

Chemical Composition Effects on Enthalpy Uncertainty in Natural Gas Energy Measurement System Using Orifice Meter in a Non-adiabatic Condition

Gunawan Marto^{1,*}, Harijono. A. Tjokronegoro¹, Edi Leksono¹, Nugraha¹, Ghuftron Zaid³

¹Research Group of Engineering Physic Institut Teknologi Bandung, Jalan Ganesha 10 Bandung 40132, Indonesia

²Development Centre of Metrological Human Resources, Ministry of Trade, Indonesia

³Research Centre for Calibration, Instrumentation dan Metrology (Pusli KIM-LIPI), Indonesia

*Corresponding author: msc.gunawan96@gmail.com

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Abstract This paper explains an enthalpy uncertainty of natural gas energy measurement (custody transfer) using orifice meter in non-adiabatic condition. The method of uncertainty analysis used in this paper was developed based on the uncertainty analysis of natural gas flow measurement using orifice meter at adiabatic condition based on AGA 3, 1992 (which reference by No 10.). In addition of non-adiabatic condition includes: critical pressure, critical temperature, real-time pressure, real-time temperature and generalized correlation constant. The measurement of enthalpy uncertainty referring to the Guide to the Expression of Uncertainty Measurement of the Guide in Metrology Working Group 1 of Joint Committee for Guide In Metrology, 2011. Based on the energy flow in orifice meter is 1000 Mmbtud, The combined uncertainty of enthalpy is 3.86×10^{-7} Mmbtud (3.86×10^{-8} %) while the expanded uncertainty analysis results 7.73×10^{-7} Mmbtud (7.73×10^{-8} %) with confidence level 95%. This number of uncertainty is smaller than the Measurement Permissible Error specified by legal metrology organization 0.1667%.

Keywords: measurement uncertainty, orifice meter, adiabatic condition, non-adiabatic condition, Maximum Permissible Error (MPE)

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1. Introduction

Precision and accuracy of a natural gas measurement using orifice meter are greatly determined by the collection of the measurement uncertainty comes from all of the involved measuring instruments. Uncertainty of the orifice meter is the uncertainty of real flow rate which is caused by the actual condition of the physical property of measured fluid, and the accuracy of installation parameters such as orifice diameter and beta ratio [1].

Orifice meters used in trade is necessary to have an ability to verify the measurement results. When choosing the meter, thoroughness and accuracy of the meter should be considered at first. If it's going to be used in control applications, the inaccuracy should be within $\pm 2\%$ acceptable range. If it's going to be used in operational applications, the inaccuracy should be within $\pm 5\%$ acceptable range. If it's going to be used in operational applications, the inaccuracy should be within $\pm 0.5 - 2\%$ acceptable range [2,3].

According to AGA 3 1992, the uncertainty of flow rate is calculated by considering the discharge coefficient (Cd), orifice meter diameter (d) calculated based on flowing

temperature (T_f), differential pressure (ΔP), velocity (E_v), dimension conversion constant (gc), universal constant (π), fluid density in flowing temperature (P_f , T_f), and expansion factor. The calculated expanded uncertainty of natural gas flow rate with 95% with expansion uncertainty value ($U_{95 S}$)² from discharge coefficient (Cd) : 0.1936, expansion factor (Y) : 0.0009, orifice diameter (d) : 0.0114, pipe diameter (D): 0.011, pressure drop (ΔP): 0.0625, compressibility factor (Z): 0.0025, flowing temperature (T_f): 0.0156, and relative density (G) : 0.09 is $\pm 0.67\%$ [1,4].

To obtain the enthalpy uncertainty one has to have information about flow rate, heating value per volume unit, and relative density of natural gas values. The heating value is significantly determined by the measured composition of natural gas. The analysis of gas chromatography, heating value (H_v) calculation, and relative density calculation use reference of ASTM D 1945-96 (GPA 2261-95) and ASTM D 3588-98 (GPA 2172-96). Base on reference, results in heating value uncertainty of $\pm 0.25\%$, and relative density uncertainty of 0.003 [4].

National Bureau of Standards [5] (NBS) of France has done a research on a comparison between two methods of calculation of uncertainty of natural gas density. Natural gas used in research are pure methane and Liquefied

Natural Gas (LNG). LNG is a mixture of methane, ethane, propane, and nitrogen. The methods are: (1) absolute densitometer based on the Archimedes principle; (2) correlation method based on measurement of composition and density. By the methods, the measurement results resulted in density uncertainty of pure methane of 0.02% and LNG of 0.025% [5].

