CHAPTER 3

Multiphase Flow Metering Principles

3.1. MFM Fundamentals

The objective of multiphase flow metering (MFM) is to determine the flow rates of the individual components, for example oil, water and gas. Unfortunately there is no single instrument, which will measure these parameters directly and it is necessary to combine several devices in an instrument package and to calculate the specific flow rates from the combined readings. As will be shown, there are many possible combinations, and the number of instruments required depends upon whether or not the three components can be mixed together upstream of the instrumentation (homogeneous flow). If homogeneity of flow can be achieved, then only three instruments are required, each measuring a characteristic of the mixed fluid flow; if not, then individual component velocities and concentrations have to be determined.

Let us consider a three-phase flow made of oil, gas and water. To measure the flow rates of each phase, two approaches are possible.

With the first approach, three independent flow parameters (functions of the three flow rates) are measured and relationships between them and the flow rates of the respective phases are established. Examples of the independent measurements are the pressure drop across a venturi, the attenuation of a gamma beam and the electrical impedance of the mixture, which will be discussed in Chapter 4. The main problem with this approach is that the relationships cannot be theoretically predicted, but must be established by calibration. Unfortunately, it is not possible to calibrate (within the same level of accuracy) over the full range of operating conditions that can be encountered by the same measurement technology with real hydrocarbon fluids. Also, there may be natural background drifts inherent in the instruments used, which would create the need for repeating their calibration after some time has passed. The calibration methodology can be enhanced using techniques such as neural networks, which aim at identifying the functional interrelationships to a higher order of accuracy. However, such techniques cannot overcome the fundamental problem that the calibrations (or ‘training’) only apply over the range of

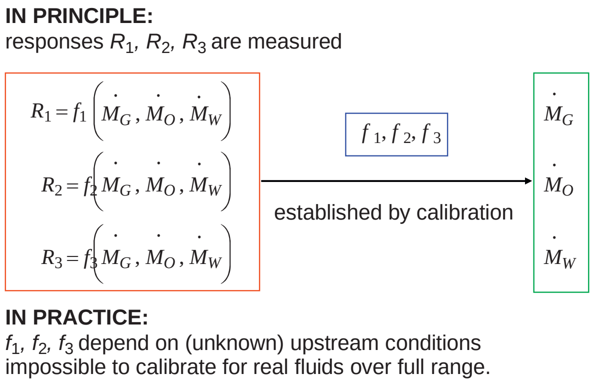


Figure 3.1 The first MFM approach.

conditions in which they are carried out. Outside that range of conditions, the established relationships between independent parameters and flow rates may become invalid. This approach is summarised in Figure 3.1, where: R_1, R_2 and R_3 are the responses of the three independent measurements; f_1, f_2 and f_3 are the functions, or relationships, between the responses and the flow rates; M_G; M_O and M_W are the mass flow rates of gas, oil and water, respectively.

With the second approach, the basic parameters of phase velocities and phase hold-ups (or quantities that can be unequivocally related to these) are measured. The phase velocities and hold-ups are then combined together to provide the phase flow rate. For a three-phase flow, three mean velocities and three-phase cross-sections are required. Thus, five measurements are needed, namely: three velocities and two-phase fractions (the third-phase fraction is obtained by difference between unity and the sum of the two measured fractions). The number of required measurements can be reduced by separation or homogenisation.

By separating the phases, the need for cross-sectional hold-up measurements disappears and the three volume flows can be established by conventional single-phase metering technology. However, it should be noted that a full separation of the three phases is difficult to achieve in many cases, due to liquid carry over in the gas phase, or gas remaining trapped in the liquid phase, or formation of emulsions and foams.

By homogenising the mixture, only one velocity needs measuring and the total measurement requirement can be reduced to three. Homogenisation can be attained by inserting in-line mixing devices or flow conditioners, or by subjecting the stream to a sudden expansion and contraction. However, a full homogenisation of the mixture can also be very difficult to achieve in some cases, for example when there is substantial slippage between a heavy and a light fluid phase. This approach is summarised in Figure 3.2.

