DRILLING MUD FLOW MEASUREMENT

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SUMMARY

Extensive studies have shown that the measurement of mud flows into and out of a well during drilling provides the basis of the most efficient method for detecting mud loss into a fractured formation and temporary gain due to an influx of wellbore fluids, known as a 'kick'. Either occurrence can cause operational and safety problems.

The limitations of current field measurement techniques are well known. Current field measurement techniques are inadequate. The mud return flow is a particularly difficult problem since the return line runs partially full and the mud contains rock cuttings in suspension.

Consequently a flow calibration facility was constructed at the British Gas Engineering Research Station to provide a test bed for various flow meters and techniques. This paper describes the facility, its commissioning and discusses the performance of various measurement techniques for water based muds and with simulated cuttings.

1. INTRODUCTION

A well kick can be defined as a temporary uncontrolled influx of wellbore fluids at pressures which are a recognised danger to operating personnel and equipment. Early detection of a kick would increase the drilling operation safety.

Kick detection can be made in a number of ways (Ref. 1). The most common method is monitoring mud pit levels. Indication may also be obtained from an increase in penetration rate or a decrease in circulation pressure. Mud loss may only be detected by the mud pit level.

The mud system on a drilling platform is given schematically in Figure 1. Mud is pumped down the centre of the drill string to the drill bit where it lubricates and cools the bit. The mud then picks up the cuttings generated by the bit and transports them back to the surface. Here the drill solids are removed and the clean mud returned to the mud pit.

The hydrostatic head of the mud column ensures that any hydrocarbons in the rock formation are maintained in the formation. Therefore the hydrostatic head of the mud must be greater than the formation pressure. It is in situations where an underbalance occurs, i.e. the formation pressure is greater than the head, that a kick occurs.

Computer simulations of kicking wells (Refs. 2 and 3) have indicated that instrumentation to detect changes in return mud flow rate offer the greatest potential in the detection of kicks. The gas, being less dense than the drilling fluid, rises at a faster rate than the drilling fluid. As it rises, the gas expands and pushes the mud above the bubble of gas out of the well bore at a rate greater than the in-flow rate. Figure 2 gives an example of a 10,000 ft well, 90 psi underbalanced with a mud flow of 300 GPM. The mud return flow, measured in the return flowline, gives a more rapid response to the influx than either the pit level or stand pipe pressure.

Mud return flowline sensors have the potential to measure directly and instantaneously, any changes in the rate of flow.

Measurement in the return flowline is frought with difficulties. Firstly the fluid in question is dirty, sticky, non-Newtonian and multiphase. Secondly, the flow seldom fills the return flowline, which may be a pipe of diameter 8 to 24 inches or a trough. Thirdly, the turndown ratio (11:1) required is high to cover the full range of flows in a drilling operation (Table 1).

Hole Size	Circulation Rate
26"	1200 - 1500 GPM
17½"	900 - 1200 GPM
12¼"	500 - 600 GPM
8½"	250 - 350 GPM
6"	140 - 180 GPM

Table 1 - Mud Circulation Rates

In a kick situation, it is desirable to detect a change in flow rate as soon as possible. Ideally, this should be before the influx is greater than 5 bbls (210 Gals). Current field experience is that many kicks go unnoticed until a 10 bbl influx has occurred.

Several studies have discussed the accuracy required (Refs 3 & 7). The conclusions are that an accuracy of between 25 and 50 GPM is necessary. Relating this to the above circulation rates yields accuracies of 3 - 18%.

As the problems of measuring the fluid are numerous, it is necessary to be able to reference any flowmeter to known conditions. Therefore, British Gas Engineering Research Station have built a test rig for both full-bore and open channel flow meters operating on water and water based drilling fluids. The objectives of the work are to test and compare metering systems for use with drilling fluids. The information is then used to advise British Gas Exploration and Production of suitable metering systems to be used during its drilling operations.

2. PAST WORK

Work over the past few years has homed in on the need for an accurate, reliable measurement system that will operate in the mud flow return line.

Anadrill/Schlumberger have developed a flow out sensor based on the measurement of the height of the mud in the return flowline using ultrasonics (Ref. 4).

Petreco A/S have presented a paper on their J-meter (Ref. 5) which deflects the flow and then determines the flowrate from the forces exerted on the pipe by the fluid.

Amoco Production Co in a paper on the diagnosis of cementing problems (Ref. 6) describe the use of out-flow measurements. These were achieved using Electromagnetic meters for water based muds, WBM, and a wedge differential flow meter for oil based muds, OBM.

Fluenta A/S have developed an ultrasonic time of flight meter for specific use with drilling fluids.

At present, however, these techniques have not been fully field proven. Hence, the only mud return flow meter in general use is the paddle meter (Fig. 3).

3. TEST FACILITY

The flow loop is shown in Figure 4.

A centrifugal pump was chosen, capable of $0.025 m^3/s$ (400 GPM). The choice of pump was governed by problems of pumping the drilling fluid with cutting content and avoiding pulsating flow. The pump also allowed control of flowrate to give changes ≤50 GPM.

The flow is circulated from a $4.54 m^3$ (1200 US gals) sump tank, through a 100 mm (4 inch) test section, then into a 200 mm (8 inch) section and finally returning to the sump tank. The 100 mm section always runs full. The 200 mm section, however, is vented to atmosphere and runs partially full.

To achieve a standard against which each meter can be compared, a weigh tank has been included in the loop. The flow is diverted by valves A & B (Fig. 4) into the weigh tank. A timer is triggered at a predetermined weight. At a second predetermined weight, the timer is stopped and the diverter valves operated to return the flow to the sump tank.

Although this method does not follow precisely BS 6199 (Ref. 8) for dynamic weighing of liquids, it has been used with success in the past (Refs. 9 & 10). The accuracies capable from gravimetric systems such as these can be as high as ±0.1%. However, from the above discussion, the requirements for this work are 3 - 18%. The aim therefore, was to build a test facility which would give a gravimetric standard to ±1.0%.

The instrumentation on the rig (Fig. 4) is monitored using a data logger. The information is then downloaded onto a mainframe computer for analysis. Digital displays of the instruments give operational control.