Colorado Experimental Engineering Station Incorporated [6] (CESSI) has done a research on natural gas flow rate using 9 turbine meters. The standard of flow rate in CESSI facility is traceable to NIST. Capacity of each turbine is 0.7 m³/s to 10.7 m³/s. Operating pressure is 7174 kPa and operating temperature is ambient temperature. The research resulted uncertainty of flow rate is 0.28% to 0.30% dependent on natural gas flow rate [6].

Gunawan et al, 2012 [7], developed a calculation system of natural gas total energy measured using an orifice meter in non-adiabatic condition. In this measurement, besides volumetric and heating value parameters were considered, the net rate of generation such as heat loss caused by friction factor and also radiation heat from the sun were also taken into consideration [7].

In this uncertainty calculation of natural gas energy, the fluid that used is natural gas. The orifice meter measuring instrument system was operated in pressure between 29 to 30 bars. The operational temperature is adjusted between 25°C to 40°C. The compressibility factor variation is 0.85 to 1 [8].

Furthermore, this paper will discuss the empirical equation of sensitivity coefficient in section 2, the enthalpy uncertainty empirical equation section 3, the research methodology section 4, the calculation result and its discussion in section 5. The conclusion and acknowledgements will be delivered in closing chapter.

2. Empirical Equation of the Sensitivity Coefficient of Enthalpy

2.1. Empirical Equation of the Sensitivity Coefficient of Enthalpy

Uncertainty of energy measurement calculation is a basic and important foundation in natural gas measurement system using orifice meter, especially in custody transfer. Without information of uncertainty, measurement quality, modelling, and testing method can't be quantified, untraceable, and the measurement result can't be proven. Without estimation of uncertainty and its traceability to The International System of Units (SI) or other international standards, the measurement result is incomplete and meaningless [1,2,9].

In estimating the uncertainty value of total energy measurement using orifice meter, the orifice meter installation facility is deeply concerned and some variables need to be considered. Mathematical context between variables determines the sensitivity of measured amount of respective variables, each variable included in the energy balance equation has its own specific sensitivity coefficient. The derived coefficient in general was based on mathematical equation or approximated from curve or table calculation [1].

One dimensional equation of total energy in orifice meter measuring system is a function of enthalpy value

(H), kinetic energy as flow rate function (v), height (z), net rate of generation (X_G), and work produced by orifice meter system (W). This relationship is expressed mathematically as [10,11,12]:

$$\dot{Q} = \Delta \left[\left(H + \frac{1}{2} v^2 + zg \right) \dot{m} \right]_{fs} + \dot{X}_G - \dot{W} \quad (1)$$

Where \dot{m} is mass flow rate, \dot{Q} is total energy, \dot{X}_G is rate of generation and \dot{W} is work. Equation (1) shows total enthalpy calculation is a sum of sensible enthalpy value and real enthalpy value. The sensible enthalpy is calculated based on heat capacity in ideal condition, while the real enthalpy such as the compressibility factor function (Z) is calculated according to Generalized Correlation as follows [10,11,12].

$$\Delta H = \int_{T_1}^{T_2} C_p^{id} dT + H_2^R - H_1^R \quad (2)$$

Equation (2) explains the correlation between total enthalpy (ΔH), a sum of sensible enthalpy value calculated based on heat capacity value in ideal condition, and real enthalpy value (H^R). To calculate the sensitivity value from the sum of enthalpy value, the equation of the total enthalpy—consisted of ideal enthalpy and real enthalpy should be derived (first derivative). Ideal enthalpy value is expressed as [10,11,12]:

$$\Delta H_1 = \int_{T_1}^{T_2} \frac{C_p}{R} dT = \frac{1}{R} \int_{T_1}^{T_2} A + BT + CT^2 + DT^{-2} dT \quad (3)$$

Equation (3) is a non-linear equation: a heat capacity function dependent on temperature. The solution of equation (3) is given by [10,11,12]:

$$\Delta H_1 = R \left[A(\Delta T) + \frac{B}{2}(T_2^2 - T_1^2) + \frac{C}{3}(T_2^3 - T_1^3) - \frac{D}{\Delta T} \right] \quad (4)$$

