DEVELOPMENTS OF MULTIPATH TRANSIT TIME ULTRASONIC GAS FLOW METERS

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SUMMARY

Ultrasonic meters that do not need flow calibration are being developed for fiscal gas measurement. As with any other new technology the lack of recognised standards is hampering this effort. Evidence is presented to advance the use of uncalibrated meters and performance validation. The meter was originally designed for distribution, i.e. clean dry sales gas at 60 Bar and ambient temperature. It is being extended into gas production where moisture can cause practical problems. Some ongoing research on the measurement of wet gas is presented.

NOTATION

c	Velocity of sound in the gas (VOS)
D	Pipe internal diameter
L	Ultrasonic path length between transducers
q	Actual volumetric flow rate
R	Pipe internal radius (D/2)
t_1	Transit time against flow component
t_2	Transit time with flow component
V	Chord velocity
V_m	Average velocity
W	Weighting factor, for integration
x	Axial component of ultrasonic path in the flow

1. INTRODUCTION

The multipath meter was developed by British Gas in the early 1980's (Ref 1 to 5) and licensed to Daniel Industries in 1986 (Ref 6 to 9). The first commercial production meters were sold in 1989. These meters had analog electronics and used a simple threshold to detect the ultrasonic signals. In 1993 Daniel introduced digital electronics with automatic gain control (AGC) and digital signal processing (DSP) to reduce electrical noise, greatly improve the signal detection and hence increase the timing accuracy. The advantage of AGC was to eliminate pressure sensitivity.
This year Daniel have released a MkII design where the drive unit electronics are installed in a Flameproof Enclosure that is directly mounted onto the meter body, instead of into a 19" rack located in the safe area. This eliminates an expensive 8-core cable, improves immunity to electrical noise and produces a smart flow transmitter.

Three developments are considered:

- Ultrasonics is a relatively new method of gas flow measurement and although capable of meeting fiscal requirements, no accepted standards exist and hence they must be developed.
- Another great attraction of ultrasonic meters is the potential for not needing a flow calibration, but this remains to be demonstrated.
- The British Gas meter was originally designed to measure clean dry gas and has been found susceptible to moisture, development is under way to extend the operation to include wet gas.

2. STANDARDISATION

The paper on the Ultraflow project by Bloemendaal & Kam, in this workshop, tackles the development of an installation standard.
The following is intended to help produce a standard for uncalibrated ultrasonic flow meters.

3. "DRY" CALIBRATION

It is not necessary to calibrate the meter with a gas flow and reference standard, basic measurements of geometry and time should suffice.

Theory of a transit time ultrasonic meter predicts (Refs 1 & 6)
For each chord the velocity $V = L^2/2x\ (t_1 - t_2)/t_1 t_2$ - (eq 1)
and the velocity of sound $c = L/2\ (t_1 + t_2)/t_1 t_2$ - (eq 2)
A multi path meter gives several chord velocities which are then integrated to give the Average velocity $V_m = \Sigma W_i V_i$ - (eq 3)
The individual chord velocities give an idea of the velocity profile and if not very distorted, the integration technique gives an accurate average.
The actual volume flow $q = V_m * Area = V_m \pi D^2/4$ - (eq 4)
The accuracy depends on area from diameter (D) and velocity, which in turn is derived from distance (L, x) and time (t_1, t_2).
The meter geometry (L, x, D) can be determined with sufficient accuracy (by a coordinate measuring machine), but the transit time is not quit so straight forward.

The absolute transit time can not be measured directly because the required time is that through the gas alone, whereas the measured time includes delays due to cables, electronics, transducers and the time into the received waveform where the DSP chooses to detect the signal arrival.

The average delay time (**AvgDly**) for a pair of transducers is measured in a test cell or the meter body using nitrogen, where the velocity of sound is known from IUPAC tables to 0.1%.

Some orders of magnitude will help examine timing accuracy:
- With an ultrasonic frequency of 100 KHz the period T = 10 μs
- For L = 0.4 m and c = 400 m/s t = 1000 μs (12" meter)
- In a test cell (L=0.2m) t=500 μs and is known to 0.5 μs (0.1%)
- A typical **AvgDly** = 25 μs and is also known to 0.5 μs

Using these values gives:
- The delay time is a 2.5% (25/1000) correction to the transit time, and hence a 5% correction to the flow (span adjustment).
- An accuracy of 0.5μs in delay time corresponds to 0.1% in flow.
- A skip of one period T in signal detection on both t_1 & t_2 (no effect on $t_1 - t_2$) is a 1% (10/1000) error in the transit time, and hence a 2% error in flow.

