REVIEW OF WET GAS FLOW MEASUREMENT USING VENTURI TUBES AND RADIO ACTIVE MATERIALS

Hossein Seraj[1], Marzuki Khaled[2], Rubiyah Yusof[3] and Mohd Fuaad Rahmat[4]

[1,2,3]Center For Artificial Intelligence and Robotics (CAIRO)
Universiti Teknologi Malaysia International Campus
Jalan Semarak, 54100 Kuala Lumpur Malaysia

[4]Control and Instrumentation Engineering Department, Faculty of Electrical Engineering,
Universiti Teknologi Malaysia Johor Bahru, 81310 Skudai, Malaysia.

E-mails: serajhossein@yahoo.com, marzuki@utm.my, rubiyah@ic.utm.my, fuaad@fke.utm.my

Abstract - This paper introduces the application of Venturi flow meter for wet gas flow measurement. Wet gas which is a gas containing small amount of liquid is mostly encountered in gas wells where the extracted gas has water and condensate inside. Venturi flow meters which originally were introduced for single phase flow measurement are adapted for wet gas measurement. In this paper, we elaborate using of Venturi meter as a device for measuring wet gas flow and explain versatile methods for correcting the reading of Venturi tube for wet gas application. Tracer injection method is introduced as a manual tool for measuring water and condensate flow rate in wet gas fluid. Also radioactive measuring method has been introduced as an automatic method for measuring the ratio between gas, water and condensate in wet gas fluid. Finally different aspects of using radioactive sources are elaborated.

Key words: Wet gas, Flow measurement, Venturi, Radio-active densitometer, Multi phase flow measurement

I. INTRODUCTION

Wet gas is defined as a gas containing small amount of liquid. For example in oil and gas industry, the extracted fluid from gas wells is a mixture of gas phase with some amount of water and condensate (hydro-carbonic liquid). In this case, each portion of this mixture (i.e. gas, water and condensate) is called a phase. Measuring different phases of wet gas is of paramount importance for following reasons:

- For custody purpose where one company selling gas products (gas, condensate) to other company.
- For allocation purpose where different gas wells are in service and there is a need to realize/adjust the production rates of each well.
- For knowing water-breakthrough phenomena in which the water flow rate in the extracted material from gas well suddenly increases. The same reflects a problem in the gas well (extraction from the water layer of the reservoir instead of gas cone).

Having said above reasons, it is obvious that the measurement of different phases in wet gas flow is one of the demanding requirements in oil and gas industry. Different methods are available for measuring wet gas flow rate. For example, Venturi tubes or V-cones can be used as primary measuring element accomplished by different secondary measuring techniques such as tomography, capacitance, cross correlation, microwave or radioactive. In this paper, we elaborate measuring wet gas flow using Venturi tube and radioactive method. First, we introduce Venturi tube as primary element for measuring wet gas flow.

II. VENTURI TUBES

Venturi is a throat shape device through which the fluid is passing through. Venturi tube cross section is shown in Figure 1.

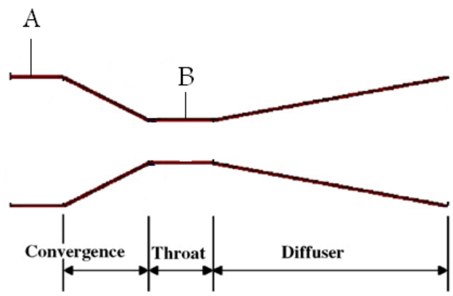

Figure 1: Cross Section of Venturi flow meter

In single phase application (e.g. gas which does not contain any liquid), venturi flow meters are proofed to be a good measuring method due to following advantages [1]:

- Permanent pressure drop which is created in the pipeline as a result of having a venturi is less than other flow measuring methods using differential pressure measurement
- Venturi does not have any moving part and therefore requires less maintenance
- Ability to withstand higher pressure drop across it comparing to other differential pressure methods for flow measurement (e.g. orifice)
- Venturi has relatively high turndown ratio (10:1) which is the maximum to minimum measurable flow rates.
- Creating less restriction for fluid passage comparing to other differential pressure methods for flow measurement (e.g. orifice)

In this paper, the application of Venturi flow meter in wet gas services is investigated.

