Wet Gas Flow Metering using PIV and Tracer Dilution

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Abstract- **This paper introduces a prototype wet gas flow metering system, named "Uletech", for flow measurement. The "Uletech" Wet Gas Meter (UWGM) is based on the combination of particle recognition and the use of Laser Imaging Technology in the form of Particle Imaging Velocimetry (PIV). PIV uses tracer particles which follow the gas or liquid phase. The high resolution digital laser cameras identify/recognize all the different sizes of particles (gas, oil and water) in a multiphase flow. The cameras have sufficiently high resolutions (pixel size) to "see" the tracer particles. The prevailing conditions of high pressure and temperature of the flow regimes makes actual measurement a great challenge. The velocity differences between phases (hold up and slip) means unless the velocities of individual phases and concentrations are known, the true flow rate is practically impossible to obtain. The system comprises two cameras, laser source, optical arrangement, computer data acquisition system, synchronizer and MATLAB based software. An algorithm that correlates the camera's view to the volume within the pipe has been developed through this research. The computer acquires image signals from the upstream and/or downstream cameras, and carries out the calculation of cross correlation between the two image frames so that the velocity of each pixel can be found. A Gas Liquid Chromatograph (GLC) provides the composition (concentration) of the gas and the liquid hydrocarbon (HC). The product of phase velocity and phase concentration provides the flow rate of the individual phase. This work provides theoretical analysis and experimental validations, and discusses the advantages of the system and its further development.**

Keywords: Wet gas flow, PIV, Tracer, Cross correlation

I. INTRODUCTION

For the purpose of this paper, multiphase flow is defined as fluid whose Gas Volume Fraction (GVF) is ≤ 80% and wet gas is a fluid whose GVF is ≥ 90%. The range between 80% ≤ GVF ≤ 90% is referred to as "high GVF" flows [1].

To achieve a high level of flow metering accuracy has traditionally meant metering a single-phase flow of either liquid or gas. However, flow measurement engineers are under increasing pressure to solve the problems associated with measuring flow containing more than one phase.

Today, in the oil and gas fields, multiphase flow measurement technology in the form of a test separator is used primarily for production testing. This is performed periodically to determine individual well production performance. Test separators are indeed used to establish the amounts of Hydrocarbon (HC) condensate, water and gas per well as they may appear in the fluid under prevailing conditions of pressure and temperature. These data are correlated to either a dedicated flow device, e.g. a Venturi wet gas meter, or to the choke valve position on top of the well [2].

In practice, a separator is too bulky and costly, and cannot be installed on every production platform, especially on marginal wells. They do not provide continuous measurement, therefore to improve the measurement reliability, more accurate flow measurement system is required [3].

The ultimate aim is to replace test separators by flow meters that are capable of distinguishing between the various phases with sufficient accuracy[4]. Hence, prime use of multiphase measurement technology (other than the traditional test separator) is not for testing, which suggests non-continuous operation, but for continuous on-line real time measurement.

II. *Uletech* SCHEME

As shown in Fig.1, the proposed *Uletech* Wet Gas Meter (UWGM) is comprised of CCD cameras C_1 and C_2 installed on the measurement spool piece. Obtaining particle images demands that the camera have the ability to record sequential images in separate frames, to achieve high spatial resolution, and to capture multiple frames at high speeds, all with high sensitivity. The camera resolution (pixels per area) is sufficiently high to "see" the smallest particles (tracer particles) that need to be seen. Depending on the diameter of the pipeline, this may be particularly difficult. If for example the internal diameter of the pipe is 50 mm and the tracer particles have a diameter of 10 µm, the one-dimensional resolution is equal to 50/0.01 = 5000.

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For a square camera image, this would mean 25 Mpixel. A Gas Liquid Chromatograph (GLC) provides liquid and gas concentration; and the pressure and Temperature meters (P1, T1) for compensation purpose.

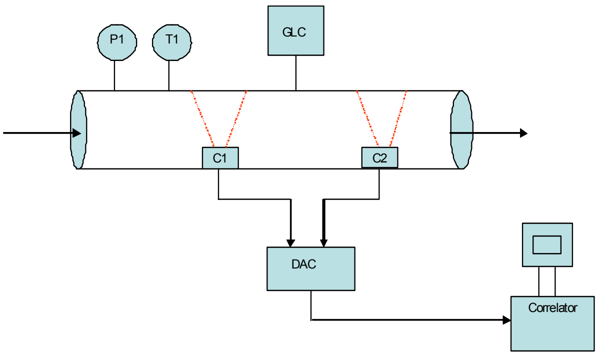

Fig.1 Overview of the Proposed "*Uletech*" Scheme.

III. PRINCIPLE OF PROPOSED SYSTEM

At the upstream of the camera, micron-sized particles, i.e., tracer particles are injected and become entrained in the flow. The flow is then illuminated with a sheet of monochromatic light from a pulsed laser. The light reflects off the particles and is recorded by a digital camera timed coincident with the laser pulses. Software is then used to correlate reflections from different frames estimating particle-paths. The differential of each particle's displacement is then taken in order to estimate velocity based on the time between laser pulses. This process is performed across the illuminated area of the flow creating a 2-D map of particle velocity. The resulting velocity measurements are not direct measurements of flow velocity, but of the velocity of the particles entrained in the flow [5].

A Gas Liquid Chromatograph (GLC) will provide the composition of the gas and the liquid hydrocarbon (HC), and their outcomes will have to be combined. However, as these phases move with different velocities (hold-up, slip), the "correlation" to an "overall" composition is only possible if the velocities of both phases are known.

An algorithm that correlates the camera view to volume within the pipes internal diameter has been developed, though this has its own peculiar challenge.