To go further we need to consider flow e.g.
- For L = 0.4 m, c = 400 m/s and V = 8 m/s then $t_1 - t_2$ = 20 μs

Using these values gives:
- A skip of one period T in signal detection on one transit time can give 50 - 100% error ($t_1 - t_2$ = 10 - 30 μs).
- A typical accuracy on time measurement is 20 ns giving 0.1% accuracy in flow (at 8 m/s), which increases to 1% at 0.8 m/s.
- Note, these magnitudes depend on the meter size and gas velocity as shown by Eqs 1 & 2.

The major potential source of error is peak switching and much effort is made to avoid this in the DSP quality checks. In fact the 80 - 120 KHz frequency range was chosen to make peak switching (of 10μs) obvious when it occurs.

3.1. First step of dry calibration

- Determine **AvgDly** for all four chords, using the actual drive unit electronics. Enter these delay times into the flow computer and check VOS same on each chord and equal N_2 value to 0.1%.
- 0.1% on VOS gives 0.2% on flow in the meter body, if a smaller test cell is used this can be improved.
- The four VOS values are a powerful self check, especially with smaller meters.

The **AvgDly** for a transducer pair is not the whole story. At zero flow t_1- t_2 is not exactly zero because of differences in electronics and transducers as transmitters and receivers, this lack of reciprocity giving typically a **DltDly** < 0.1 µs. At 8 m/s in the above example this would give 0.5% error (0.1/20), which would increase to 5% at 0.8 m/s

3.2. Second step of dry calibration (zero adjustment)

Determine the **DltDly** on each chord at zero flow, using the actual drive unit electronics, to at least 0.02 µs. It is not easy to achieve zero flow in the field, because shut off valves are not normally close to the meter and convection currents occur due to temperature differences. Insulation will help, but zero flow is easier attained in a temperature controlled lab with blind flanges on the meter, or better still in a test cell. It may be necessary to run the zero test over varying temperatures, to estimate the range and mid value of **DltDly** (typically +/- 10 ns).
A good zero should give V_m < 0.005 m/s, dependent on meter size.

3.3. Field check - validation

The dry calibration done in the factory should ensure that the meter works in the field. In addition field checks are possible:
- VOS should be same on all four chords.
- VOS should agree with calculations from gas composition, pressure and temperature.
- The velocity profile given by the four chords should indicate any installation problems and zero problems at low velocities.
- The standard deviation of transit time measurements is normally < 1 µs, larger values indicate disturbed flow (dependent on D).
- It is also possible to observe the received ultrasonic signal on an oscilloscope and check for amplitude, noise and distortion.

3.4. Verification by Flow Calibration

We have recently had the opportunity to flow calibrate several meters for our clients (Norsk Hydro, Statoil) that were first dry calibrated in our works:
A 6" meter at 37.5 Bar and 38.3 °C, see Fig 1 and a 12" meter at 140 Bar and 55 °C, see Fig 2, both at K-Lab.
Several 20" meters at K-Lab and British Gas Bishop Auckland.
K-Lab tested the effect of changing the pressure from 60 to 132 Bar on two meters and British Gas Bishop Auckland then calibrated them all at 60 Bar, see Fig 3.
The results showed that:

- Most meters attain 1% accuracy over 1 - 21 m/s velocity range with the factory dry calibration.
- Some problems with poor zero setting in the field especially with large meters. Fig. 3 shows that two out of five meters could have a better zero. It may not be good to zero in the field, as the effect of gas composition, pressure and temperature are not as great as thermal convection (non-zero flow) problems.
- One meter (filled square) was outside 1%, due to known problems with thermal equilibrium during dry calibration in the 20" body, it is probably better to use a smaller test cell.
- Negligible pressure effect between 60 - 130 Bar or temperature effect from 10 - 55 °C on flow calibration.

3.5 Conclusions

If the geometry is measured accurately, the timing set to give the correct VOS in nitrogen and the zero flow adjustment performed (with real zero flow), the dry calibration meets the +/- 1% accuracy spec over the 1 - 21 m/s velocity range.

4. WET GAS MEASUREMENT

The objective is to measure the gas flow, preferably unaffected by any liquid present, no attempt is made here to measure the two phase flow.

The original British Gas meter was designed for dry clean gas, with transducers recessed in ports, and further recessed by the use of transducer isolating valves (to facilitate transducer exchange). Moisture can cause several problems:
Moisture collects in the transducer ports, short circuits the acoustic isolation between transducer and body, bridges the small clearance between port and transducer, and contaminates the transducer front face.