If the fluid passes through the Venturi, it creates a pressure drop between the inlet and throat section of Venturi (points A and B in Figure 1). Flow rate of the fluid, m_g is proportional to the square root of this pressure drop, P_g. This relation is the basis of flow measurement using Venturi.

$$m_g \propto \sqrt{\Delta P_g} \qquad (1)$$

This relation is called Bernoulli formula. Based on Bernoulli formula, mass flow rate of single phase fluid (e.g. pure gas) is proportional to the square root of differential pressure across Venturi as per following formula [2, 3]:

$$m_g = \frac{C\varepsilon A_T}{\sqrt{1-\beta^4}}.\sqrt{2\rho_g \Delta P_g} \qquad (2)$$

Where C is discharge coefficient; is the area of the Venturi throat; ε is expansibility factor; is gas density; β is diameter ratio (throat diameter at point B to pipe diameter at point A in Figure 1).

III. OVER-READING

If we use Venturi for measuring the gas phase of wet gas fluid, then the flow rate obtained from Bernoulli formula is more than the actual gas flow rate. This is due to presence of liquid in the fluid which introduces more pressure drop across Venturi. When we use Bernoulli formula to predict gas flow rate in wet gas application, pressure drop caused by liquid (in addition to pressure drop caused by gas phase), will be attributed to some more gas flow rate. This phenomenon is called over-reading. The over-reading is defined as the ratio of the reading obtained from Bernoulli formula (virtual gas flow rate) to the actual gas-phase flow rate in the wet gas [3].

$$OR = \frac{m_g^{'}}{m_g} \qquad (3)$$

is the gas mass flow rate obtained from Bernoulli formula if wet gas is passing through the Venturi as per following equation. In the following equation is differential pressure across Venturi in case of wet gas.

$$m_g^{'} = \frac{C\varepsilon A_T}{\sqrt{1-\beta^4}}.\sqrt{2\rho_g \Delta P_{tg}} \qquad (4)$$

is the actual gas flow rate from Bernoulli formula if only gas portion of the wet gas passes through the Venturi. Assuming that is differential pressure across Venturi in this case, then:

$$m_g = \frac{C\varepsilon A_T}{\sqrt{1-\beta^4}}.\sqrt{2\rho_g \Delta P_g} \qquad (5)$$

Since in actual case, liquid is not separated from gas, so we cannot measure and therefore we cannot directly measure .

However, we can measure (differential pressure across Venturi in case of wet gas passing) and then we can calculate . If we can estimate the over-reading (OR), then it is possible to calculate the actual gas mass flow rate in wet gas flow using following relation (by converting equation 3 above).

$$m_g = \frac{m_g^{'}}{OR} \qquad (6)$$

IV. ESTIMATING THE OVER-READING

In order to estimate over-reading, we need to introduce some parameters as follow:

a. Gas quality

Quality (χ) is defined as the ratio of gas mass flow rate to the total (gas +liquid) mass flow rate [2].

$$x = \frac{m_g}{m_g + m_l} \tag{7}$$

  is the gas mass flow rate and   is liquid mass flow rate.

b. Lockhart-Martinelli parameter

Lockhart-Martinelli parameter is defined as the square root of the differential pressure across venturi if only liquid is passing through it to the differential pressure across Venturi if only gas is passing through Venturi. It is also related to quality as follow [4]:

$$X = \sqrt{\frac{\Delta P_l}{\Delta P_g}} = \frac{1-x}{x}\sqrt{\frac{\rho_g}{\rho_l}} \tag{8}$$

Having defined quality and Lockhart-Martinelli parameters, now we can estimate the over-reading using different approaches mentioned below:

c. Estimating over-reading using homogeneous model

If we assume that the liquid phase is homogeneously distributed in the gas phase (i.e. the concentration of liquid in wet gas is the same in all cross section area of the pipe), then over-reading can be estimated using following formula [5]:

$$OR = \frac{1}{x}\sqrt{\frac{\rho_l}{\rho_g} + \left(1 - \frac{\rho_g}{\rho_l}\right)x} \tag{9}$$

Where   and   are liquid and gas density respectively and χ is quality as defined above. Gas density is highly dependent to pressure (considering gas PVT relation). For measuring gas density, normally the pressure and temperature of the line is measured and using PVT relation for gas, the density of the gas at operating pressure and temperature of the line is measured.

