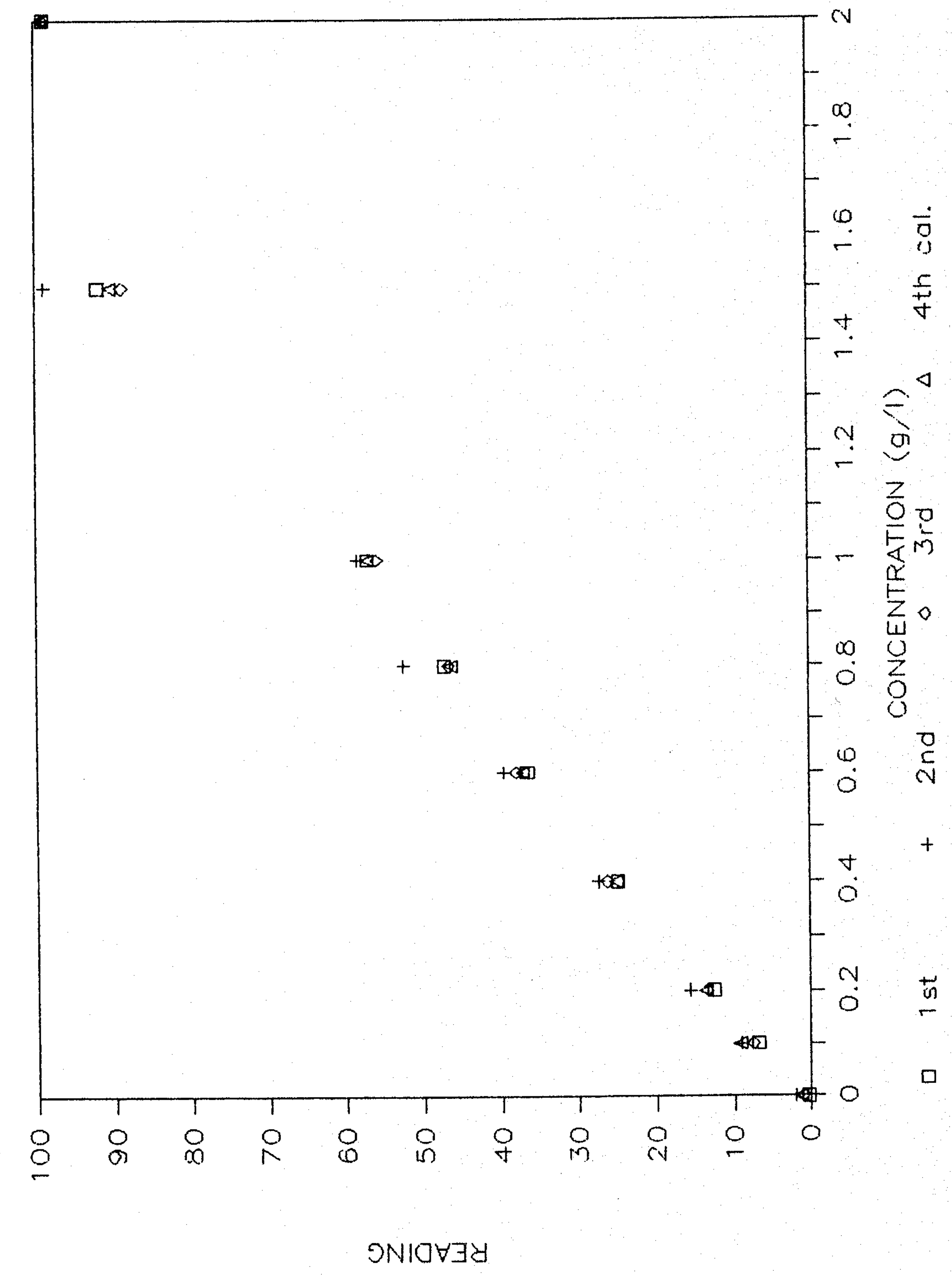

Fig 9 Laboratory calibration curves of MEX-3DC sensor with Grangemouth mud

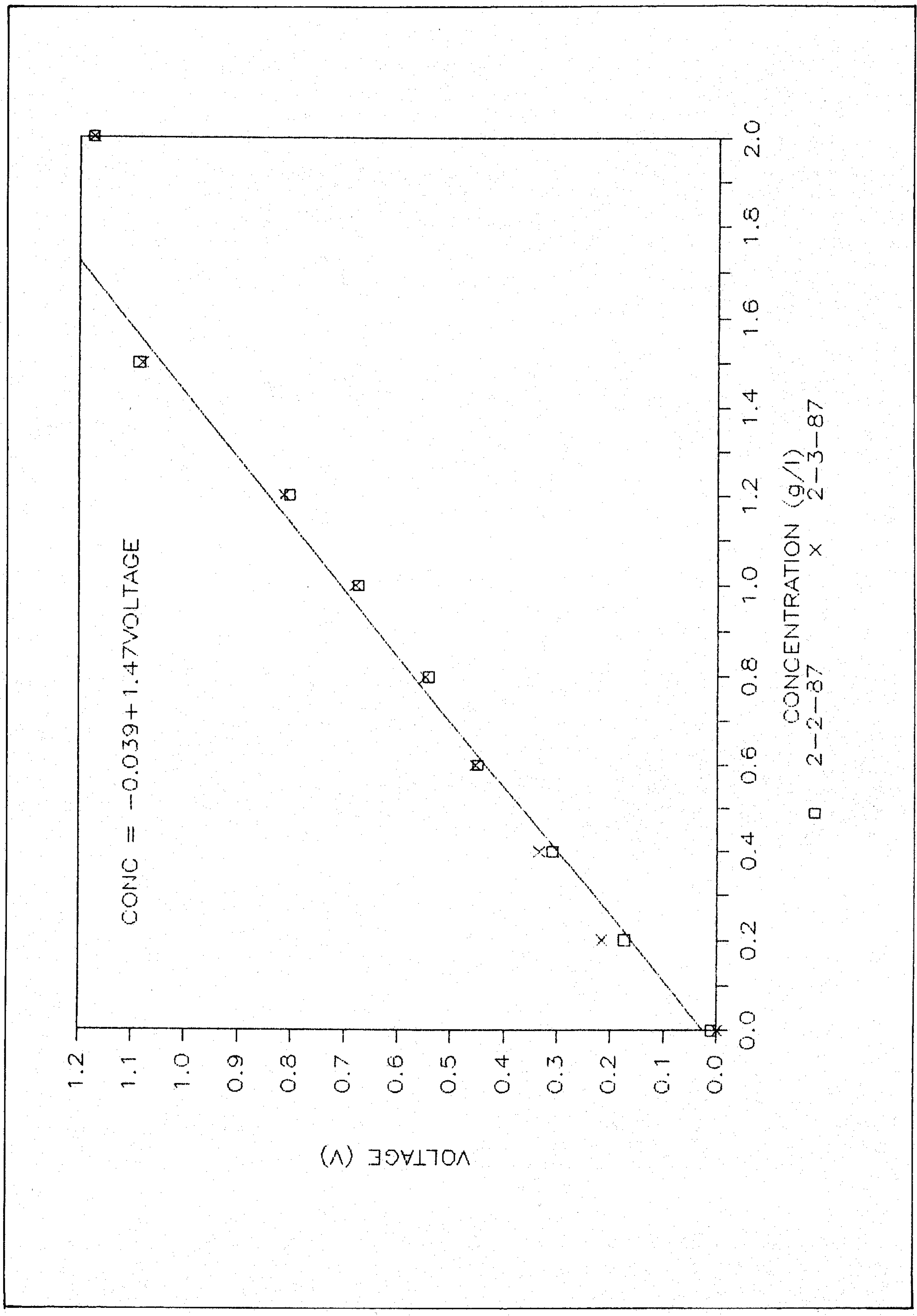