The wet gas design aims to overcome these problems by:
- Using self draining ports, back into the body.
- Increasing the clearance between transducer and port.
- Placing the transducer face at the bore/port intersection, to both get a cleaning action from the flow and not be recessed.
- Better acoustic isolation and damping of the transducer.
- Reducing side emission from the transducer.

4.1. Testing

Two 6" meters were built for testing, with electroless nickel plating (ENP) to improve the corrosion resistance in wet gas, particularly for the air/water.
- Both were installed in horizontal lines with the chords in an horizontal plane.
- One at NEL on air and water in laboratory simulated conditions, that could be closely controlled.
- The other at Shell Bacton on natural gas with condensate, under real two phase flow conditions, dependent on production and the process plant requirements.

4.2. Test Results

- NEL injected mist, via a multitude of nozzles that atomized the water, in accurately controlled and stable conditions. Fig 4 shows a typical result (note the logarithmic scale).
- Bacton was originally conceived as a 6 month survival trial in a line attached to a gas treatment plant, see Fig 5.
- The success of the Bacton survival prompted some additional condensate injection tests, summarised in Fig 6 and shown in more detail in Fig 7.

4.3. Discussion

The Bacton trial lasted 9 months with at least 6 months of flow, which included 4 liquid slugs and complete flooding of the meter. The original concern was survival, not accuracy. When the meter showed potential for +/- 1% accuracy with wet gas, Bacton offered to do some controlled liquid injection tests. The main advantage at Shell Bacton was that known equilibrium two phase flow regimes could be established, based on previous work by KSLA.

The 2% shift in meter error after a liquid slug in Dec (Fig 5) is difficult to explain. The meter was not set up very well for the survival tests, it was reset for the liquid injection tests, showing some errors in the original set up which might have affected performance. The transducers were removed after this slug, but inspection showed no problems with liquid retention.

Fig 6 shows that with mist flow, especially at high gas velocity, 3% liquid by volume makes the ultrasonic meter read about 3% high. The gas and condensate appear to be travelling at the same velocity and the meter reads the total volume flow.
At the lowest velocity (5 m/s) the two phase flow is stratified (i.e. a river running in the bottom of the pipe). Under these conditions 1% liquid by volume makes the ultrasonic meter read about 4-5% high, indicating that the river flows much slower than the gas and hence occupies a larger volume (hold up).

Fig. 7 shows more detail of the Bacton injection tests:
With stratified flow (5 m/s) the D-chord fails at 1.3% liquid injection. The D-chord is at the bottom of the pipe at 0.809R and the area occupied by the segment is 4.8% of the circle. The failure is due to the river flooding the transducers on the D-chord and the error (4-5%) corresponds exactly to the area occupied by the river, confirming the stratified flow.
With mist flow the D-chord and eventually the C-chord fail at higher liquid injection. The failure is due to the mist attenuating the ultrasound transmission (scattering) and not flooding of the transducers. This is further confirmed by measuring the amplitude of the received signal, the speed of sound and the standard deviation of the transit time.

The NEL tests show that the flow is stratified, despite atomizing the water, it seems to settle onto the bottom of the pipe. The errors with air/water seem to be greater than with gas/condensate, this is probably due to water having higher density, higher viscosity and higher surface tension than condensate, all increasing the hold up. Air/water is a two-component flow rather than a two-phase flow.

4.4. Further work

The wet gas development is ongoing and requires extension to:
- Commercially produce wet/sour gas transducers (so far only prototypes have been made for a 6" meter) and investigate the manufacture of other meter sizes.
- Consider vertical installation, as vertical two phase flow might eliminate stratification, giving a more homogeneous flow and the ability to measure higher liquid volume fractions.
- Examine the possibility of two phase flow measurement.

4.5. Conclusions

- Wet gas ultrasonic meter design works.
- Meter survived 9 months operation with plant upsets.
- Meter recovers from complete flooding .
- Less than 1% condensate has a small effect, typically +1% for mist flow and the meter seems to measure the total (gas + liquid) flow.
- Different behaviour in stratified flow, larger errors (~5 times) than mist flow due to liquid hold up.
- Above 1% liquid D-chord (on bottom) fails giving larger errors.
- The results are understandable in terms of liquid effects on the ultrasonic signals.
- The main objective of measuring the gas flow was achieved.
- Air/water is not a good model for gas/condensate flow.
- Information probably exists in the ultrasonic meter signals to recognise two phase flow.