3.1 Calculation

The mean mass flow rate into the weigh tank is given by:

$$q_m = \frac{w_f - w_i}{t_f - t_i} \qquad (1)$$

where q_m = mass flowrate (kg/s)

w_f = final mass of fluid (kg)

w_i = initial mass of fluid (kg)

t_f = time to collect final mass of fluid (s)

t_i = time to collect initial mass of fluid (s)

The mean volumetric flowrate is therefore given by:

$$q_v = \frac{q_m}{\rho} \qquad (2)$$

where q_v = volume flowrate (m³/s)

ρ = density of the fluid (kg/m³)

hence,

$$q_v = \frac{w_f - w_i}{t_f - t_i} \frac{1}{\rho}$$

3.2 Uncertainties

The standards relating to gravimetric calibration techniques (Ref. 8) for closed pipeflow measurement state that dynamic errors are negligible for the dynamic weighing method. However, one of these errors is not negligible as this test loop is not completely closed flow. In addition, there are other uncertainties which must be taken into account.

The major uncertainties in the system are:

1 - weighing

2 - time

3 - density

4 - change in flowrate during test due to loss of head at the pump

3.2.1 Weighing Uncertainty

The load cell weighing system is sensitive to 0.6 kg. For a total weight of 800 kg the error due to the load cells is ±0.075%.

3.2.2 Timing Uncertainty

Two timing methods are employed. The first is a digital quartz crystal clock on the control panel which has an error of ±0.01s. The second method is the quartz crystal clock in the data logger which logs every second. This also has an accuracy of ±0.01s. For the maximum flow, 400 GPM ($0.025m^3/s$) the time to collect 600 kg of fluid is 23.8 seconds. Therefore, the error due to the time measurement is ±0.042%.

3.2.3 Density Uncertainty

3.2.3.1 Water

The density for the water test is taken from a standard reference book. Hence, the uncertainty of the density value is due to uncertainty in the temperature measurement. The line temperature is measured using a pipe surface resistance thermometer. The error of this method is ±0.11% which results in an uncertainty in the density value of ±0.11%.

3.2.3.2 Drilling Fluid

The density of the drilling fluid is measured before and after testing by sampling the circulating flow. The density is measured using a Mud Balance which gives readings directly in Pounds per Gallon (PPG) and specific gravity. This instrument is claimed to be sufficiently accurate to allow measurement of density to within ±0.1PPG. The range of densities will be 8.33 to 10.5PPG. The temperature of the flow loop is allowed to stabilise such that the temperature during a test remains constant. Hence, the uncertainty of the density measurement is ±1.2%.

3.2.4 Flowrate Uncertainty

As the flow enters a channel flow section, the outlet head from the pump remains constant. Therefore, for steady flow, it is necessary to maintain a constant inlet head. However, when the weigh tank is in use, the fluid does not return to the sump tank, causing a loss in inlet head. To achieve constant priming head would require a constant head feeder tank for the pump, in addition to the sump tank, and pumping capacity between the sump and the header greater than the maximum flow around the loop.

The effects of the drop in flow rate have to be accounted for as the element of fluid entering the weigh tank at the start of the timed period passed through the meter being examined a finite time before. The time taken for the fluid to travel from meter position 1 to the bottom of the weigh tank was calculated. Assuming that this time is known to within ±5 secs, then the uncertainty of the mean flowrate through the meter being examined is ±1.2%.

3.2.5 Aeration

A source of error in a liquid calibration facility is the presence of air bubbles. Aeration can be caused by entrainment due to the agitation of the fluid. Additionally, it may be caused by points of local pressure far below atmospheric.

The latter was covered as far as possible, by ensuring that the pressures in the system are above atmospheric. However, during commissioning of the loop, air bubbles were noted.

Following the recommendations of Hayward (Ref 11), a mesh was placed in the sump tank separating the pump inlet from the return flow and agitator. Hayward had illustrated using a fine mesh gauze. Due to the nature of the drilling fluid and also the inclusion of sand to simulate cuttings, a fine mesh was impracticable. A coarse expanded metal screen was adopted.

3.2.6 Total Systematic Uncertainty

Using the "root-sum square method" (Ref. 12), the total uncertainty of the flowrate measurement using the loop is determined.

The total systematic uncertainty of the weigh tank system (E_T) is:

3.2.5.1 Water

$$E_T = \pm\sqrt{(0.075^2) + (0.042^2) + (0.11^2) + (1.2^2)} \tag{4}$$

$$E_T = \pm 1.2\%$$

3.2.5.2 Drilling Fluid

$$E_T = \pm\sqrt{(0.075^2) + (0.042^2) + (1.2^2) + (1.2^2)} \tag{5}$$

$$E_T = \pm 1.7\%$$

4. TEST PROGRAMME

With meters installed in either the 100 mm full bore test section or in the 200 mm "channel flow" section, the flow is set using a thyristor control on the pump. The flow is allowed to stabilize for half an hour. The flow is then diverted into the weigh tank and the time to collect 600 kg of liquid is noted.

This operation is then repeated four times.
The flow is then varied by increasing or decreasing the pump speed. The aim is to examine response time and sensitivity of the meters to changes in flow in the region of 25 - 50 GPM ($0.0032 m^3/s$).

4.1 Fluids

The range of fluids being examined for each meter are:

a) Water

b) bentonite mud; viscosity 40cP, density 8.5 PPG

c) bentonite mud + barite; viscosity 40cP, density 10.5 PPG

d) bentonite/bar mud + 10% cuttings (sand); viscosity 40cP, density 10.6 PPG

4.2 Flowrates

The flow rate at which calibrations are made are:

a) 100 GPM

b) 200 GPM

c) 300 GPM

d) 400 GPM

4.3 Measurement Techniques

The first step was to review the current state of the art in flow measurement to ascertain the techniques most likely to be applicable to measuring non-Newtonian dirty fluids. As a result five techniques were highlighted.

1. Electromagnetic

2. Ultrasonic

3. Target

4. Differential pressure

5. Coriolis

Each of these techniques have advantages and disadvantages which must be taken into account in addition to their overall accuracy and repeatability. As the Coriolis technique generally causes a high pressure drop by its tortuous path and that the largest available system is 4 inches diameter, this was rejected at this stage.