Fig 10 Field calibration curves of MEX-3DC sensor with Grangemouth mud

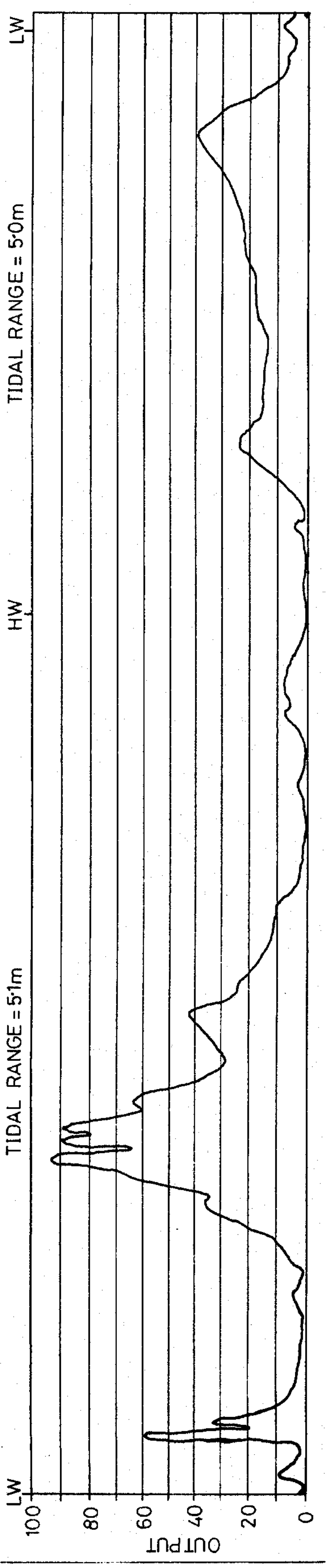

Fig 11 Typical Partech sensor output to Rustrak chart recorder.