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FIG 1. Calibration of 6" meter

Natural gas 37.5 Bar, 38.3 Deg C

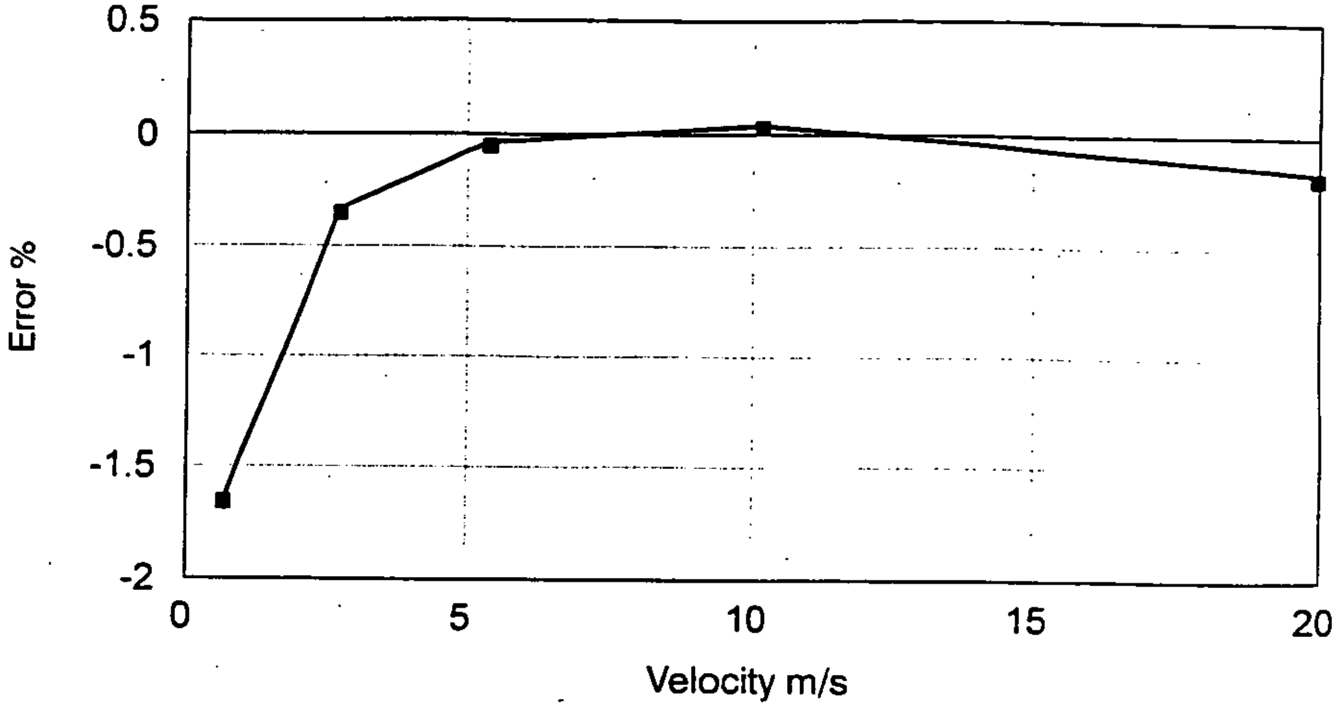