d. Estimating over-reading using Chisholm correlation

Chisholm has proposed following correlation for measuring over-reading. In his correlation, the over-reading depend on Lockhart-Martinelli (which itself depend on liquid flow rate) and on pressure (due to highly dependence of (gas density) to pressure) [6, 7].

$$OR = \sqrt{1 + \left(\left(\frac{\rho_l}{\rho_g} \right)^{1/4} + \left(\frac{\rho_g}{\rho_l} \right)^{1/4} \right) X + X^2} \qquad (10)$$

e. Estimating over-reading using De Leeuw correlation

De Leeuw has claimed that the over-reading not only depends on Lockhart-Martinelli parameter but also depend on Froude number. Froude number is defined as follow [7]:

$$Fr_g = \frac{v_g}{\sqrt{gD}} \sqrt{\frac{\rho_g}{\rho_l - \rho_g}} \qquad (11)$$

De Leeuw correlation is similar to Chisholm's correlation with the difference that the power factor of 1/4 in Chisholm correlation is replaced with parameter n as defined below [7]:

$$OR = \sqrt{1 + \left(\left(\frac{\rho_l}{\rho_g} \right)^{n} + \left(\frac{\rho_g}{\rho_l} \right)^{n} \right) X + X^2} \qquad (12)$$

$$n = \begin{cases} 0.41 \ldots\ldots\ldots\ldots\ldots\ldots 0.5 \le Fr_g \le 1.5 \\ 0.606\left(1 - e^{-0.746 Fr_g}\right) \ldots\ldots\ldots Fr_g > 1.5 \end{cases}$$

By introducing Froude number in over-reading correlation, De Leeuw implicitly shows the dependency of over-reading to the form of gas-liquid mixture in the line (called flow pattern) since Froude number is an important factor in determining the form of gas-liquid mixture.

f. Estimating over-reading using Steven correlation

Steven has also derived another correlation for estimating over-reading in which over-reading depend on Lockhart-Martinelli, Froude number and pressure. Steven correlation is as follow [8]:

$$OR = \frac{1 + AX + BFr_g}{1 + CX + DFr_g} \tag{13}$$

$$\begin{aligned}
A &= 2454.51\left(\rho_g/\rho_l\right)^2 - 389.568\left(\rho_g/\rho_l\right) + 18.146 \\
B &= 61.695\left(\rho_g/\rho_l\right)^2 - 8.349\left(\rho_g/\rho_l\right) + 0.223 \\
C &= 1722.917\left(\rho_g/\rho_l\right)^2 - 272.92\left(\rho_g/\rho_l\right) + 11.752 \\
D &= 57.387\left(\rho_g/\rho_l\right)^2 - 7.679\left(\rho_g/\rho_l\right) + 0.195
\end{aligned}$$

As seen above, all the correlations for estimating over-reading depend on quality or Lockhart-Martinelli parameters. Also quality and Lockhart-Martinelli parameters are themselves depend on liquid flow rate. Therefore we can conclude that for correcting the over-reading, we need to know the liquid flow rate in the pipe. Below we explain the tracer injection method which can be used for measuring liquid flow rate in wet gas application.

V. TRACER INJECTION METHOD

In tracer injection method, a liquid (called tracer liquid afterward) which is either solvable in the water or in the condensate is selected. This tracer liquid also contains some florescent material. Then this tracer liquid is injected into the pipeline where wet gas is passing through. After injecting tracer liquid into line, the same is solved in the water or condensate depending whether the chosen tracer liquid is solvable in water or in condensate. Then after certain distance from injection point, there is a sampling point where some sample is taken from the material in the pipe. The distance between injection and sampling point should be long enough to allow the tracer liquid to be solved properly in the water or condensate.

The concentration of florescent material in the injected tracer liquid ( ) is known before injection. Also the flow rate of the injected tracer liquid ( ) is measured during injection period. After getting the sample from the pipe, the same sample is transferred to laboratory and the concentration of florescent material in the sample ( ) is measured. Finally we can estimate the flow rate of water (or condensate depending on solvability of tracer liquid in water or condensate) from following formula:

$$F_{target} = \frac{F_{inj} C_{inj}}{C_{sample}} \qquad (14)$$

Tracer injection method has several draw backs. First of all, it is not a fully automated solution and therefore it needs operator attendance. Secondly, it needs expensive tracer liquid and also laboratory facilities. Finally, since it is not an on-line measurement, so it is assumed that liquid flow rates are constant between two consequent measurements while the same assumption may not be correct.

To overcome these drawbacks, the radioactive measuring method can be used. In the following section, the fundamental of radioactivity is briefly explained. Subsequently, the application of radioactive materials in wet gas flow measurement is explained.

VI. RADIO-ACTIVE MEASURING METHOD IN WET GAS FLOW MEASUREMENT

For explaining the application of radio-active materials in wet gas application, first we need to briefly explain the basis of radio activity as below.

a. Basis of Radioactivity

Radioactivity is a characteristic of certain materials which has unstable nuclei. Nuclei of radioactive materials give off energies in the form of particles and/or electromagnetic radiation.

In most cases, there are two main principles which cause radioactivity. These two principles are Alpha-decay and Beta-decay. In Alpha-decay, the nuclei of the radioactive material emit Alpha particle which consists of 2 protons and 2 neutrons. Alpha particles are having positive charges and in order to have charge equilibrium, the radioactive material is emitting Beta particles which consist of negatively charged electrons. Also during Alpha-decay, electromagnetic energy is emitted in the form of Gamma rays. In Beta-decay, a neutron is converted into a proton and an electron and some energy. Produced electrons are emitted as Beta ray (radiation of electron particles) and produced energy is emitted in the form of Gamma rays.

Different radioactive materials are decaying with different rates. The time in which exactly half of the radioactive nuclei of certain material decay, is called "half-life" of that radioactive material.

Activity of a certain amount of radioactive materials is defined as the nos. of disintegration (decay of a nucleus by which it emit Alpha, Beta or Gamma rays) per second. Becquerel (Bq) is the unit of activity and is equal to one disintegration per second. Another unit of activity is Curie (Cr) which equals to Bq.

Both Alpha rays (particles with 2 protons and 2 neutrons) and Beta rays (electron particles) have electrostatic charged particles. When Alpha or Beta particles are emitted from a certain radioactive source, these Alpha and Beta particles pass though surrounding material (medium) and during this passage, they interact with the nuclei and electrons of medium. Since both Alpha and Beta particles have electrostatic charges, therefore there is electrostatic force between these particles and the nuclei and electrons of medium. Due to these electrostatic forces, the energy of Alpha and Beta particles are reduced and the same cause reducing the number of Alpha and Beta particles which can finally pass through the medium of specified thickness. The particles which cannot pass through the medium are the ones which lost their energy due to electrostatic interaction or direct collision with the nuclei and electrons of medium. It is generally said that these Alpha and Beta particles are absorbed by the medium. The absorption process causes attenuation of the intensity of Alpha and Beta radiation.

Gamma radiation is a type of electrostatic wave and therefore it does not have any electrostatic charges. As per quantum theory, the electromagnetic waves consist of particles called photons. When Gamma ray is emitted from a radioactive source, photons of Gamma ray are passing through surrounding medium. Since these photons do not have any electrostatic charges, therefore there is no electrostatic force between these particles and the nuclei and electrons of medium. The only interaction which happens is in form of direct collision of photon with orbital electrons of medium. Since the probability of direct collision is very less due to small size of the photons and electrons comparing to the empty space between electrons, therefore Gamma rays can penetrate into medium much more than Alpha and Beta particles. For example, Alpha particles are almost absorbed by a paper, Beta particle can be absorbed with somebody's hand, whereas Gamma particle can only be attenuated by one meter of concrete and theoretically they can never be stopped completely.

Absorption of radiations from radioactive materials (Alpha, Beta and Gamma rays) in different medium is used for attenuating the radiation and reducing the harmful effects of these radiations to human body. The process of putting a medium to reduce the intensity of radioactive radiation is called shielding. Normally lead is used for shielding of Gamma radiation since it has heavy nuclei and therefore has good absorption capability of Gamma radiation. Normally radioactive sources (e.g. Barium 133 or Cesium 137) are place within a lead container. There is a small perforation in certain portion of this lead container and Gamma rays are emitted in the form of a narrow beam from this perforation. In other directions where there is no perforation, the radiation is attenuated by the lead shielding around the radioactive source. Therefore by having shielding around radioactive source, Gamma rays are only radiated in the direction which is required. Other forms of radiation (Alpha and Beta rays) are completely shielded by the lead container.

b. Wet gas measurement using radioactive sources

Gamma rays are used to detect the volumetric percentage of gas, water and condensate in wet gas fluid. Volumetric percentage of each phase (gas, water and condensate) is called fraction of that phase (e.g. water fraction means the volumetric percentage of gas to the total volume of wet gas fluid). As explained before, we need to know the quality of the wet gas (ratio of mass flow rate of gas to the total mass flow rate of gas, water and condensate) in order to be able to correct the over-reading of Venturi tube using Bernoulli formula. By using the Gamma ray, we estimate the gas, water and condensate fractions. Since we know the density of the gas, water and condensate and by assuming that the gas, water and condensate are travelling with the same speed, we can calculate the quality of the wet gas using following relation:

$$x = \frac{m_g}{m_g + m_w + m_c} = \frac{q_g \rho_g}{q_g \rho_g + q_w \rho_w + q_c \rho_c} = \frac{vA\alpha_g \rho_g}{vA\alpha_g \rho_g + vA\alpha_w \rho_w + vA\alpha_c \rho_c}$$

$$\Rightarrow x = \frac{\alpha_g \rho_g}{\alpha_g \rho_g + \alpha_w \rho_w + \alpha_c \rho_c} \tag{15}$$

In above relation , , and are gas mass flow rate, gas volumetric flow rate, gas density and gas fraction respectively. Similarly the subscription of “w” and “c” are used for similar values for water and condensate. is the speed of wet gas fluid and A is the area of the pipe.

For obtaining gas, water and condensate fractions in wet gas fluid, two types of Gamma rays at different frequencies are used. In this case, Gamma rays at two frequencies are emitted at one side of the pipe which carries wet gas fluid. Then the intensity of Gamma rays at each frequency is measured at other side of the pipe. Following formula can be used for estimating the intensity of gamma rays after passing through the wet gas fluid [9]:

$$I(e) = I_0(e)e^{-\sum_{i=1}^{3}\alpha_i\mu_i(e)d} \qquad (16)$$

In this formula I(e) is the intensity of Gamma ray after passing through wet gas fluid (e denote the frequency of Gamma ray). (e) is the intensity of measured Gamma ray when the pipe is empty (air at atmospheric pressure). is fraction of each phase (gas, water and condensate) and is the attenuation coefficient of Gamma ray in each phase when the frequency of Gamma ray is e. d is also the diameter of the pipe. If we take logarithm from both side of above relation, we can get below relations.

$$\begin{aligned} Ln\big(I(e_1)\big) &= Ln\big(I_0(e_1)\big) - \alpha_g\mu_g(e_1)d - \alpha_w\mu_w(e_1)d - \alpha_c\mu_c(e_1)d \\ Ln\big(I(e_2)\big) &= Ln\big(I_0(e_2)\big) - \alpha_g\mu_g(e_2)d - \alpha_w\mu_w(e_2)d - \alpha_c\mu_c(e_2)d \end{aligned} \qquad (17)$$

Also since the wet gas consists of gas, water and condensate, therefore the summation of fraction of these phases is equal to one (i.e. the sum of percentages of different phases is equal to 100%).

$$\alpha_g + \alpha_w + \alpha_c = 1 \qquad (18)$$

If we represent above three relations in matrix form, we can obtain following relation:

$$\begin{bmatrix} \mu_g(e_1)d & \mu_w(e_1)d & \mu_c(e_1)d \\ \mu_g(e_2)d & \mu_w(e_2)d & \mu_c(e_2)d \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} \alpha_g \\ \alpha_w \\ \alpha_c \end{bmatrix} = \begin{bmatrix} Ln(I_0(e_1)) - Ln(I(e_1)) \\ Ln(I_0(e_2)) - Ln(I(e_2)) \\ 1 \end{bmatrix} \quad (19)$$

Then we can obtain gas, water and condensate fractions using below relation:

$$\begin{bmatrix} \alpha_g \\ \alpha_w \\ \alpha_c \end{bmatrix} = \begin{bmatrix} \mu_g(e_1)d & \mu_w(e_1)d & \mu_c(e_1)d \\ \mu_g(e_2)d & \mu_w(e_2)d & \mu_c(e_2)d \\ 1 & 1 & 1 \end{bmatrix}^{-1} \begin{bmatrix} Ln(I_0(e_1)) - Ln(I(e_1)) \\ Ln(I_0(e_2)) - Ln(I(e_2)) \\ 1 \end{bmatrix} \quad (20)$$

One can have a better understanding by looking to the graphical representation of the logarithm of intensity measurement (in the form of count rate of the gamma ray received) for each energy level in figure 2 [1, 9]. In this graph, the Intensity of measured gamma ray in each frequency (energy level) is represented in logarithm scale along one axis. The pure water, pure gas and pure condensate are forming the corners of the triangle while any point inside the triangle represents a combination of water, gas and condensate.

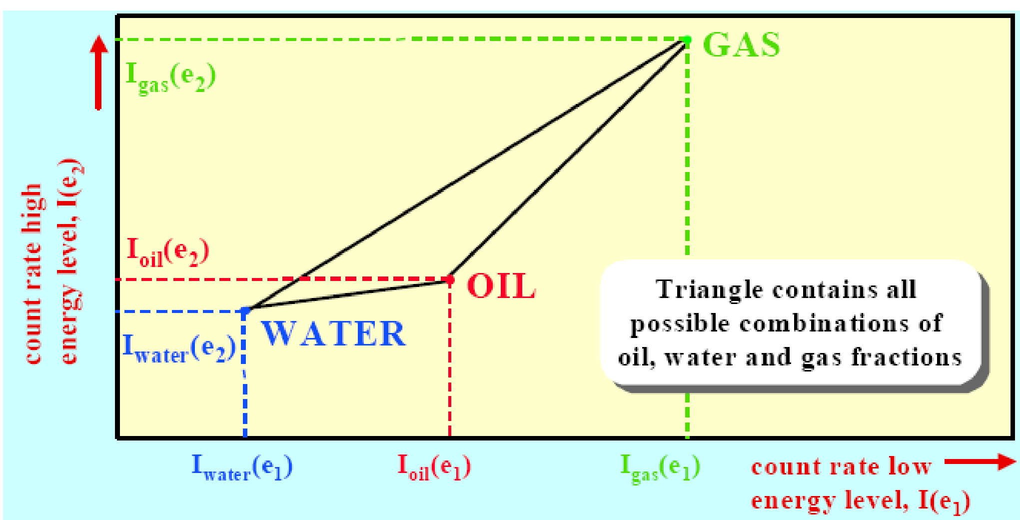

Figure 2: Graphical representation of measurement results of dual energy gamma ray on wet gas fluid [9]

By prior knowledge of attenuation coefficient of Gamma rays in gas, condensate and water at each of these frequencies, percentages of gas, water and condensate in the wet gas can be estimated using above relation. Then gas, water and condensate fractions in wet gas fluid are used in calculating quality (using relation 7-1) and Lockhart-Martinelli number (using relation 4-2). As explained above, quality and Lockhart-Martinelli number can be used for correcting the over-reading obtained from Bernoulli formula for measuring gas fluid.

In addition, water mass flow rate can be estimated using fractions of different phases and also using gas mass flow rate obtained after correcting the over-reading.

$$\frac{m_w}{m_g} = \frac{Av\alpha_w\rho_w}{Av\alpha_g\rho_g} = \frac{\alpha_w\rho_w}{\alpha_g\rho_g}$$
$$\Rightarrow m_w = \frac{\alpha_w\rho_w}{\alpha_g\rho_g} m_g \tag{21}$$

Similarly condensate mass flow rate can be estimated using following relation:

$$m_c = \frac{\alpha_c\rho_c}{\alpha_g\rho_g} m_g \tag{22}$$

Dual energy Gamma rays are generated using radioactive sources which are emitting at two different frequencies. For example Barium 133 is one of the materials which is used in wet gas flow measurement and generate Gamma rays at two different frequencies [10].

If the human body is exposed to Gamma ray, some biological damages will occur. The severity of these biological damages depends on the intensity of the Gamma rays, the area of the body which is exposed to the Gamma rays, the period of exposure and also the frequency/energy of Gamma rays. Therefore using radioactive sources necessitates following strict safety roles. Usually these safety roles put a limit of the intensity of radiation on any touchable surface of wet gas flow meter. For example, normally the intensity of radiation should not be more that 7.5 μSv/hour (micro Sivert per hour) at any touchable surface. Also there are operational roles for the workers which are exposed to Gamma rays. These safety roles try to limit the accumulative exposure of each worker in certain period. For example the accumulative exposure of each worker should not be more than 100 mSv over a period of five years. Also in each year it should not be more than 50 mSv.

In order to meet the safety requirements, proper shielding of radioactive sources is a must. Normally lead is used for shielding the radioactive materials [11]. Few centimeters of lead can reduce the intensity of gamma radiation several times. Since a radioactive material emits in all directions while we only want the radiation to pass through the pipe, therefore by making proper lead shielding around the radioactive source, we limit the radiation to a narrow beam (typically a cone shape radiation with 2-5 Degree of opening at the cone. This beam is focused to the pipe. So the intensity of radiation in other directions around the source is very minor (less than 7.5 μSv/hour).

There are various methods for measuring the Gamma ray intensity after it passes through the pipe. Nowadays there is a common practice to use photomultiplier. In this method, certain detecting materials which emit photons (lights) upon receipt of Gamma rays are used. These materials are placed where intensity of Gamma rays should be measured. NaI is a typical material which has such characteristic [11]. Since the number of photons which are emitted from these detecting materials are very minor, therefore they cannot be measured directly by any electronic circuit, Therefore a device called photomultiplier is used. This device multiplies the number of photons which are received from the detecting material (e.g. NaI). The multiplied photons are then sensed by an electronic device. The output of this electronic device is related to the intensity of the Gamma rays. Figure 3 shows a typical arrangement of different elements used for applying radio-active measuring method in wet gas flow meters [11].

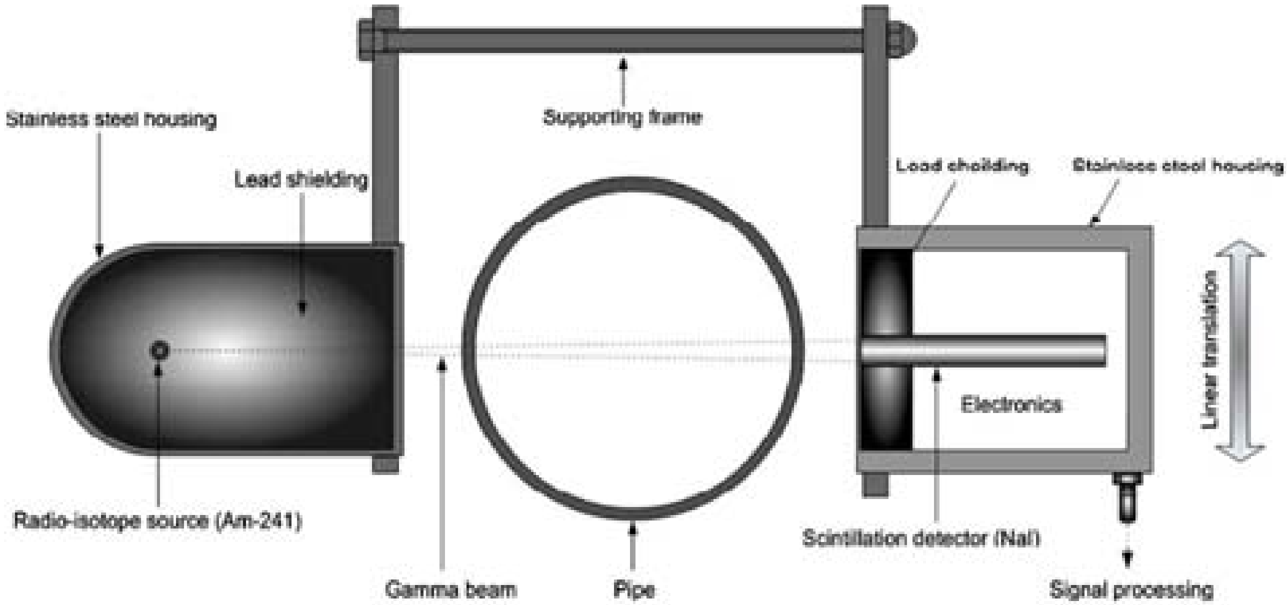

Figure 3: (a) Different elements of radio-active measuring method in wet gas flow meters [11]

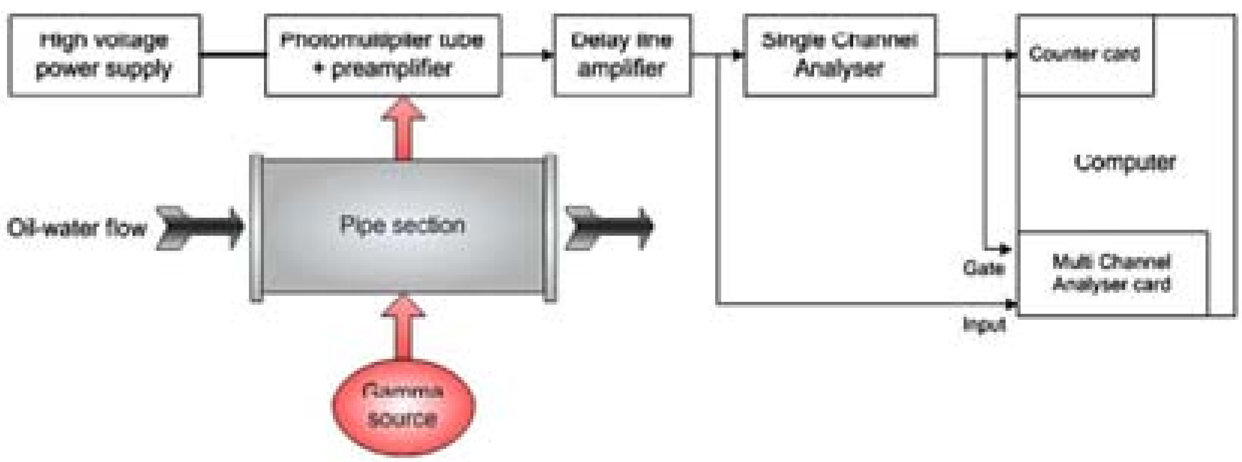

Figure 3(b): Block diagram of radio-active measuring method in wet gas flow meters [11].

Figure 4 shows an example for installation of wet gas meters using radio-active material to identify water and condensate fractions [10].

Figure 4: An example for installation of wet gas meters [10]

VII. CONCLUSION

In this paper, we introduce Venturi meter as a tool for measuring wet gas flow. Then we explain different methods for correcting the over-reading obtained from Bernoulli equation. Thereafter we elaborate tracer injection method which is used to measure water and condensate flow rates in wet gas application. As a substitute for tracer injection method, radioactive substances for measuring the ratio of gas, water and condensate is explained. Then we explain how the results of radio-active measurement can be used for correcting of over-reading of Venturi meter in wet gas application.

VIII. NOMENCLATURE

	Area of Venturi throat
A	Area of the pipe
C	Discharge coefficient of Venturi tube
	Concentration of florescent material in the sample
	Concentration of florescent material in the injected tracer liquid

d	Diameter of the pipe
	Froude number
	Flow rate of water (or condensate depending on solvability of tracer liquid in water or condensate)
	Flow rate of the injected tracer liquid
	Intensity of measured Gamma ray when the pipe is empty (air at atmospheric pressure)
I(e)	Intensity of Gamma ray after passing through wet gas fluid (e denote energy of Gamma particle at certain frequency)
	Mass flow rate of gas
	Mass flow rate of water
	Mass flow rate of condensate
	Mass flow rate of liquid (i.e. water and condensate)
	Gas mass flow rate obtained from Bernoulli formula
OR	over-reading obtained in calculating gas flow rate from using Bernoulli law
	Velocity of wet gas fluid
	Velocity of gas (assumed to be equal to Velocity of wet gas fluid)
χ	Quality of gas (ratio of gas mass flow rate to total wet gas fluid mass flow rate)
X	Lockhart-Martinelli No.
β	beta ratio (throat cross section to pipe cross section in Venturi tube).
ε	Expansibility factor
	Density of gas
	Density of water
	Density of condensate
	Density of liquid (water and condensate)
	Attenuation coefficient of γ ray in each phase (gas, water. Condensate) when the energy of Gamma particle is e
	Attenuation coefficient of Gamma ray in gas
	Attenuation coefficient of Gamma ray in water

	Attenuation coefficient of Gamma ray in condensate
	Gas fraction (percentage of gas to total fluid in a section of pipe)
	Water fraction (percentage of water to total fluid in a section of pipe)
	Condensate fraction (percentage of condensate to total fluid in a section of pipe)
	Differential pressure across Venturi in case of pure gas
	Differential pressure across Venturi in case of wet gas

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