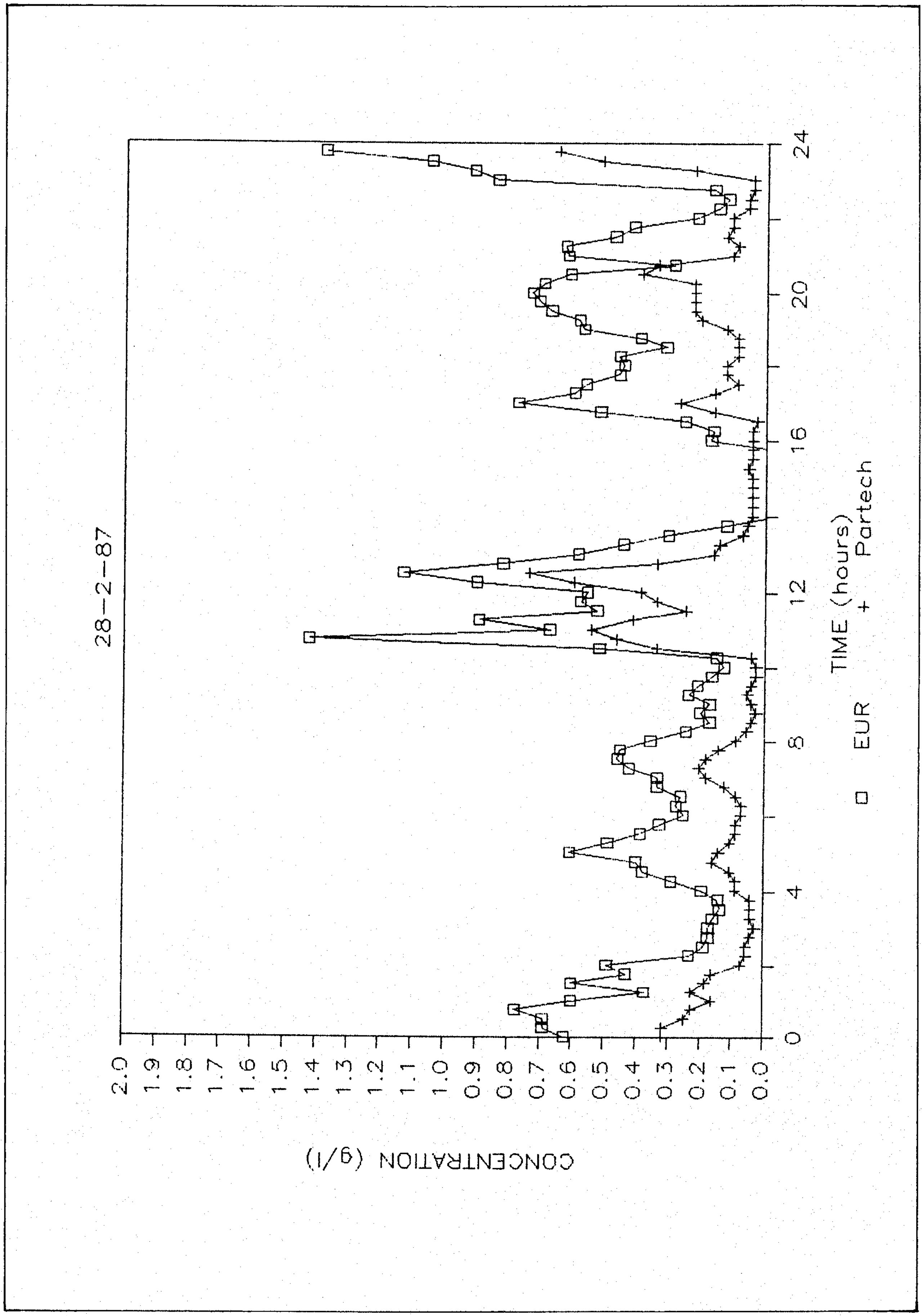

Fig 12 Comparative field trial of MEX-3DC sensor : spring tides

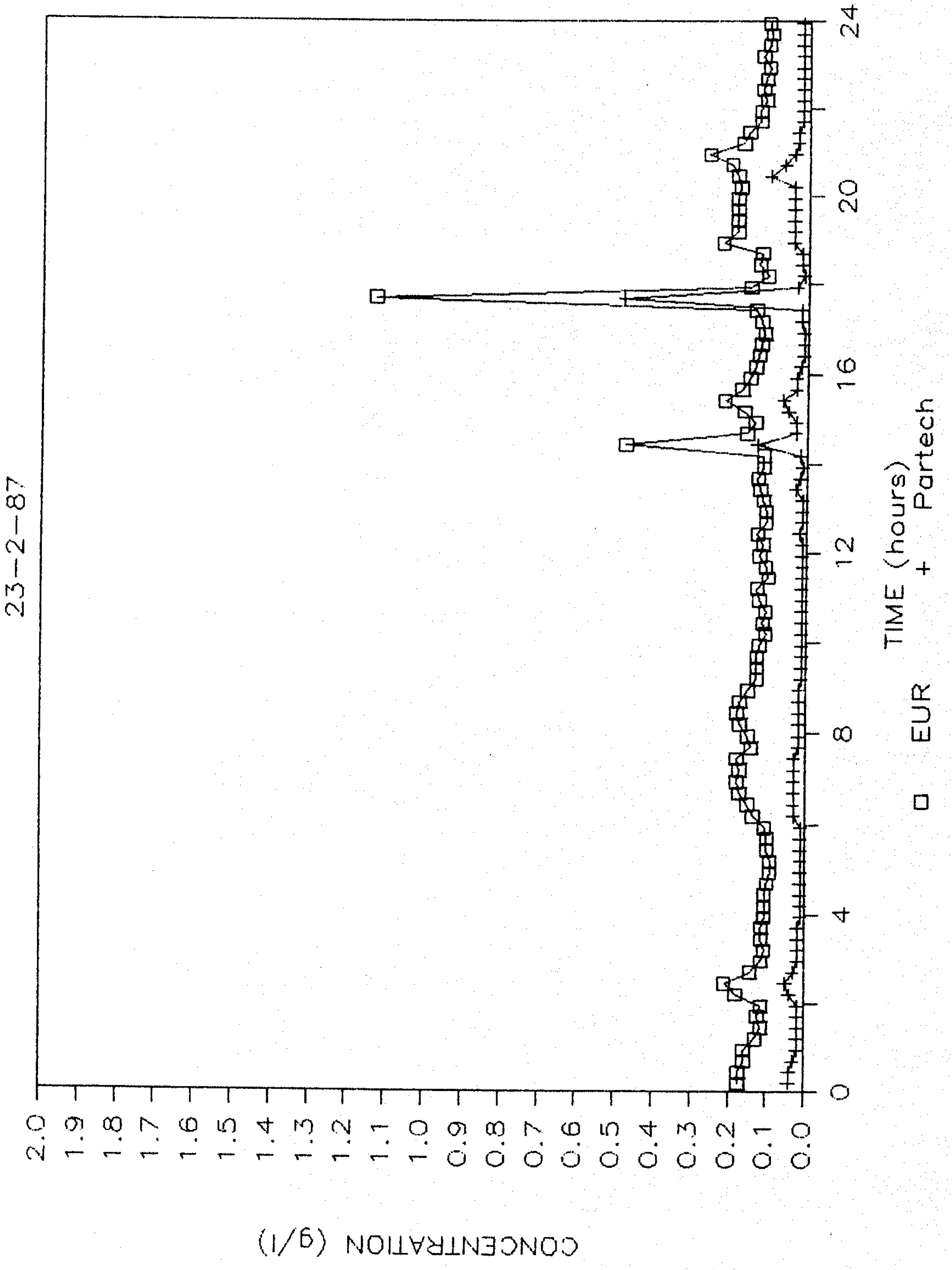

Fig 13 Comparative field trial of MEX-3DC sensor : neap tides