FIG 2. Calibration of 12" meter

Natural gas 140 Bar, 55 Deg C

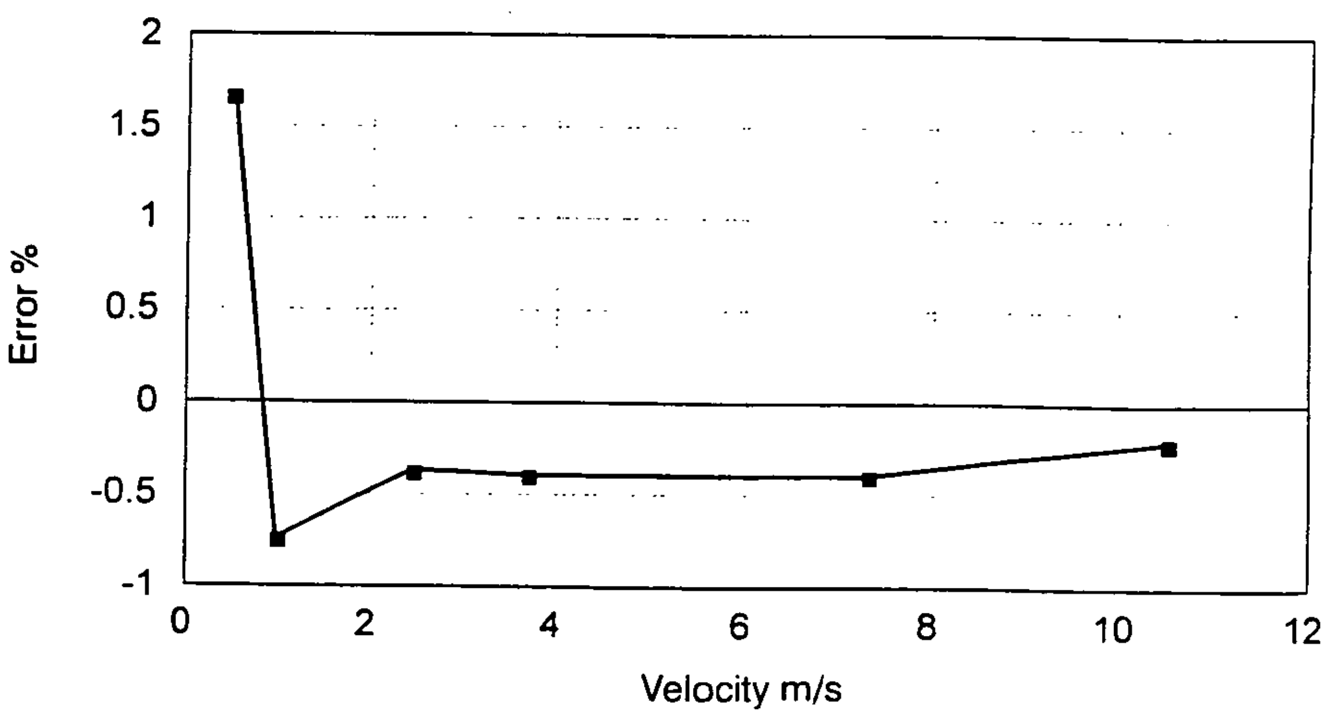

FIG 3. Calibration of five 20" meters

