Applied Radiation and Isotopes 70 (2012) 1080–1084

Contents lists available at SciVerse ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

# Tomographic multiphase flow measurement

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ARTICLE INFO

Available online 2 February 2012

*Keywords:*
Gamma-ray densitometry
Multibeam
Flow regime identification
Tomography
Gas fraction
Salinity measurement

ABSTRACT

Measurement of multiphase flow of gas, oil and water is not at all trivial and in spite of considerable achievements over the past two decades, important challenges remain (Corneliussen et al., 2005). These are related to reducing measurement uncertainties arising from variations in the flow regime, improving long term stability and developing new means for calibration, adjustment and verification of the multiphase flow meters. This work focuses on the first two issues using multi gamma beam (MGB) measurements for identification of the type of flow regime. Further gamma ray tomographic measurements are used for reference of the gas/liquid distribution. For the MGB method one Am-241 source with principal emission at 59.5 keV is used because this relatively low energy enables efficient collimation and thereby shaping of the beams, as well as compact detectors. One detector is placed diametrically opposite the source whereas the second is positioned to the side so that this beam is close to the pipe wall. The principle is then straight forward to compare the measured intensities of these detectors and through that identify the flow pattern, i.e. the instantaneous cross-sectional gas-liquid distribution. The measurement setup also includes Compton scattering measurements, which can provide information about the changes in the water salinity for flow segments with high water liquid ratio and low gas fractions. By measuring the transmitted intensity in short time slots ( $<100$ ms), rapid regime variations are revealed. From this we can select the time sections suitable for salinity measurements. Since the salinity variations change at the time scale of hours, a running average can be performed to increase the accuracy of the measurements. Recent results of this work will be presented here.



## 1. Introduction

Measurements of gas, oil and water in oil production fields have preferably been performed at sections where one assumes homogeneous flow. For down-hole metering the oil pipes are often non-vertical, and the flow components will mainly be separated. The challenges for multiphase flow measurements when non-homogeneous flow are identification of the regime, and rapid measurements relative to the flow pattern changes. This will also be important for measuring the water salinity in intervals of homogenous flow.

For down-hole metering the conditions are high temperature ( $>200\,^{\circ}$C) and high pressure (15,000 psi) (Belani and Orr, 2008). The multiphase flow meters should thus be robust, simple and non-intrusive. Gamma ray methods are attractive in this case, in particular the multi gamma beam (MGB) principle which does not require energy sensitive detectors. Gamma ray methods are non-intrusive, sufficiently fast, and can be used for component fraction measurements of components with sufficiently different densities like gas and liquid. Gamma radiation techniques are often applied in existing multiphase measurement gauges. There is a long tradition for using gamma ray methods for measuring in harsh environments like these in oil well logging. By measurements at several narrow transmission gamma beams, one can obtain information of the flow pattern. The total gas fraction of the oil pipe cross-section can then be derived. This requires water cut (WC, the water volume flow rate relative to the total liquid volume flow rate) measurements from another measurement device. That could be capacitance (Hjertaker et al., 2005; Kvandal et al., 2009; Schüller et al., 2004), conductance (Liu et al., 2010), or ultrasound (Toftevåg, 2005; Aandahl, 2006). Previous work on compact low-energy multibeam gamma-ray densitometry showed that a multibeam densitometer provides more accurate gas fraction measurements than single-beam, and that the multi gamma beam (MGB) measurement principle yields flow regime information (Tjugum et al., 2002; Sætre et al., 2010).

Varying water salinity is another challenge for most multiphase flow meters because it affects volume fraction calculations

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doi:10.1016/j.apradiso.2012.01.022

based on gamma-ray, electrical conductance and other measurements. There have been a few approaches to solve this without relying on off line calibration. One of these utilizes the difference in the composition of the gamma ray attenuation coefficient at different energies (Scheers and Letton, 1996). The method presented here take advantage of the same effect, but though simultaneous measurements of transmitted and scattered gamma-rays from an Am-241 source. Once again the challenge is to minimize the effects of changes in the flow regime. Salinity measurements at flow sections with appropriate water and gas content, allow more accurate calculations of the gas volume fraction and other parameters measured by the multiphase flow meter. The principle of dual modality densitometry (DMD) of the water salinity variations has also been investigated for a compact gamma-ray densitometer. This work has shown an empirical relationship between the gas fraction and the ratio between the scattered and transmitted gamma-ray intensity for homogeneous flow (Johansen and Jackson, 2000). For non-homogeneous flow the DMD principle can be utilized when the water liquid ratio is high (close to 100%) and the gas fraction is low (less than 30%) (Sætre et al., 2010). This work was based on measurements and Monte Carlo simulations.

A complete mass flow measurement requires an inferential method including other measurement techniques for measurements of the oil and water component fractions, velocities and densities (see Fig. 1). An iterative process must be applied for salinity independent component fraction measurements. The salinity measurements should be performed as running average over short time segments with high water liquid ratio and low gas fractions. The salinity changes are slow and the monitoring can be done on the time scale of hours.