5. DISCUSSION

5.1 Meter Selection

A number of commercially available and development meters were chosen for investigation. Each meter has been identified with a letter. The following is a list of the meters and their mode of operation.

Meter	Mode of Operation
A	Pulsed AC Electromagnetic
B	Pulsed DC Electromagnetic
D	Ultrasonic Level plus Doppler Velocity
E	Ultrasonic Time of Flight
F	Target
G	Target
H	Differential Pressure
I	Differential Pressure

5.2 Advantages and Disadvantages

5.2.1 Electromagnetic

The electromagnetic flow meter for clean conductive liquids has a proven field record. Electromagnetics are only, however, applicable to WBM's and require to be full bore.

The velocity through the meter is specified as 0.5 m/s minimum and 11 m/s maximum. This means that the size of flowmeter required will be 125 mm (5 inch) diameter to cover the range of flowrates. One manufacturer states that for fluids with a solids content, the minimum velocity must be between 3 and 5 m/s, to prevent deposition of the solids and abrasion. The lower flowrates ($\leq$ 585GPM) will fall into this category. Dual systems are therefore required to cover the full range of flows.

The possibilities for return flow meter location are given in Figure 5. The first is to add a U tube to be existing return flow line which will remain full. The combination of bends and low flow rates may give serious blockage problems with solids drop-out.

The second configuration will cause less problems with blockage, except in the instance of GUMBO shale being encountered, but does require major alteration to the Bell Nipple.

5.2.2 Target

A target meter, the paddle meter is already in use in the exploration industry, but field experience has shown it to have accuracies of ±30-50%.

Target meters tend to be intrusive although a development meter is to be tested which operates on deflecting the flow by a bend in the pipe. In both cases, the forces of the fluid hitting a solid boundary are measured.

The major advantage of this technique is that it may be used in channel flow and it is robust.

5.2.3 Differential Pressure

Differential pressure devices, the mainstay of flow measurement, are intrusive therefore increase the likelihood of blockage. The sizing of the meter for a suitable differential pressure is also a major concern. Meter H was sized to give 1.25 bar (500 in WG) differential. The resulting pipe diameter for a maximum flow of $0.0252m^3/s$ (400GPM) is 75 mm (3 inch). The turndown of the meter is 3:1, hence, the minimum flow is $0.0084m^3/s$ (133GPM).

5.2.4 Ultrasonic

Ultrasonic meters come in two categories: fluid level plus doppler velocity; and time of flight.

5.2.4.1 Level plus Doppler

The advantage of this system is that it will operate in a channel section. It is widely used in the water industry to measure sewage.

However, field experience of the doppler measurements to determine velocity show accuracies of around ±15%.

The fluid level detection system requires accurate knowledge of the pipe shape to determine the area of the flow and accurate knowledge of the density of the fluid. A wavy surface may cause problems in the detection of the surface, due to scatter of the signal and uncertainty of the true level. Even with averaging and smoothing, small changes in level may go undetected.

5.2.4.2 Time of Flight

As in the case of the electromagnetic meter, for the ultrasonic time of flight meter the pipe cross-section must run full. Hence, the meter must be mounted in the same configurations as the electromagnetic meter (Fig. 5). It will be subject to the same problems of either deposition of solids or redesign of the Bell Nipple.

5.3 Preliminary Results

A proprietary paddle meter used in the return flowline whilst drilling, was placed in the channel flow section of the loop at position 3. The output from this was compared with an electromagnetic flow meter at position 1. The results for 100 GPM and 400 GPM, Figures 6 and 7 show the scatter of the paddle meter signal when tested on water.

The comparisons of the calibrations against the weigh tank of two electromagnetic meters, A & B, and paddle meter F are given in Figure 8. The electromagnetic meters are consistent at about the 2% mark. Meter A rose to 6% at 25% of full flow (100 GPM). Meter B showed ±2% scatter at 100% flow, whilst meter A gave a maximum scatter of ±0.4%.

The paddle meter was generally within -4% at 100% flow. At 25% flow, the meter showed -34% error. However, the scatter of the signal from the meter was ±50%.

6. CONCLUSIONS

6.1 British Gas have constructed a laboratory facility to compare and evaluate flow metering systems for both full pipe flow and open channel flow. The facility operates using a range of fluids from water to water based drilling fluids containing simulated cuttings.

6.2 The facility includes a standard reference weigh tank. The uncertainty of the reference is ±1.2% using water, and ±1.7% when using drilling fluids.

6.3 The signal from a currently used paddle flow meter has been shown to be highly scattered, ±50%.

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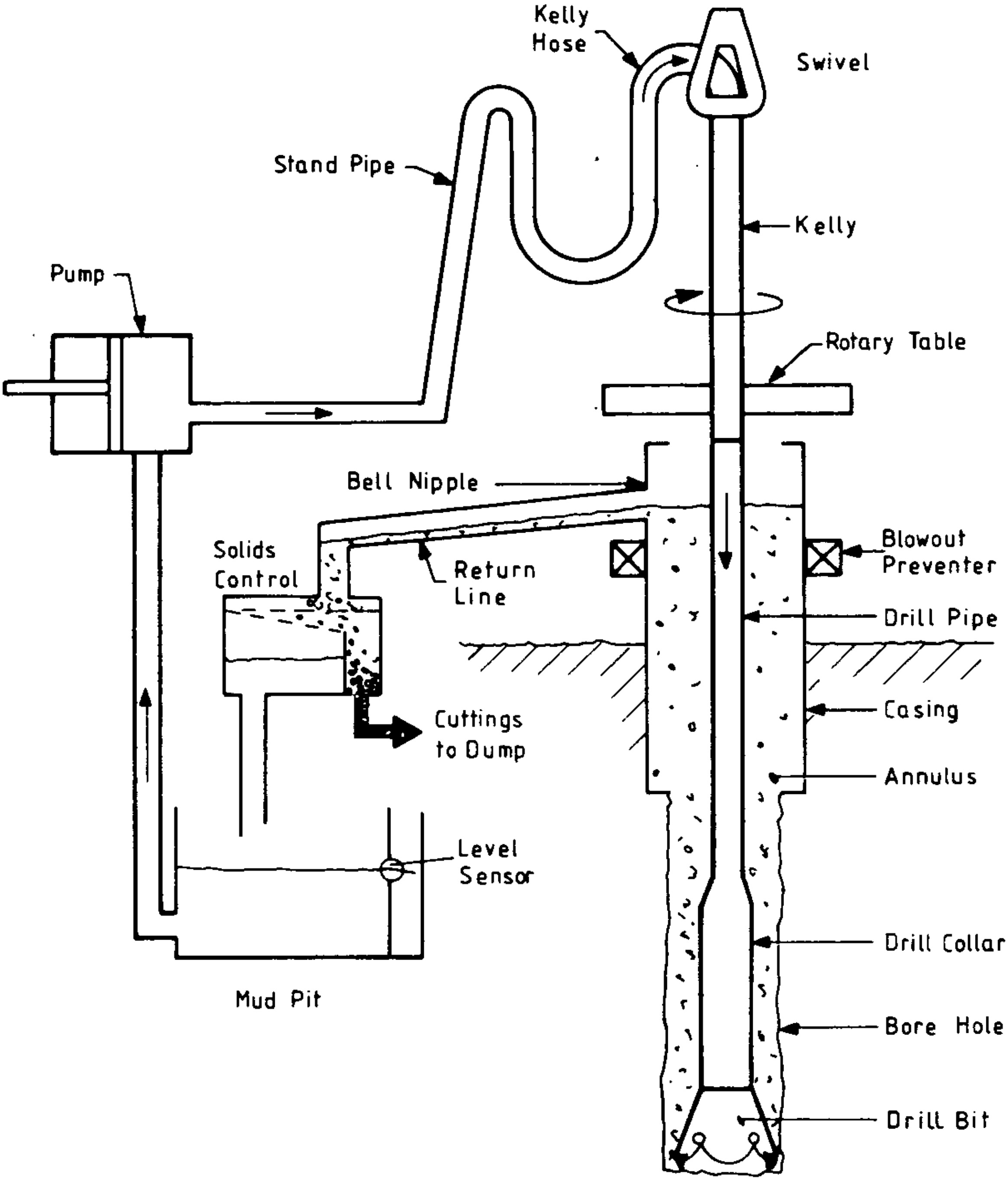

Fig.1 : Schematic Diagram of Drilling Fluid Circulation System

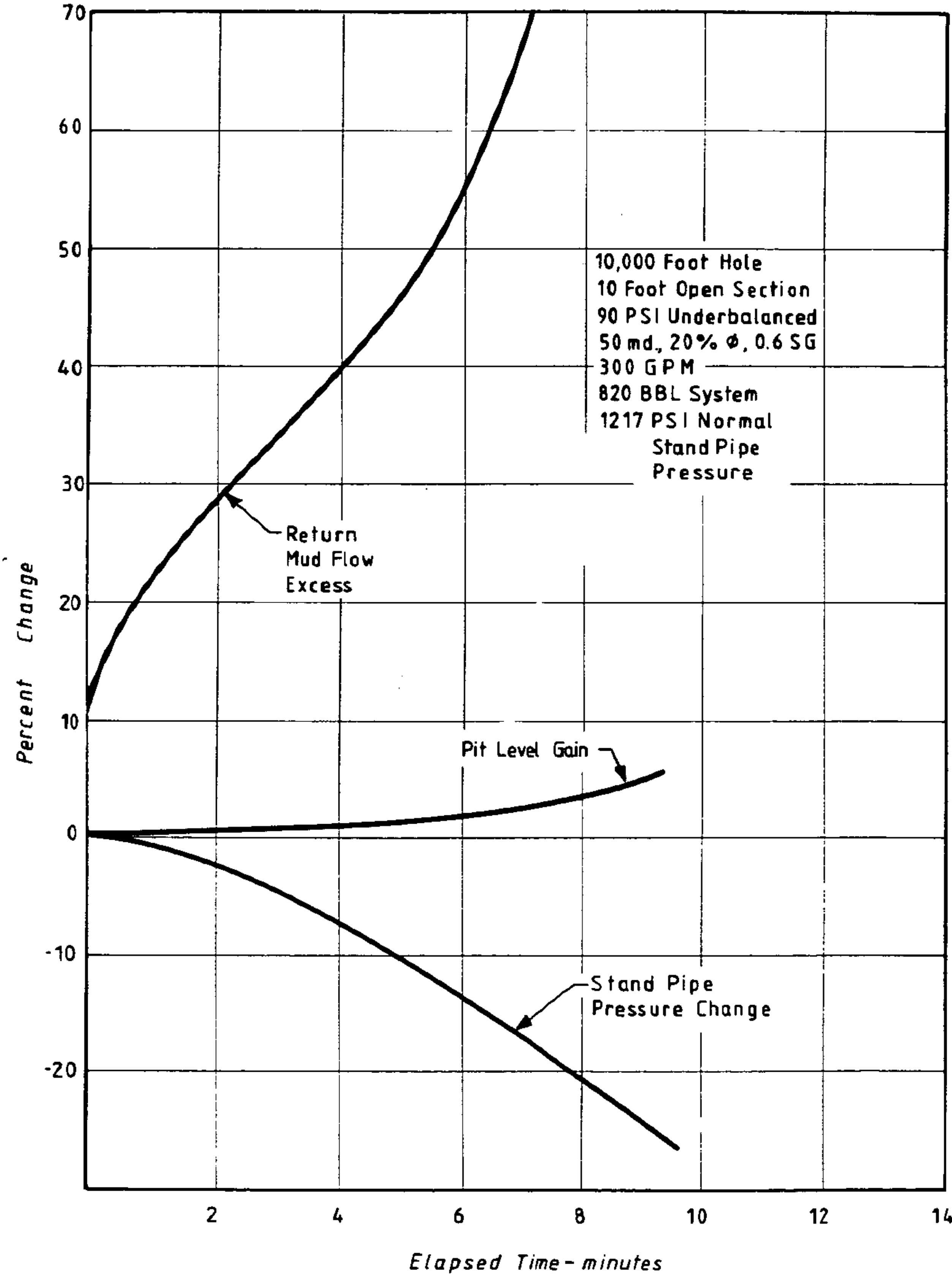

Fig.2 : Detection Criteria Changes in Percent of Total Measurement *vs* Elapsed Time

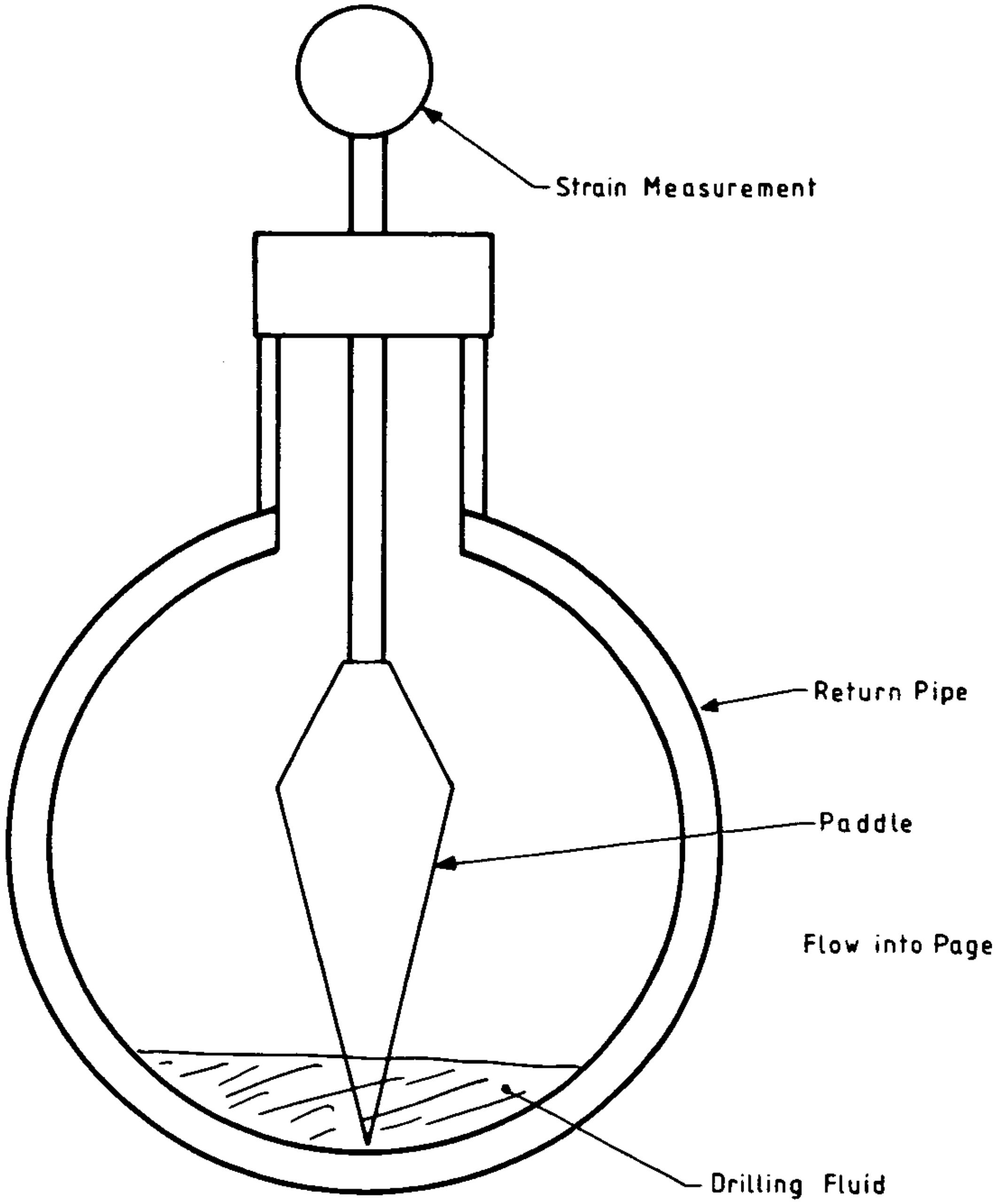

Fig. 3 : Paddle Meter

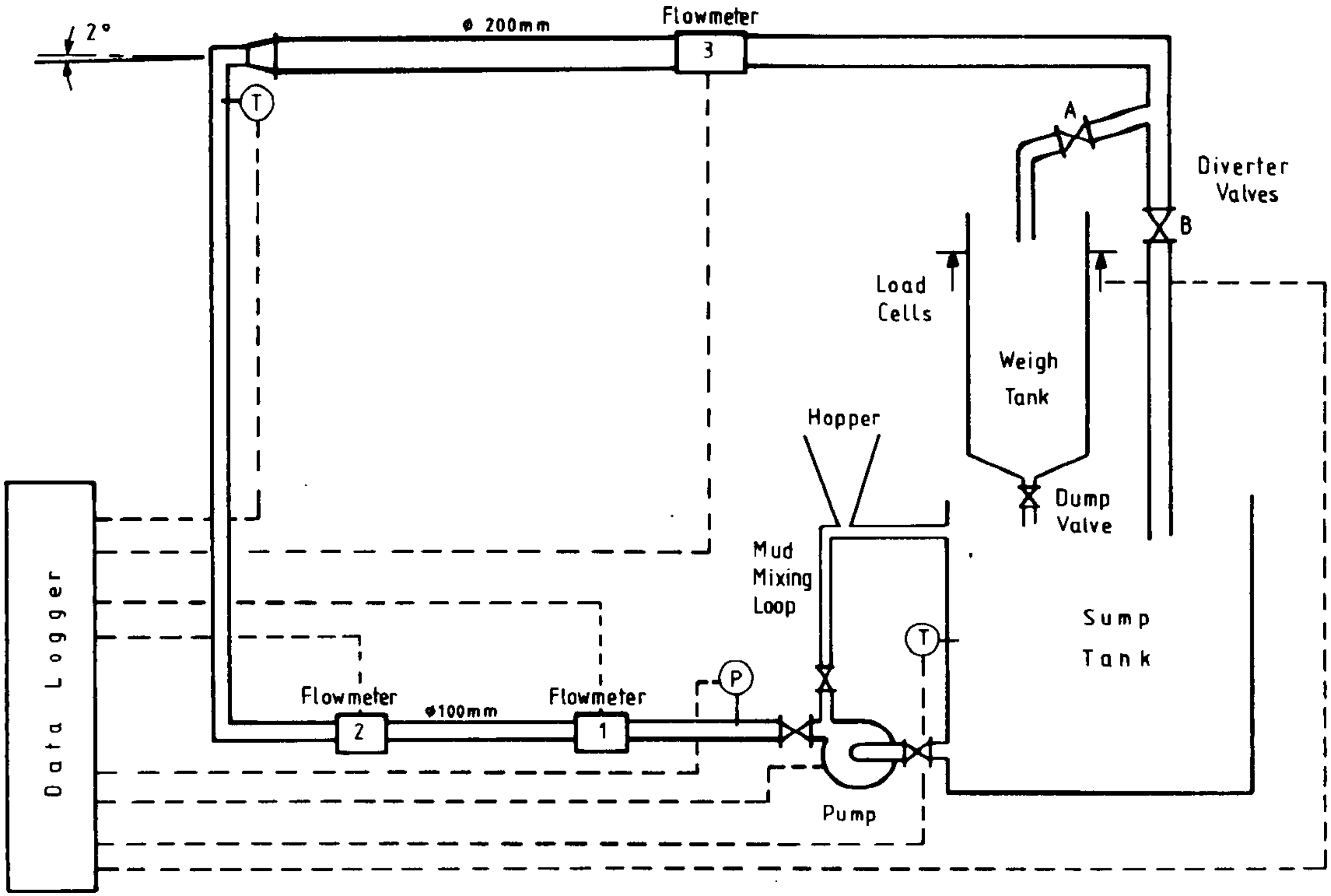

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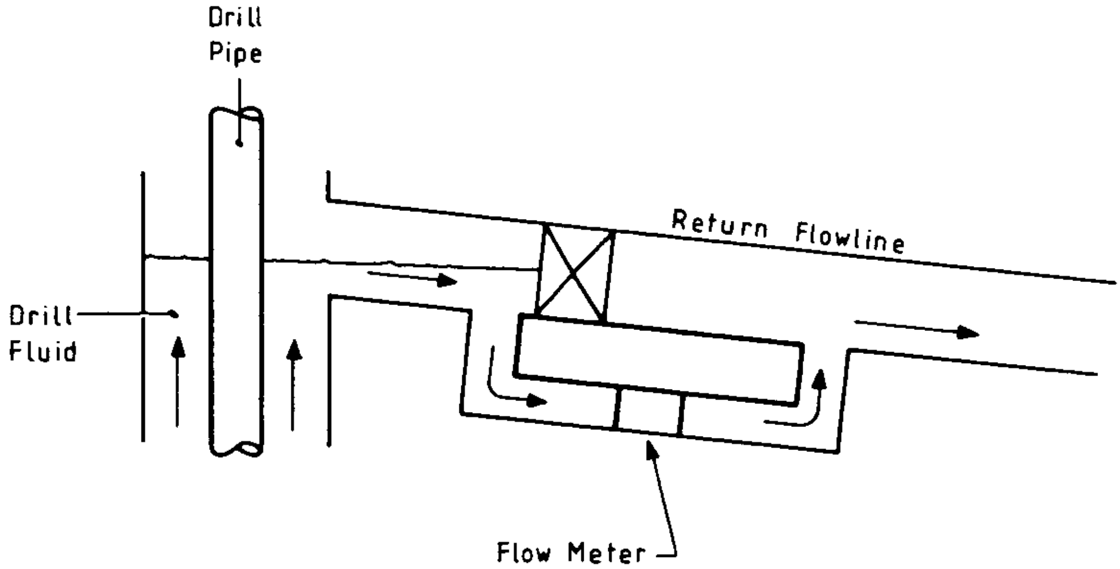
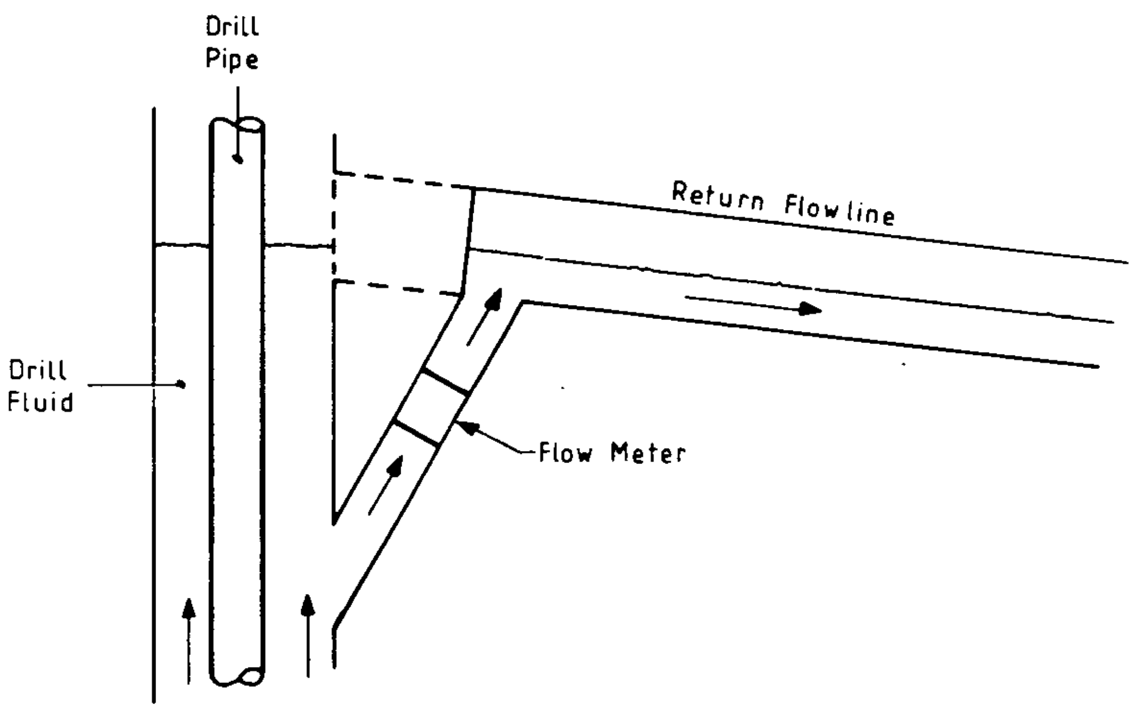
Fig. 4 : Schematic of Mud Flow Measurement Rig



(a) U Tube Configuration



(b) Modified Bell Nipple Configuration

Fig. 5 : <u>Meter Installations for Full Bore Flow</u>

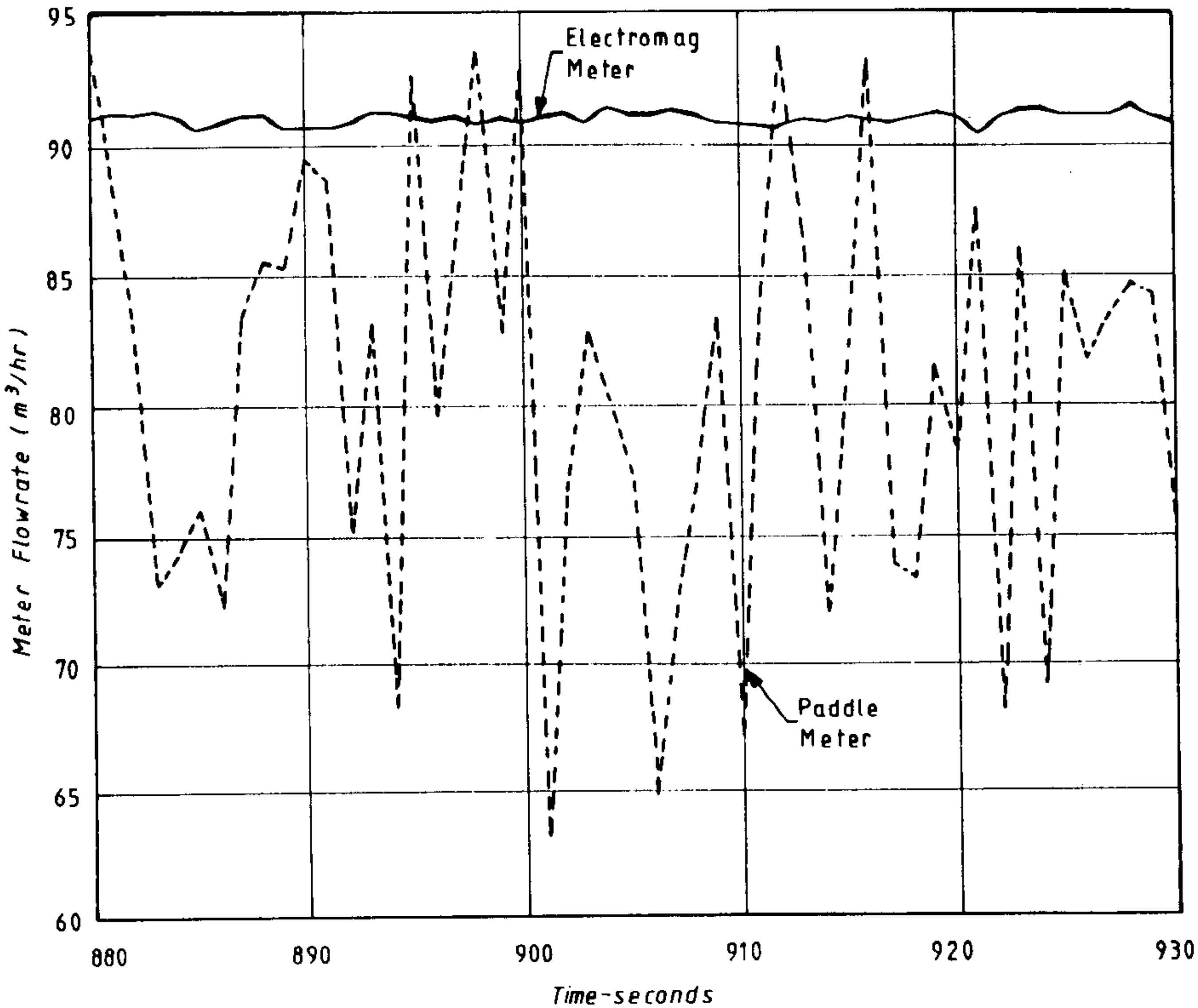


Fig. 6 : Comparison between Electromagnetic and Paddle Meters at 400GPM

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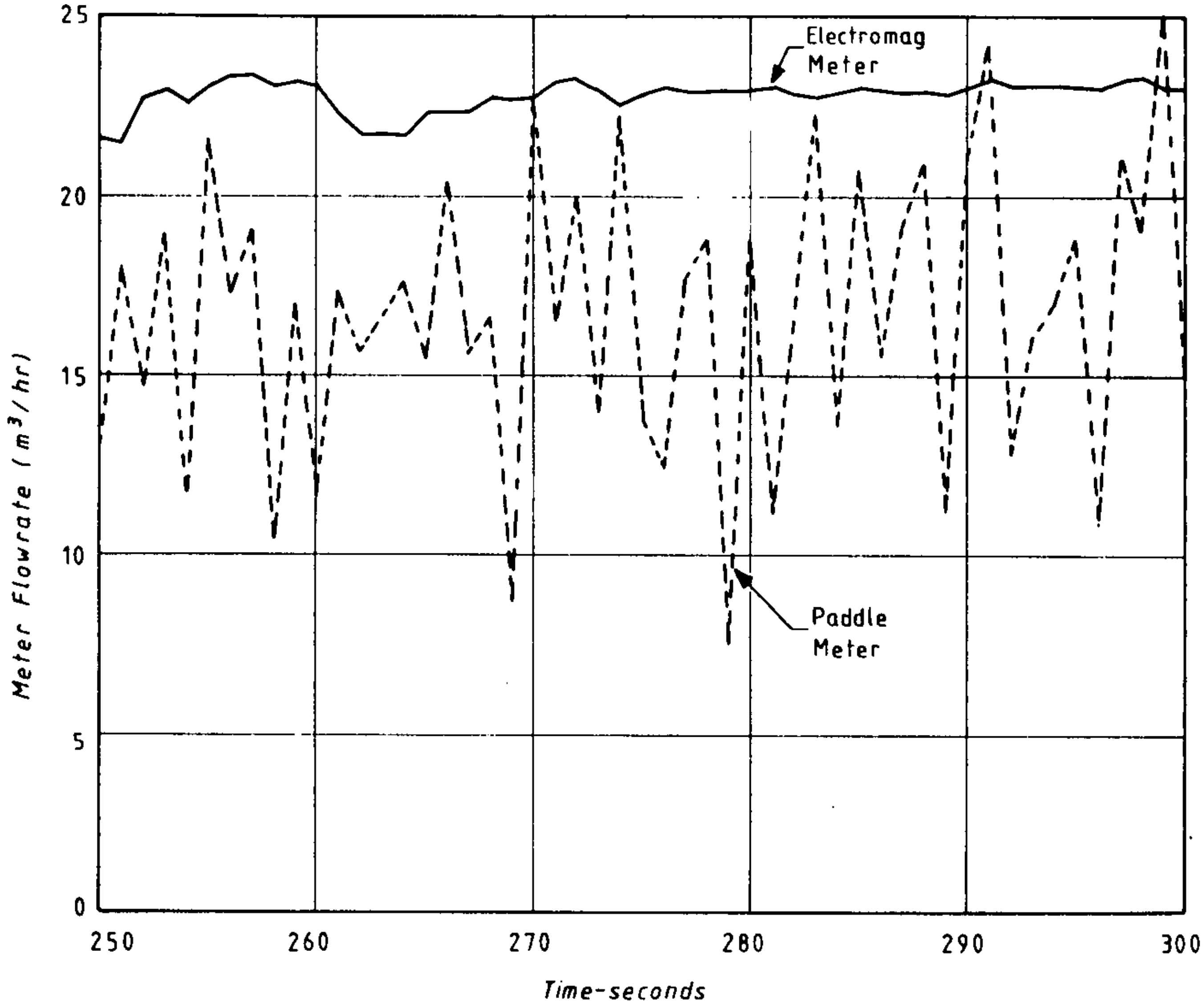

Fig. 7 : Comparison between Electromagnetic and Paddle Meters at 100GPM

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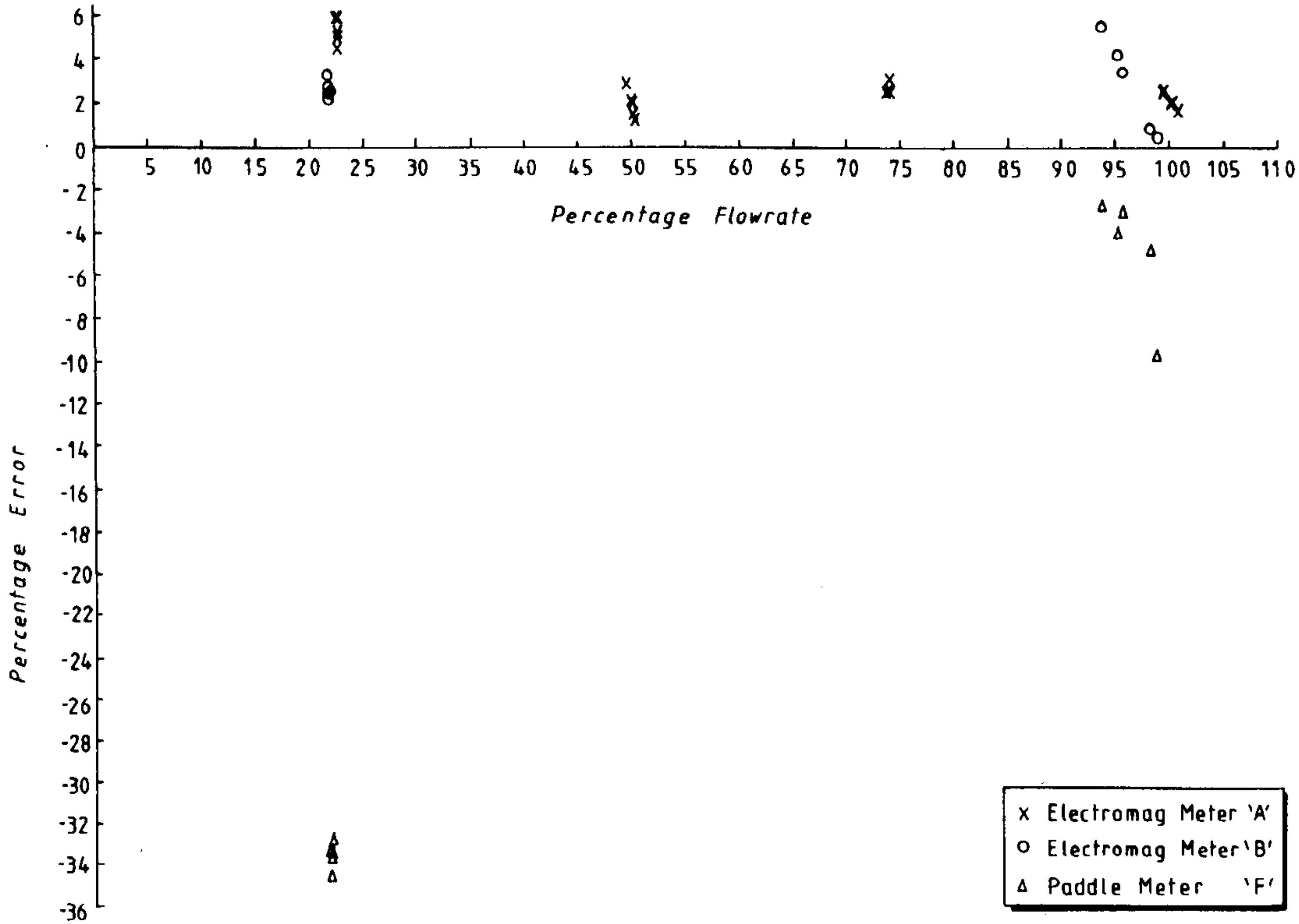

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Fig. 8 : Comparison of Meters A, B & F Against Weigh Tank