Natural gas 60 Bar, 10 Deg C

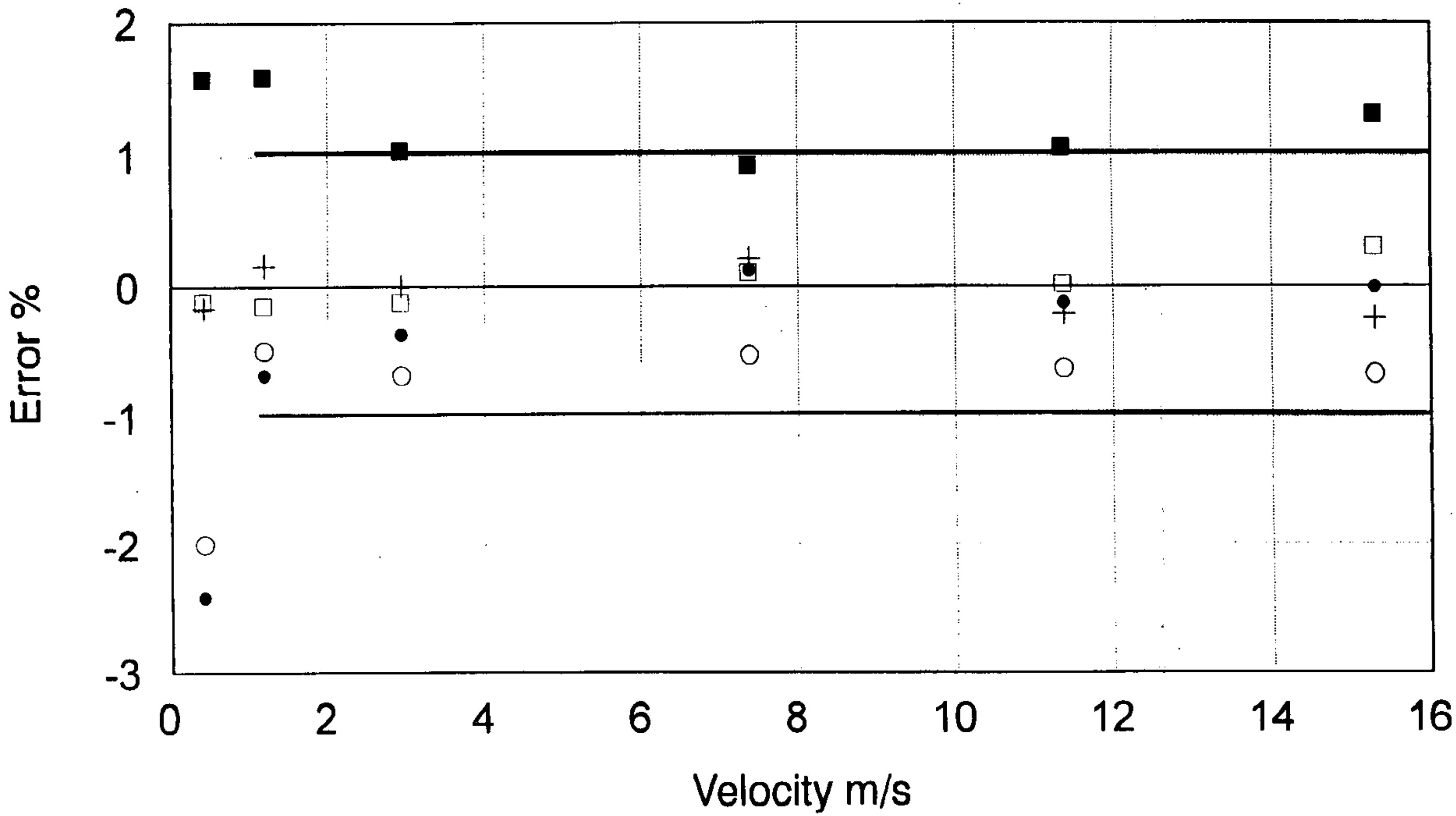

FIG 4. Wet gas tests at NEL

70 Bar air, atomized water at 50D