In this work we will present a case study of gas fraction measurements at rapid flow pattern variations. The measurements were performed at a multiphase flow loop with diesel, water and gas. In this study the compact low-energy multi gamma beam measurement setup is comprised of one Am-241 source and two narrow beam transmission detectors. The high-speed gamma-ray tomograph was used for reference of the actual flow regime and the gas fraction of the pipe cross-section as function of time. The main goal of this work is to investigate the feasibility of a simple and fast gamma-ray measurement setup in terms of detecting the rapidly varying gas fractions in multiphase flow.

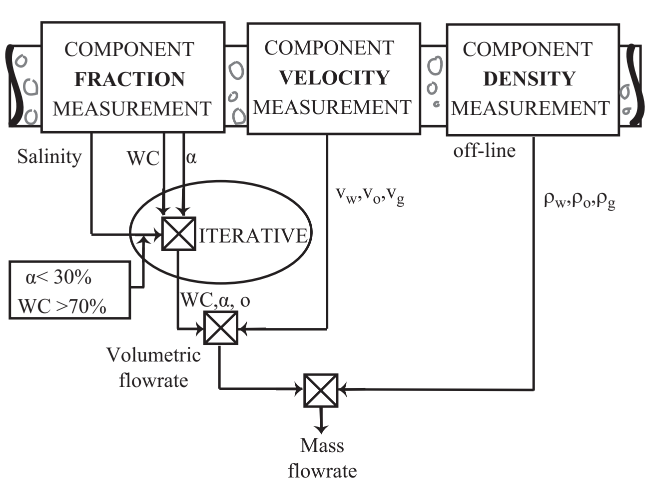


**Fig. 1.** The inferential method of three-phase flow measurements with an iterative process for deriving the component fractions independent of the water salinity. The density measurements are based on off-line sampling. α is the gas fraction as defined in Eq. (1).

## 2. Theory

For a mixture of gas and liquid the instantaneous gas fraction (α) of the measurement cross-section can be estimated as (Tjugum et al., 2002);

$$\alpha = \frac{\ln(I_{Tflow}/I_{Tliq})}{\ln(I_{Tgas}/I_{Tliq})} \quad (1)$$

where $I_{Tflow}$ is the measured transmitted gamma-ray intensity through the flow. $I_{Tgas}$ and $I_{Tliq}$ are calibration measurements of empty pipe and pipe filled with liquid, respectively.

Fig. 2 shows the multibeam and dual modality measurements setup used in this work. With a fan beam collimated gamma-ray source and narrow collimated transmission detectors, the gas fraction is measured along two beams; through the center of the pipe and closer to the pipe wall. For a homogeneous mixture of gas and liquid the measured gas fraction for the different transmission detectors in the MGB measurement system should be the same. If the flow regime is stratified, with the liquid on the lower part of the flow, the gas fraction derived from the transmission gamma-beam closer to the pipe wall will be higher than that from the center beam. The geometrical differences in the measurement setup are taken into account when the calibration measurements for each of the detectors are used as reference. The corrected gas fraction $\alpha_s$ for stratified flow for the center transmission detector, can be calculated according to Eq. (2) (Sætre et al., 2010). For other flow regimes, like annular flow,

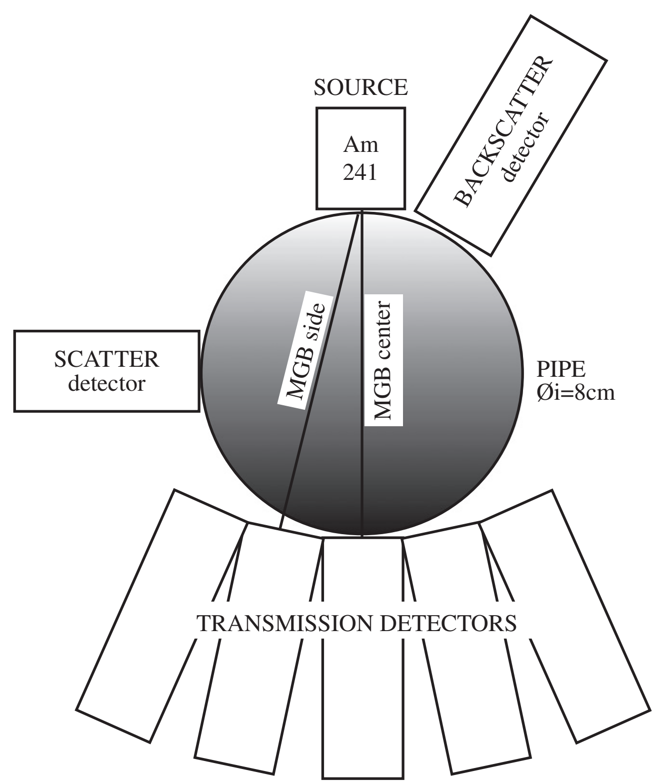


**Fig. 2.** The MGB and DMD measurement setup used in the multiphase flow measurements. Orientation top-bottom. On the top: Am-241 gamma source with symmetric fan beam collimation and backscatter radiation detector. In the middle: aluminum pipe cross-section (inner diameter 8 cm), and scattering detector. Five narrowly collimated transmission detectors. During this test we used two transmission detectors (center and side). The side detector used was at a 12° angle relative to the center detector.