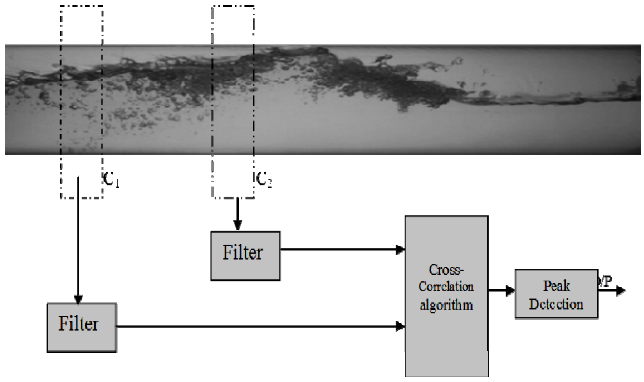

Fig.2 Inferential method of Multiphase Flow measurement.

IV. Preliminary Test Results

Experiments have been conducted on a rig which is comprised of a gas cylinder to provide wet gas, tracer used were silicon carbide with a mean diameter of 1.5µm and silver coated hollow glass sphere with a mean diameter of about 10µm. The tracers were injected inturn into the wet gas flow. The flowrate of tracer was controlled via manual injection using a syringe pump. The measurement system was installed in the system , and the pipe diameter is 50 mm.

The detailed setup can be seen from the following list

- NIKON lens 60mm F1.4
- HiSpec 4 camera (1696 x 1710 pixels)
- Field of View : 85mm (each pixel is approximately 50um)
- Manual injection syringe pump (tracer injection)
- Laser, 532nm, 2W with Analog / TTL modulation
- Synchronizer
- Exposure time: 80µs

The images in Fig. 3 were captured by a CCD cameras C1 in Fig.2, the exposure time was 80 µs, the time gap between two flash is 10 µs.

Fig. 4 provides an example of cross correlation between the two image frames in Fig.3. The spatial displacement of the tracer particles within the flow can be found. 2-D velocity of each pixel can be calculated in the same way.

The test results confirm the viability of the proposed technique. Further experiments will be carried out in near future. Once the velocity of each phase can be identified, the flow rate of each phase can then be measured with higher accuracy.

It is envisaged that the biggest obstacle for this technique to be used for wet gas measurement could be the reflection of water film on the inner pipe wall which can blur the tracer particle images. To measure the velocity of each phase, the system has to work in time sequences, so that the flow profile need to be stable over the measurement period, which is around a few seconds.

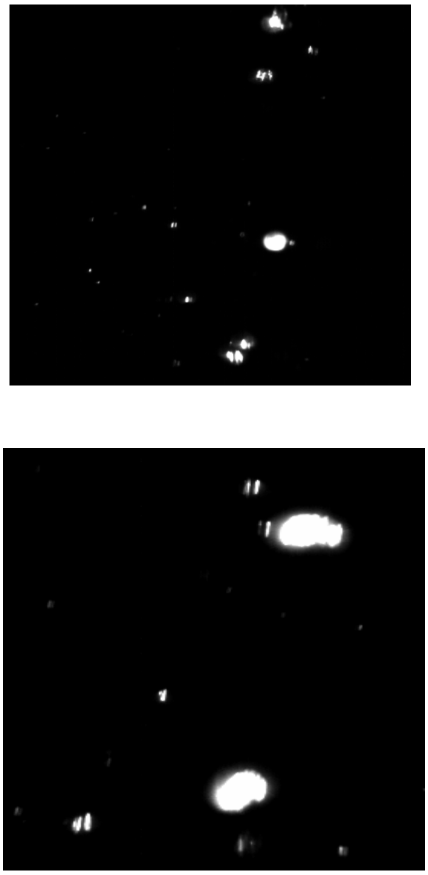

Fig. 3 Two flash images captured by CCD camera.

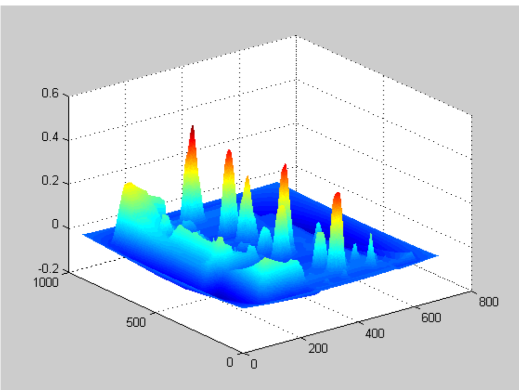

Fig. 4 Correlation of CCD images of flow.

V. FUTURE WORK

The work described in this paper is the first step to verifying the principle of the system which is the first step towards a practical system for field application.

For example, the current form of the "*Uletech*" measurement has not tackled the window fouling problem yet, and PIV in multi-phase flows is very difficult as, in this case, the droplets will create a mist, which probably prohibits getting a clear view, of the laser-illuminated sheet. In a wet-gas flow, the wall is covered with a liquid film, which severely distorts the camera view of the laser-illuminated sheet, thus effectively reducing the resolution.

The tracer injection method is still very laborious and further research will be necessary to automate the process. Gas-tracer particles may very quickly be covered by liquid.

There are at the moment no florescent tracers for gas that would not need to be separated from the flow. For "*Uletech*" to become applicable for control purposes, florescent gas tracer needs to be developed.

VI. Conclusion

This research work has demonstrated that low cost and simple non-intrusive CCD camera, in combination with a complex digital processing technique can be used to infer the superficial gas and liquid phase velocities of very high Gas Volume Fraction (GVF). It enables the individual component mass flow rates of wet-gas flow to be determined to a degree of accuracy surpassing several commercially available multiphase flow meters. It is believed that with further developmental work on this PIV based system. The ideal multiphase flow meter is in sight.

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