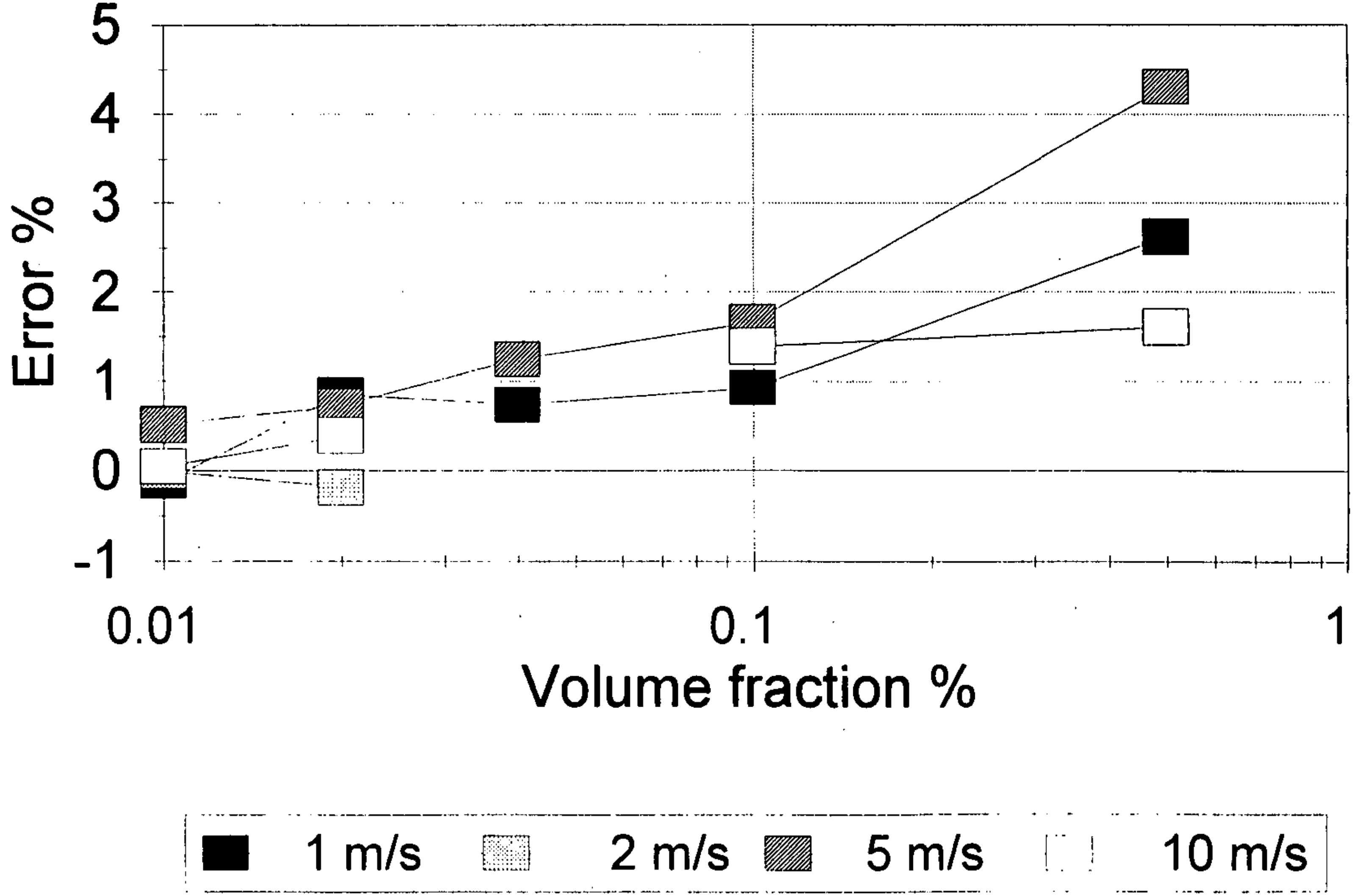

FIG 5. Bacton Trials Overall Summary

%Error and Reference Flow Rate for Complete Test Period

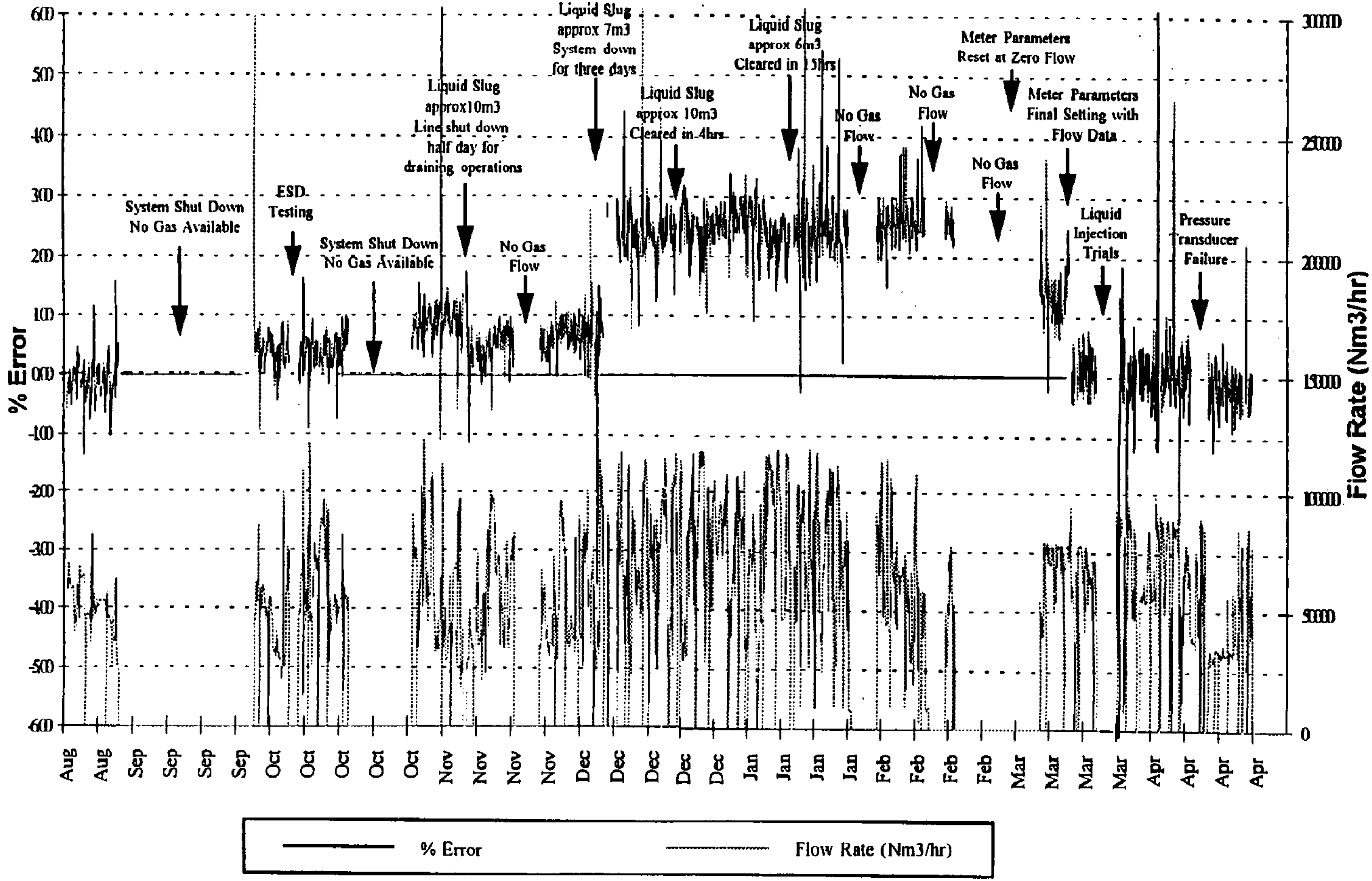

FIG 6. Bacton condensate injection

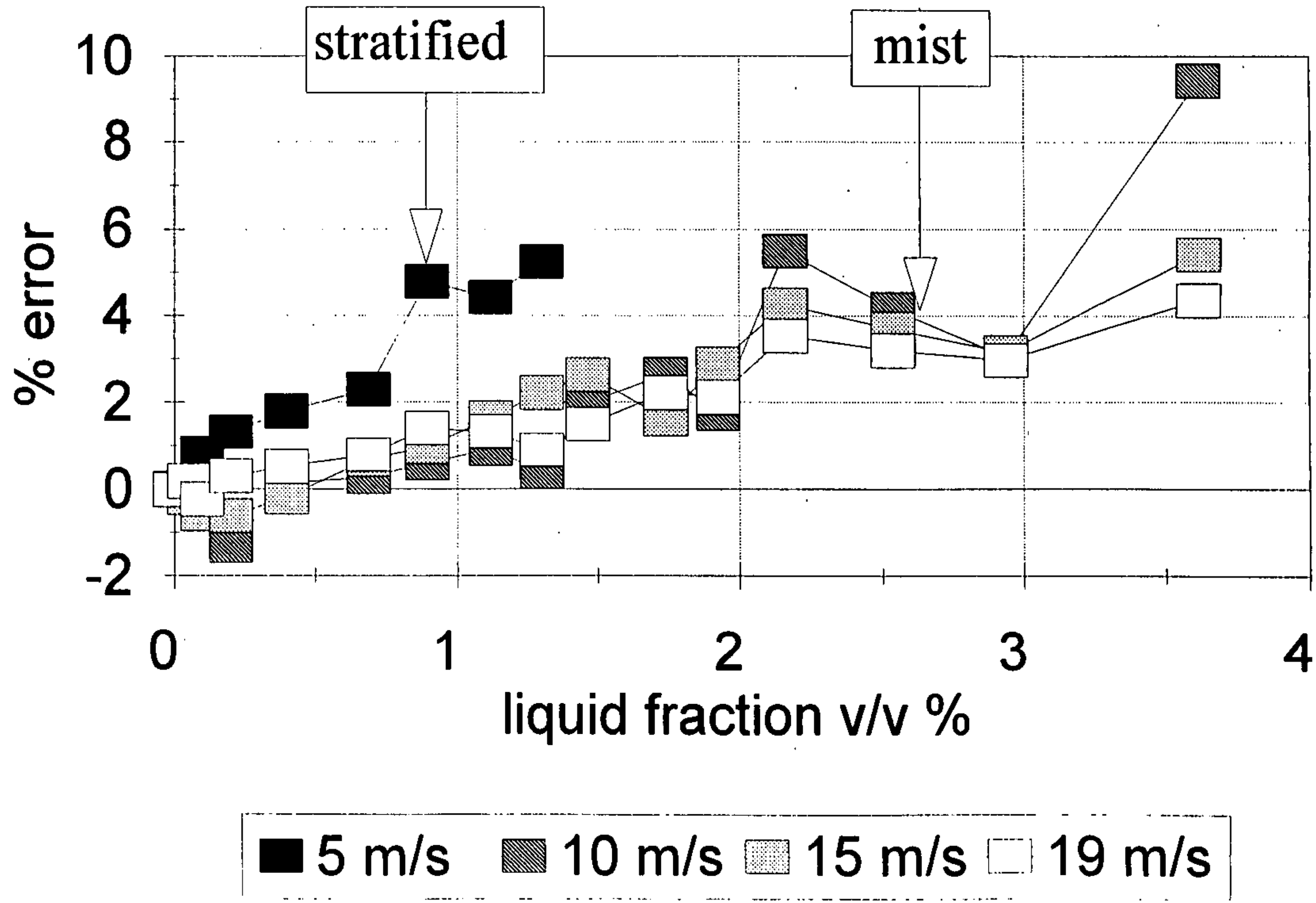

FIG 7. Bacton condensate injection tests