SPE
Society of Petroleum Engineers

SPE 19261

A Synergistic Approach to Multiphase Flow Metering

T. Darwich, H. Toral and J. S. Archer, Imperial College, U. K.

ABSTRACT

A novel synergistic approach has been adopted to develop a multiphase flowmeter (ESMER). The technique is based on the extraction of stochastic features from turbulent waveforms of pressure and void fraction and the application of pattern recognition techniques to recognise the individual phase flow rates.

ESMER is a non-intrusive flowmeter which can work with any sensor (pressure, void fraction, *etc.*.) available on the flow line and linked to an IBM PC compatible computer with a built in analogue to digital interface. The software provides a real time graphical display of individual phase flow rates.

1. INTRODUCTION

Accurate measurement of multiphase flow from oil and gas wells is essential for fiscal measurements, custody transfer, reservoir management and well-head control. The current practice for multiphase well and pipe flow metering involves a test separator in which the different fluid phases are first separated and then metered in their respective single phase flow lines by utilising any single phase flow measurement device. This approach suffers from two main disadvantages: inaccuracy and high cost.

A series of papers[1,2,3] have been published reviewing the current and future developments in the field of multiphase flow rate measurements in crude oil production systems. It has been stated that future developments may fall into one of two categories: improvements in the current technique by improving the design of test separators which can be considered as a short term development or introducing new on-line techniques which do not involve phase separation.

Notwithstanding the considerable efforts to exploit the powerful technology in the last two decades, no fully successful multiphase flowmeter is yet on the market. However, the Coriolis-type mass flowmeter[4] was shown to be capable of measuring total mass flow rate up to qualities of 10% beyond which it becomes unreliable. Koube *et al.*[5] have also presented a non-intrusive metering method for two-phase slug flow which depends on void fraction measurements using capacitance sensors coupled with the drift velocity model. A new separator for multiphase flow metering is to be tested by Texaco on the deck of the Tartan platform. The target accuracy of the meter is ±5% for flowrates up to 18,000b/d and for gas contents up to 90%[6].

This paper presents a novel a multiphase flow meter based on signal analysis and pattern recognition techniques. The new system is offering the following advantages: simplicity of sensors, simplicity of operation, inexpensive installation and on-line flow rate measurement for a wide range of flow conditions of various flow regimes.

2. BACKGROUND

Drawing parallels between "fluid sound" and "human speech", our previous studies[7,8] have used recent developments in voice recognition theory to analyse two-phase pressure and void fraction fluctuation signals. An analogy with methods of speaker identification from the spoken word can be drawn. If speakers utter the same words as those which make up the "training set", then current speech identification technology is capable of producing identification accuracies close to 100%. Our approach depends on the premise that turbulence characteristics of two-phase flow are uniquely related to the flow rate of the individual phases in given flow line under given conditions. Thus, given the same pipeline (i.e. same diameter and upstream effects), the fluids (physical property effects) same flowrates will produce same turbulent characteristics. The proposed system can identify these characteristics from its "training set" and hence measure the underlying unique combination of individual phase flowrates.

Our previous studies[7,8] show that two-phase pressure and void fraction fluctuations within the amplitude and frequency domains contain adequate information that are directly related to the flow velocities of individual phases. The various signal analysis techniques entail the characterisation of the waveforms of absolute pressure, differential pressure and void fraction into a more informing state so that the turbulent characteristics of the multiphase flow associated with any combination of gas and liquid flow rates can be enhanced and directly related to the flow rate of individual phases.

The structure of the proposed on-line two-phase flow metering system (ESMER), can be demonstrated in terms of the block diagram shown in Fig. 1. Similar to any other single or multiphase flowmeter, ESMER, can be considered to consist of two distinct parts each of which has a different function to perform. The first part comprises the sensor(s) which provide the waveform(s) representing various physical properties of the flow. The second part translates these waveforms into flowrates. This part can be represented by: 1. an extractor to select from the waveforms the significant features of the flow; and 2. a categoriser or recogniser to identify the flow velocities of the phases.