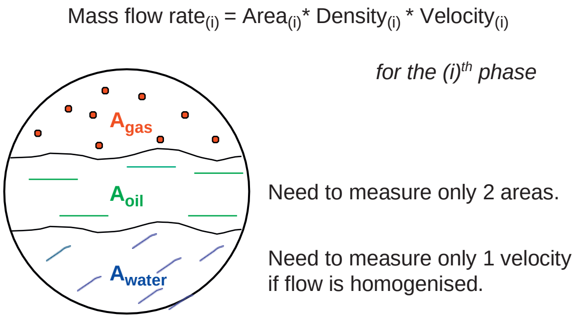


Figure 3.2 The second MFM approach.

3.2. Categories of Instruments

Irrespective of the whether the selected metering strategy is based on separation or homogenisation of the flowing phases, potential MFM devices may be categorised according to the parameter, which they measure. The flow rates of each phase are then inferred from these measured parameters, in different ways depending on the specific metering technology. A detailed description of the measurement principles employed with each instrument will be given in Chapter 4.

There are five basic parameters that can be measured by MFM devices and are mentioned below.

3.2.1. Density, r

Instruments in this category measure mean density of the fluid in a section of the pipe, or a parameter, which is directly related to density, such as gamma-ray absorption or electrical impedance. Devices of this kind respond to the mass of fluid in a given volume of pipe, or to particular atomic constituents, but they reveal nothing about the velocity of the fluids.

3.2.2. Velocity, *v*

The second category includes all those devices which measure fluid velocity, either directly by cross correlation or indirectly by volumetric flow measurement in a turbine flow meter. In homogeneous flow, the measurement is the common velocity of the mixture; and in non-homogeneous flow the interpretation of the recorded signals is more complex.

3.2.3. Momentum, rv^2

Another measurable parameter is the momentum of the fluid stream, namely the product of the mass flux, rv and the velocity, v. This third category of devices includes classical pressure drop instruments such as the venturi and orifice meters.

3.2.4. Mass flow, rv

Although individual component mass flow rates cannot be measured directly, but the total mass flow can, using a true mass flow meter (TMFM) or Coriolis device.

3.2.5. Elemental analysis

The final category covers devices that measure the concentration and velocity of individual atomic species such as oxygen, hydrogen or carbon. These are the instruments, which are needed if the flow of oil, water and gas is not thoroughly mixed and homogenised. Only nuclear techniques have this capability, as will be seen in Chapter 4.

Instruments may also be classified according to the physical principle upon which they are based. Of these there are eight main types which are as follows.

3.2.5.1. Mechanical

These are instruments which depend upon the transmission of force or movement from the fluid to a mechanical device attached to the pipe, for example turbines and vibrating tubes.

3.2.5.2. Hydraulic

Instruments which respond to fluid pressure or fluctuations fall into this class.

3.2.5.3. Acoustic

This class includes all instruments depending upon sound waves, for example acoustic attenuation or Doppler effects.

3.2.5.4. Electrical

A few instruments operate on the basis of electrical properties of the fluids, for example electromagnetic flow meters or impedance density gauges.

3.2.5.5. Gamma and X-ray

There is a large class of instruments which depend on the attenuation and scattering of gamma or X-rays.

3.2.5.6. Neutrons

This category is one of the most important since it includes neutron interrogation of individual atomic species.