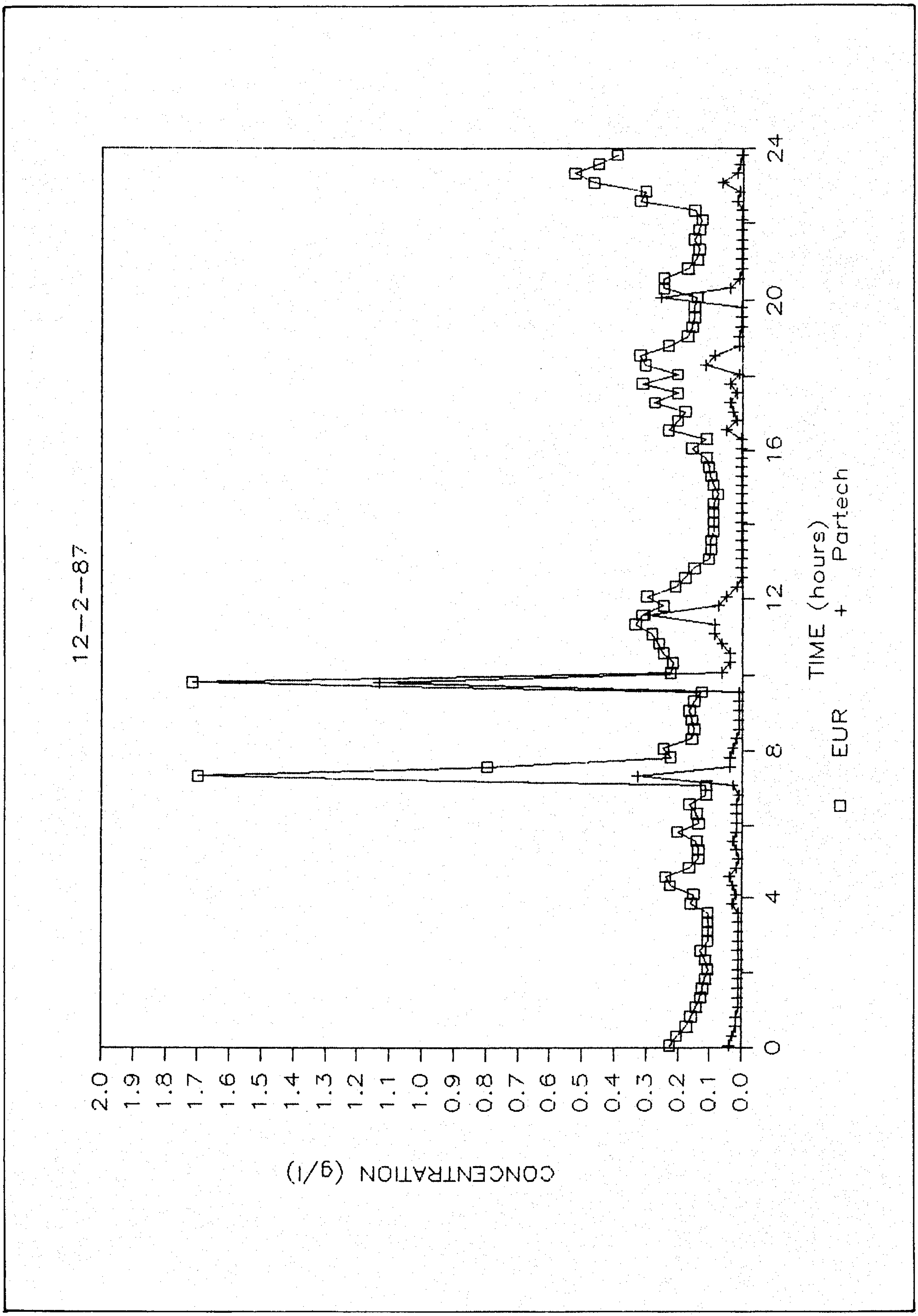

Fig 14 Comparative field trial of MEX-3DC sensor : mean tides (1)

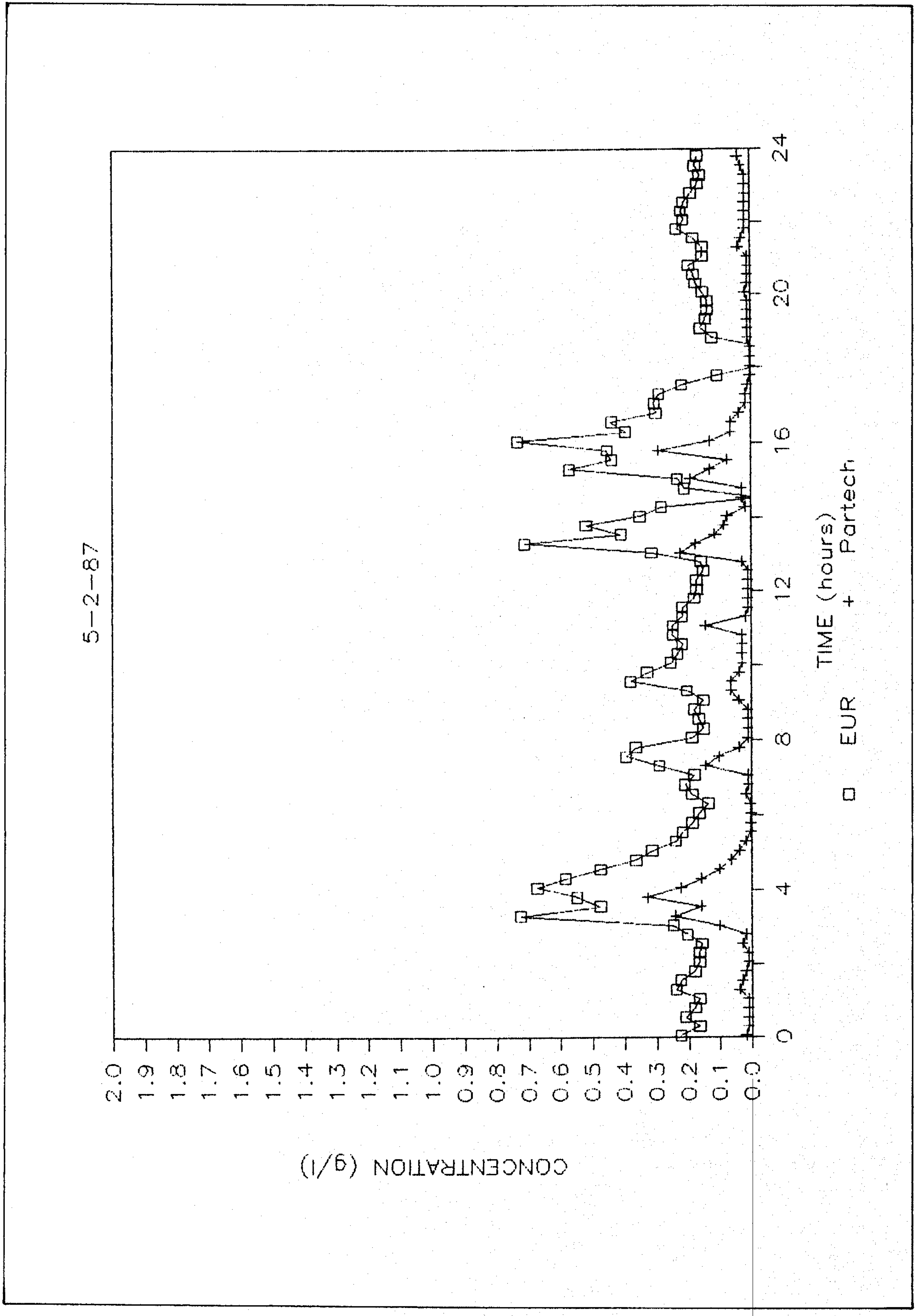

Fig 15 Comparative field trial of MEX-3DC sensor : mean tides (2)