The sensors can be absolute and/or differential pressure gauges to obtain pressure waveforms and/or void fraction sensors (e.g. capacitance or gamma ray transducers) to obtain void fraction waveforms.

The extractor is used to extract a set of stochastic parameters (the "feature vector") from the waveforms, consisting of: amplitude domain features (standard deviation, coefficient of kurtosis and coefficient of skewness) and frequency domain features (the linear prediction coefficients and cepstrum coefficients).

The categoriser uses the features of the measured waveform to assign it to a certain combination of gas and liquid flow rates in the training set.

3. SYSTEM DESCRIPTION

ESMER detectss the naturally occurring turbulence structures in the gas-liquid flow stream as tracers to measure the flow rate of the individual phases. It consists of both hardware and software components. The hardware components are an IBM PC compatible computer with a built-in multichannel A/D converter and pressure or void fraction sensors.

The software component of ESMER contains a menu driven interface with interactive help and error checking for automatic data sampling, calibration and measurement. ESMER maintains multiple sets of the calibration database (e.g. for different pipeline configurations), and provides a real time graphical display of individual phase flow rates. The software has been developed using a combination of dBASE, ASSEMBLER and FORTRAN languages. dBASE is used mainly for data and file management, while ASSEMBLER is used for sampling and digitising the waveforms and FORTRAN for data analysis.

At present, ESMER is a rig-dependent flowmeter that requires *in-situ* calibration. The software provides exclusive guidance required for successful calibration and use of the flowmeter. ESMER can be also used without precalibration for on-line monitoring of flow condition stability.

The main menu of ESMER, as shown in Fig. 2, consists of six main functions: preliminary signal analysis and filter design, set parameters, calibration, inspect and update calibration, flowrate measurement and flow monitoring.

3.1 Preliminary Signal Analysis and Filter Design:

Absolute pressure, differential pressure and capacitance transducer void fraction signals have proved useful in characterising different horizontal two-phase flow conditions[7,8]. Results from other investigations for flow regime identification (References 9–16) suggested that our method for two-phase flow metering can be extended for different pipe configurations and diameters utilising different sensors. Our laboratory studies in a 26mm and 50mm I.D. horizontal lines have shown the existence of an optimum sampling frequency for pressure and void fraction signals[7]. In order to inspect this finding for different pipe configurations and different sensors, the Preliminary Signal Analysis option allows the user to select the optimum sampling frequency by providing time and frequency domain (using Fast Fourier Transform) representations of the signal under different sampling conditions (Fig. 3). ESMER provides the operator with a recommendation for the optimal sampling frequency.

The signals are often contaminated with noise which can enter the system through electrical mains or through cables picking electromagnetic radiation. Filter Design option allows the user to design a digital filter which can be implemented in the analysis of the waveforms. Two types of filters can be designed: recursive and nonrecursive. The user has the option to view the gain characteristics of the designed filter. Filters parameters are stored in the Filters File from where they can be readily selected.

3.2 Set Parameters

This function allows the user to set Rig and Sampling Parameters.

Rig Parameters include pipe code, site or field name, pipe diameter, sensors attached to the rig, the sensor(s) to be used for the current calibration or measurement test and the minimum and maximum gas and liquid flow rates for this particular rig. All these parameters are to be stored in a database file, which can be updated at any time, containing a list of all pipelines and the attached sensors.

Sampling Parameters includes the sampling frequency for each sensor, the output range of the sensor to be used [four different output ranges are allowed: 1) -10 to 10 volts; 2) -1 to 1 volt; 3) -100 to 100 mvolts and 4) -20 to 20 mvolts], the number of points in the record and the A/D channel number for that particular sensor. Sampling Parameters also allows the user a filter by selecting the required type of filter from the Filters File. Sampling parameters are stored in a database file for use in future calibration and measurement runs.