3.2.5.7. Microwave attenuation

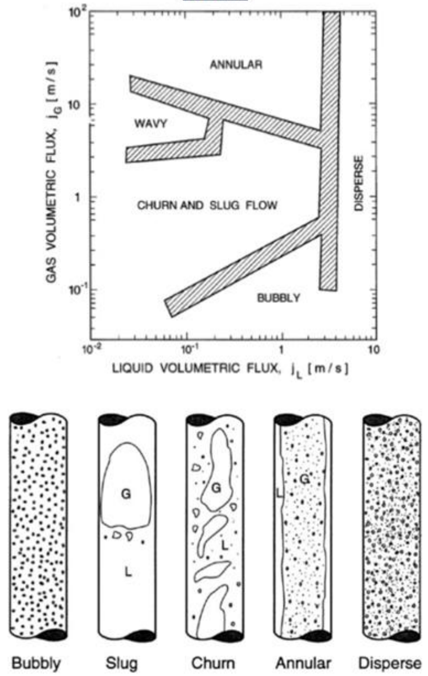
This depends on attenuation and absorption of microwaves by water molecules.

3.2.5.8. Infrared spectroscopy

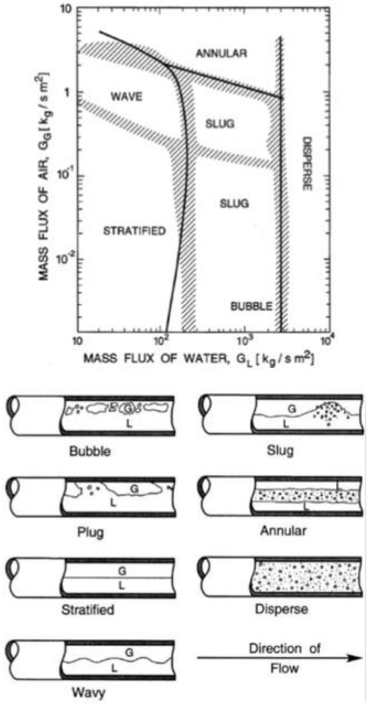
Water cut (WC) meters based on this principle aim at measuring the volumetric proportion of oil in a mixture of petroleum and water by passing a beam of infrared light through the stream, which is absorbed by oil, but not water.

Flow Regime maps are useful tools for getting an overview over which flow regimes we can expect for a particular set of input data. Each map is not, however, general enough to be valid for other data sets. It gives a description of the geometrical distribution of a multiphase fluid moving through a pipe. Different flow regimes are used to describe this distribution, the distinction between each one being qualitative and somewhat arbitrary. In vertical or moderately deviated pipes, the most common flow regimes for gas-liquid mixtures are bubble flow, slug flow, mist flow, churn flow and annular flow. In horizontal wells, there may be stratified or wavy stratified flow in addition to many of the regimes observed in vertical wells. Two-phase flow regimes have often been presented as plots, or maps, with the phase velocities or functions of them on each axis. Earlier maps were named after their authors, for example Griffith-Wallis, Duns-Ros and Taitel-Dukler. The following Figures give an example of flow regime map for a vertical and horizontal flow of a Gas/Liquid mixture.

Flow regime map for vertical flow of a Gas/Liquid Mixutre



Flow regime map for horizontal flow of a Gas/Liquid Mixutre



Bubble flow:

The gas phase is distributed in the liquid phase as variable-size, deformable bubbles moving upward with zigzag motions. The wall of the pipe is always contacted by the liquid phase.

Slug Flow:

Most of the gas is in the form of large bullet-shaped bubbles that have a diameter almost reaching the pipe diameter. These bubbles, called Taylor bubbles, move uniformly upward, and are separated by slugs of continuous liquid that bridge the pipe and contain small gas bubbles. The gas bubbles velocity is greater than that of the liquid.

Churn Flow:

If a change from a continuous liquid phase to a continuous gas phase occurs, the continuity of the liquid in the slug between successive Taylor bubbles is destroyed repeatedly by a high local gas concentration in the slug. This oscillatory flow of the liquid is typical of churn flow. This flow regime may not occur in small-diameter pipes.

Annular -Mist Flow:

During annular, the liquid phase flows regularly as an annular film on the wall with gas flowing as a central core. Some of this liquid is entrained as droplets in this gas core (mist flow).

The following video demonstrates common liquid-air flow regimes that can be established in pipes at various liquid and air flow rates and various angles of pipe inclination: