University of HUDDERSFIELD

# Phase Flow Rate Measurements of Annular Flows.

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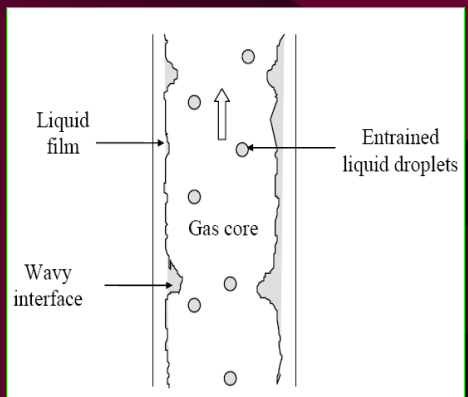
## Aims and main objectives:

The Annular flow regime makes measurement of the total liquid flow rate difficult. It is even more difficult to measure the individual flow rate of either the oil or the water. In a vertical Perspex tube (i.d. = 50 mm) using a newly-designed flow loop in the University of Huddersfield, annular flow was established and different measurements were carried out. One possible on-line measurement technique to achieve the oil volume fraction measurement is an automated bypass system using solenoid valves. An ultrasonic flow meter was designed to serve the purpose of measuring the velocity of the gas in the core. In this study, the used techniques include the use of Conductance Flow Meter to measure the liquid film thickness and to obtain the film velocity using the cross-correlation technique. The results of the present work have shown a good agreement with Zabaras and Dukler's work which indicates the success of the new measurement techniques.

## Measurement Importance:

- Annular wells in the Middle East: → Natural gas (50,000 $m^3$/day)
  - → Crude oil (50 $m^3$/day)
  - → Water (950 $m^3$/day)
- Oil Companies face flow rate measurement difficulty!!
  - → PDO, Oman (Petroleum Development Oman)
- Nevertheless.. Assume average oil price of 60 dollars/barrel
  - → Oil well producing about 50 $m^3$/day
    - → Produced oil worth $7 million/year!!

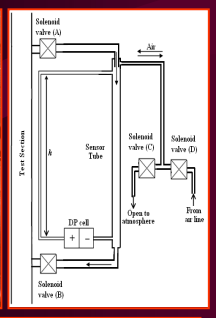


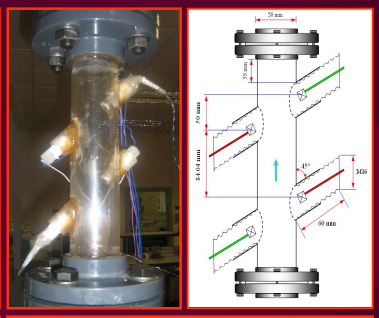
Schematic of two-phase annular flow.

## Research Methodology

**Flow Rate Measurement**

- Volume fraction (α) → Automated Bypass System + Density Measurement
- Liquid film thickness (δ), Liquid film velocity ($V_f$), Entrainment fraction (E) → Conductance Flow Meter + Cross Correlation
- Core gas velocity ($V_{gc}$) → Ultrasonic Flow Meter + Phase Shift



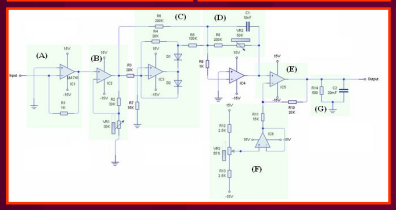
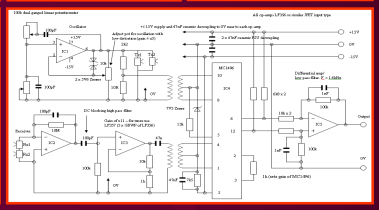

$$\Delta P = \rho_M g h$$

$$\rho_M = \varepsilon_O \rho_O + \varepsilon_W \rho_W$$

$$\varepsilon_O + \varepsilon_W = 1$$

$\varepsilon_O$ Oil Volume Fraction

$\varepsilon_W$ Water Volume Fraction

## Mathematical Model

Turbine flow meter → $Q_{w,ref}$ (1)

CFM → $\delta$ → $A_f = \pi[R^2-(R-\delta)^2]$ (2)

Cross correlation → $U_{f,xcor} = x/\tau_p$ (3)

From (2) & (3) → $Q_f = A_f * U_{f,xcor}$ (4)

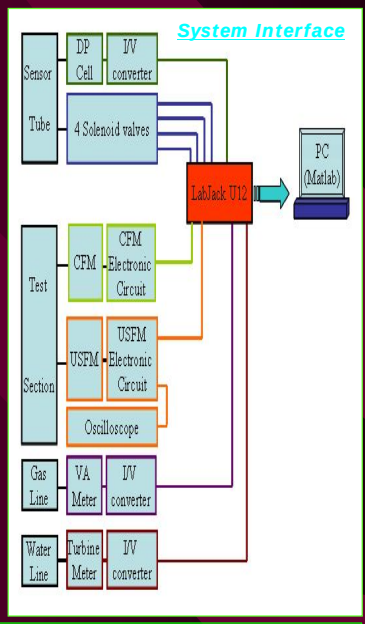
From (1) & (4) → $Q_e = Q_{w,ref} - Q_f$ (5)

From (4) & (5) → $E = Q_e / (Q_e + Q_f)$ (6)

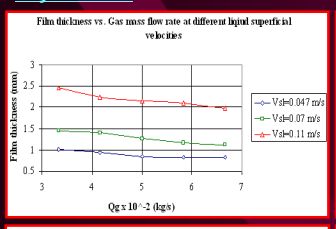
USFM → $U_{gc}$ (7)

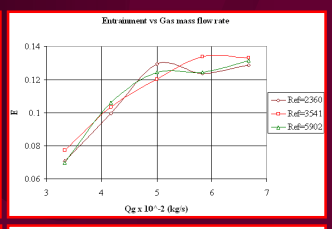
From (2) & (7) → $Q_{gc} = U_{gc}[\pi(R-\delta)^2]$ (8)

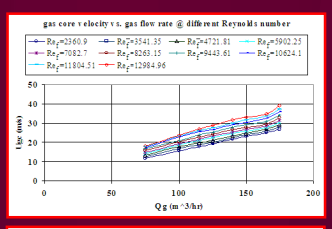
## System Interface

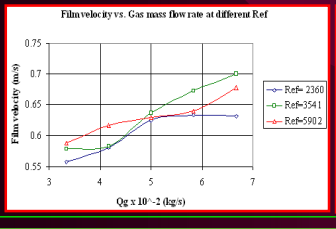


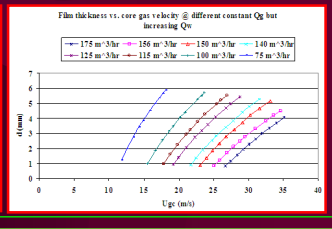

## Key results:

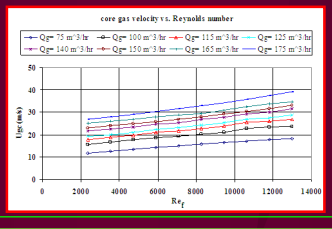













## Conclusions:

✓ New measurement devices and techniques have been developed and they showed excellent measurement success.

✓ The study has introduced a new measurement combination in terms of the used devices and developed techniques.

✓ Being able to characterise the entrainment fraction $E$, hence the total liquid flow rate $Q_{l,tot}$ can be obtained.

✓ The developed system shows an error below 1% for the gas flow rate and between ± 6% for the liquid flow rate.

✓ Overall, good quantitative and qualitative agreements were obtained between the present work and a previous study in similar experimental situation using different techniques.