3.3 Calibration:

At present, ESMER is a rig-dependent flowmeter and requires *in-situ* calibration. However ESMER's data requirements are very modest and can be fulfilled by available pressure sensors in existing well testing and process measurement installations.

A calibration database is constructed for each pipeline by acquiring various waveforms from different sensors at different flow conditions. The Calibration Function contains the core algorithms for the construction of the calibration database. At each calibration point [i.e. one combination of gas and liquid flow rates], the sample record [i.e. absolute pressure, differential pressure or void fraction waveform(s)] undergoes the following stages of analysis:

– Displaying the waveforms in the time domain to detect any defects in the sensors.

– Digital filtering (if selected from Set Parameters).

– Extracting the statistical features of the waveforms which will represent the elements of the feature vector for this particular calibration point.
– Storing the feature vector in the calibration database.

The single phase gas and liquid flow rates from the calibration equipment (e.g. the test separator) can be entered directly to A/D converter linked to single phase flowmeters or keyed in by the user.

Finally, ESMER allows the calibration process to be carried out in either an active mode or a passive mode. The normal mode is the active mode where the user informs ESMER with the starting of any calibration run and the calibration database are constructed in a systematic way. ESMER can also be operated in a passive mode in which it will not interfere with the operation process of the pipeline under calibration. In this mode, ESMER builds up its calibration database by detecting any variation in the readings of the gas and liquid single phase flowmeters connected to the calibration equipment (e.g. the test separator). A variation beyond a present threshold triggers ESMER to start new calibration run.

3.4 Inspect Calibration:

This function allows the user to inspect the calibration points that have been collected within the gas and liquid flow ranges specified from Set Parameters. Graphs show the distribution of the calibration points and the feature contour maps (Fig. 4). ESMER measures the strength of various stochasic features (i.e. their response to changes in flow conditions) by the *F*-ratio parameter devised by Atal[17] and indicates the sufficiency of the calibration points contained in the database.

3.5 Flowrate Measurements:

ESMER's calibration database can be seen as points in m*n dimensional stochastic feature space, where 'm' is the number of hydrodynamic variable waveforms and 'n' is the number of stochastic features (the feature vector) extracted from each waveform. The Flowrate Measurement function is equivalent to a categoriser that has the ability to identify the individual phase velocities by matching the measured feature vector to the calibration prototype set. ESMER uses its built-in expertise to select the best pattern recognition algorithm that can be used efficiently to measure the individual flow rates. The individual flowrates are shown as an analog rotameter on the VDU with a response time of few seconds.

3.6 Flow Monitor:

In some applications, it is important to detect deviations from set/normal conditions (e.g. in gas-lift operations). The Flow Monitor function is ideally suited for this task. Under normal operating conditions, ESMER uses the results of the analysis of the various waveforms from different sensors to construct a 'finger print' of the normal operating conditions. ESMER, then, performs on-line monitoring of the pipeline to detect changes in flow conditions.

4. APPLICATIONS

ESMER is now ready for field trials in one of the following forms:

1. Against the test separator:

ESMER can be calibrated by installing it close to the inlet of the test separator where it can be calibrated against producing fluids from individual wells or combination of wells. This will allow ESMER to be calibrated for a wide range of gas and liquid velocities. Once ESMER has been calibrated, it can be used as an alternative to the test separator.

2. Calibration during new installations:

ESMER can also be calibrated during the installation of new pipeline systems using field gas and liquids. In such a case, ESMER could be expected to eliminate the need for interstage flow separation between a remote producer and a central processing facility.

3. Flow monitoring:

ESMER can also be used for flow monitoring in the following situations:

–monitoring changes in the production wells (increasing gas/oil ratio, mechanical problems)

–monitoring gas kicks during well drilling

–monitoring the stability of gas-lift operations.

5. FUTURE WORK

The development of a general flowmeter is a difficult task that requires huge number of runs covering various parameters such as pipe size, pipe material, physical properties of the fluids under different flowing conditions as well as adequate crossover data for the same conditions to verify consistency between different facilities. Therefore, the concept of a "universal" flowmeter that can measure flowrates with high accuracy over wide ranges under different operating conditions is not a practical one even for single phase flow. Consequently, it is recommended that the metering device together with the flow section in which it is mounted should be individually calibrated. At the moment, ESMER has proved successful as a rig-dependent flow meter[8] and requires *in-situ* calibration. However, our current research investigations hold hope for the isolation of flowline and fluid property effects from the calibration database.

ACKNOWLEDGEMENTS

The authors wish to thank Occidental Petroleum Ltd. for their financial support during this phase of the project.

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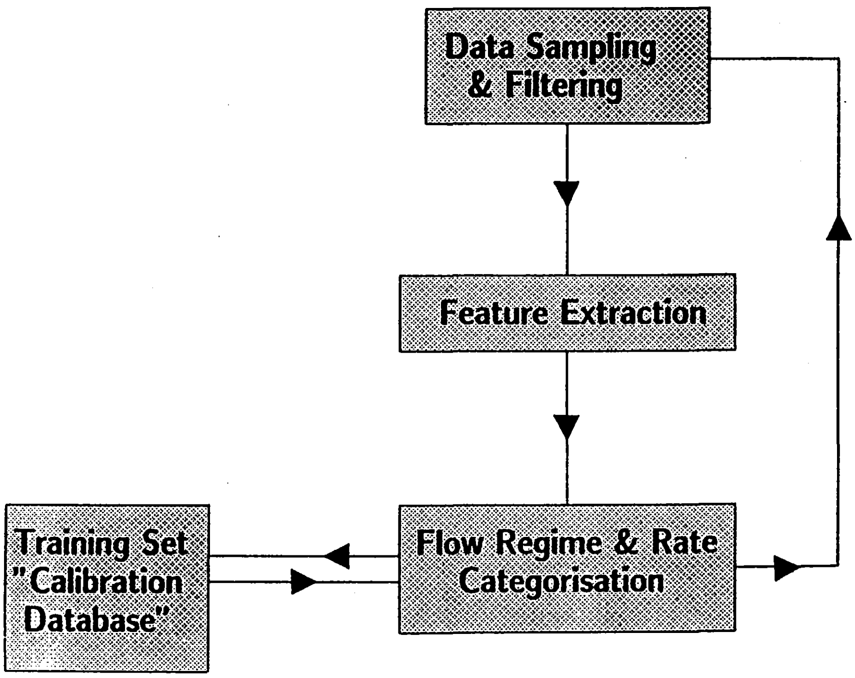

Fig. 1 ESMER's Block Diagram

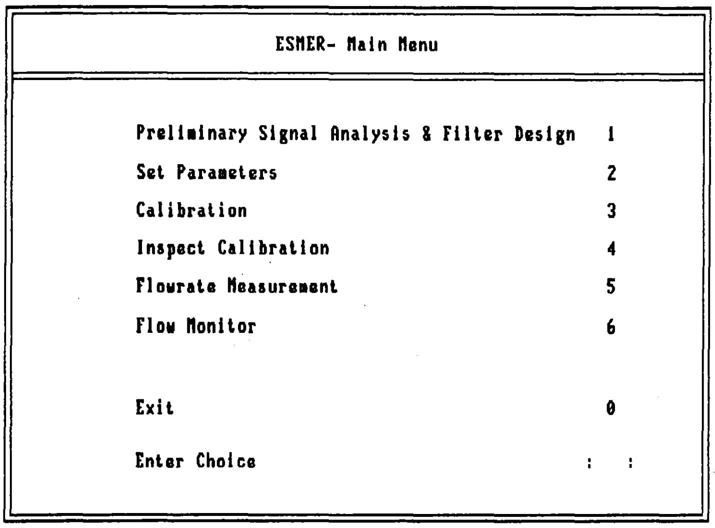

Fig. 2 ESMER's Main Menu

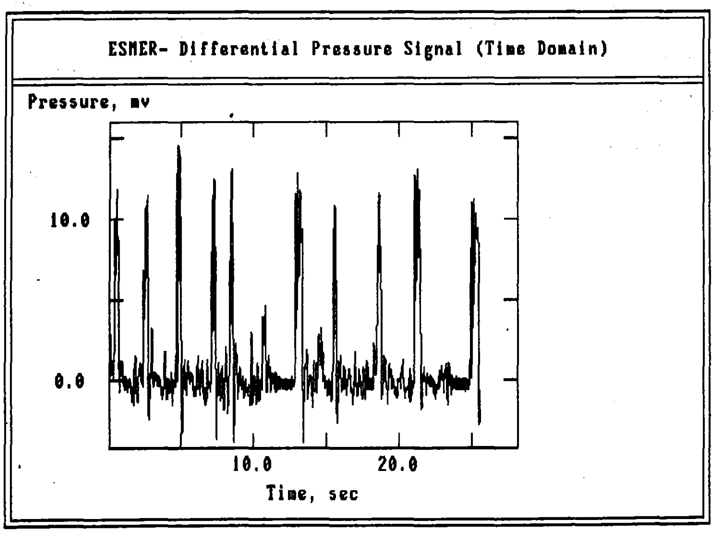

Fig. 3(a) Differential Pressure Signal (Time Domain)

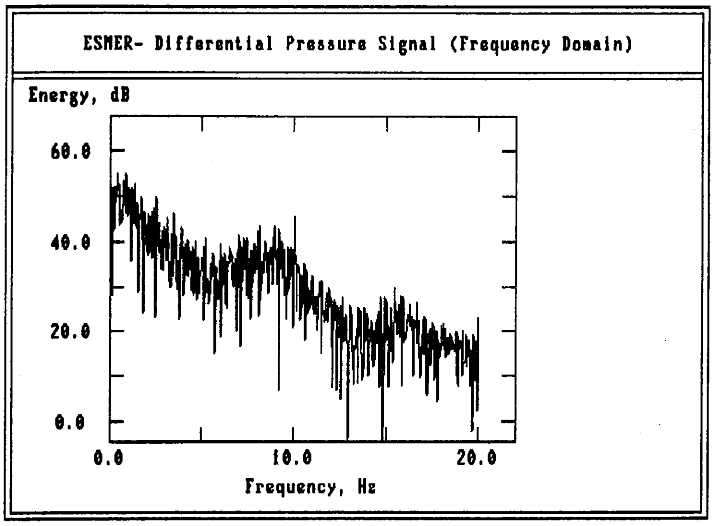

Fig. 3(b) Differential Pressure Signal (Frequency Domain)

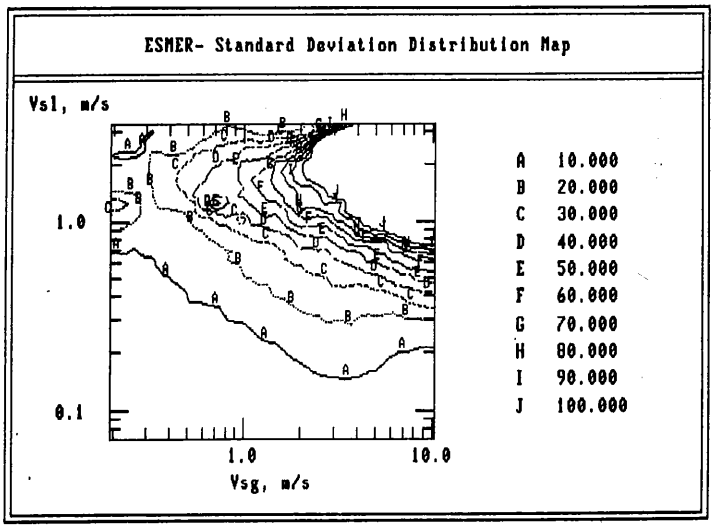

Fig. 4 Standard Deviation Distribution Map