Where ΔT is the difference between T_2 and T_1 . Equation (4) explains the ideal enthalpy value as the product of ideal gas constant (R) expressed in (J mol⁻¹ K⁻¹) and the heat capacity derived from empirical equation of natural gas component constants (A, B, C, D) as a temperature function. In equation (5), if the temperature of upstream part (T_1) is almost the same as the temperature of downstream part (T_2), then ΔH_1 is assumed to be significantly influenced by the value of ideal gas constant (R), gas component constant (A), and temperature difference between upstream and downstream (ΔT).

$$\Delta H_1 = R[A(\Delta T)] \quad (5)$$

The sensitivity coefficient of ideal enthalpy is the first derivative of ideal enthalpy and expressed as:

$$c_{\Delta H_1} = \frac{d\Delta H_1}{d\Delta T} = RA \quad (6)$$

Equation (6) explains the sensitivity value of ideal enthalpy as the first derivative of ideal enthalpy value. This coefficient of sensitivity value is the product of ideal gas constant (R) and natural gas component constant (A). The total value of real enthalpy is expressed as:

$$\Delta H^R = P_r R T_c \left[B^o - T_{r2} \frac{dB^o}{dT_r} + \omega \left(B^1 - T_{r2} \frac{dB^1}{dT_r} \right) \right] - P_r R T_c \left[B^o - T_{r1} \frac{dB^o}{dT_r} + \omega \left(B^1 - T_{r1} \frac{dB^1}{dT_r} \right) \right] \quad (7)$$

Equation (7) explains the real enthalpy value. The real enthalpy value is significantly influenced by the value of real pressure (T_r), ideal gas constant (R), critical temperature (T_c), and generalized correlation constant as a temperature function ($B^o, B^1, \frac{dB^o}{dT_r}$, and $\frac{dB^1}{dT_r}$).

The value of pressure and operational temperature is given by:

$$P = P_c P_r \quad \text{dan} \quad T = T_c T_r \quad (8)$$

where P_c is critical Pressure, P_r real Pressure, T_c is critical temperature and T_r is real temperature. To calculate the coefficient value of real enthalpy, the first derivative of real enthalpy with respect to the each building blocks of the real enthalpy function components

should be obtained. For example, the sensitivity coefficient of real pressure is a partial derivative of real enthalpy (H^R) respective to real pressure (P_r). This equation is expressed as:

$$c_{Pr} = \frac{\partial H^R}{\partial P_r} = R T_c B^o - R T_c T_{r2} \frac{dB^o}{dT_r} + R T_c \omega B^1 - \omega R T_c T_{r2} \frac{dB^1}{dT_r} - R T_c B^o + R T_c T_{r1} \frac{dB^o}{dT_r} - R T_c \omega B^1 + \omega R T_c T_{r1} \frac{dB^1}{dT_r} \quad (9)$$

Equation (9) explains the sensitivity coefficient of real enthalpy respective to the real pressure as a function of real pressure (T_r), ideal gas constant (R), critical temperature (T_c), and generalized correlation constant as temperature function ($B^o, B^1, \frac{dB^o}{dT_r}$, and $\frac{dB^1}{dT_r}$).

By using the same method, the sensitivity coefficient of other components/variables of the real enthalpy function is given by [Table 1](#).

Table 1. Sensitivity Coefficient of Real Enthalpy (H^R)

Mathematical equation of Sensitivity Coefficient of Real Enthalpy (H^R)	Equation Number
$c_{B^o} = \frac{\partial H^R}{\partial B^o} = P_r R T_c T_1 \frac{d^2 B^i}{dT_r^2} - P_r R T_c T_{r2} \frac{d^2 B^i}{dT_r^2}$	(10)
$c_{\omega} = \frac{\partial H^R}{\partial \omega} = T_{r1} T_c R P_r \frac{dB^1}{dT_r} - T_{r2} T_c R P_r \frac{dB^1}{dT_r}$	(11)
$c_{T_c} = \frac{\partial H^R}{\partial T_c} = -P_r T_{r2} \frac{dB^o}{dT_r} R + \omega T_{r2} R P_r \frac{dB^1}{dT_r} + P_r T_{r1} \frac{dB^o}{dT_r} R + \omega T_{r1} R P_r \frac{dB^1}{dT_r}$	(12)

2.2. Empirical Equation of Enthalpy Uncertainty

Uncertainty of total energy that is obtained by orifice meter is considerably influencing the measurement result. For example, in determining the enthalpy uncertainty (H), enthalpy value is a function of heat capacity as temperature function (T). Based on this fact, the enthalpy uncertainty is estimated from the temperature uncertainty. This is different from the determination of kinetic energy uncertainty. The kinetic energy uncertainty calculation result is determined by the fluid flow rate, therefore it is estimated from the uncertainty of flow rate [\[1,13\]](#).

The occurrence of error in every measurement is a basic in determining uncertainty. Error is the difference between measurement result and the true value. With the presence of error, a measurement result could have deviated from its true value. Because error can't be solved with correction and eliminated due to human limitations or measuring instruments used in measuring system, a lot of mathematical theories are used to anticipate this limitation. Probability theory is used in measurement in order to handle the irremovable error [\[14\]](#).

Determination of error is also related to the standard deviation with probability. The measurement results can also be related to probability. Due to the presence of doubts from various factors in a measurement, these doubts can be addressed with the determined-distribution measurement probability. The combination of various distributions will result in a normal distribution described

in Central Limit Theorem. The standard deviation of this normal distribution will be used as a basis in determining the measurement of uncertainty [\[15\]](#).

By taking a lot of things and references in determining the value of uncertainty into account, the determination of uncertainty value of each function of orifice meter total energy measurement can be done empirically or even analytically.

After obtaining the uncertainty value of each component from orifice meter energy equation function, the calculation of combined uncertainty with estimated error from Taylor Series is performed. It results in combined uncertainty value of [\[13\]](#):

$$u_c^2 = \sum_{i=1}^n c_i^2 u_i^2 \quad (13)$$

Where u_c is combined uncertainty, c_i is sensitivity coefficient of enthalpy component and u_i is uncertainty of enthalpy component. Equation (13) explains square root of combined uncertainty. Combined uncertainty can therefore be viewed as a sum of the product of square sensitivity coefficient of enthalpy component and square uncertainty of enthalpy component [\[13\]](#).

The u_c symbol is obtained from the abbreviation of combined uncertainty. To get a range with a certain probability, the combined uncertainty is multiplied by a constant called the coverage factor. In general, the 95% confidence level is used for reporting measurement uncertainty.

If the normal distribution obtained from the coverage factor is given the k symbol, it will give $k=2$ [13].

$$U = k \cdot u_c \quad (14)$$

Equation (14) explains the expanded uncertainty (U), which is a product of combined uncertainty (u_c) and coverage factor (k) in order to obtain minimal probability from measurement result.

3. Calculation Methodology of Uncertainty

3.1. Materials

The natural gas used in this uncertainty calculation is a mixture of natural gas from various locations with up to 21 types of components. The largest content of this natural gas is methane gas (82.54% mole). This natural gas also contains a heavy fraction of propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}), and hexane (C_6H_{14}). Table 2 shows the results of laboratory analysis of the composition of the natural gas used in the calculation of the total uncertainty of energy in orifice meter [8].

Table 2. Laboratory Analysis of Natural Gas Composition

Component	Chemical Composition	Composition Analysis(% Mole Fraction)			
		Gas A	Gas B	Gas C	Gas D
Methane	CH ₄	82.54	91.44	89.66	88.12
Ethane	C ₂ H ₆	7.320	3.41	3.72	3.48
Propane	C ₃ H ₈	5.460	0.89	1.10	1.10
Iso-butane	C ₄ H ₁₀	0.800	0.29	0.33	0.32
n-butane	C ₄ H ₁₀	1.080	0.27	0.32	0.35
Iso-pentane	C ₅ H ₁₂	0.390	0.10	0.18	0.18
n-pentane	C ₅ H ₁₂	0.270	0.06	0.11	0.12
Pseudo hexane	C ₆ H ₁₄	0.470	0.05	0.14	0.20
Pseudo heptane	C ₇ H ₁₆	0.000	0.02	0.05	0.10
Carbon dioxide	CO ₂	1.64	3.34	4.28	5.92
Nitrogen	N ₂	0.03	0.13	0.11	0.11
Density (kg/m ³)	-	27.245	23.285	24.099	24.814
Compressibility (Z)	-	0.9114	0.938	0.9350	0.934
Heating Value (Btu/Scf)	-	1000	1041.8	1071.4	1062

3.2. Instrumentation

The instrumentation system used in this research is depicted by Figure 1. The system constitutes (1) Temperature -1 (2) Gas Analyzer (3) Pressure gauge-1 (4)

Flow Computer Non Adiabatic (5) Temperature Transmitter-2 (6) Differential Pressure (7) Pressure Transmitter-2 (8) Flow Computer Adiabatic and (9) Meter orifice installation [1].

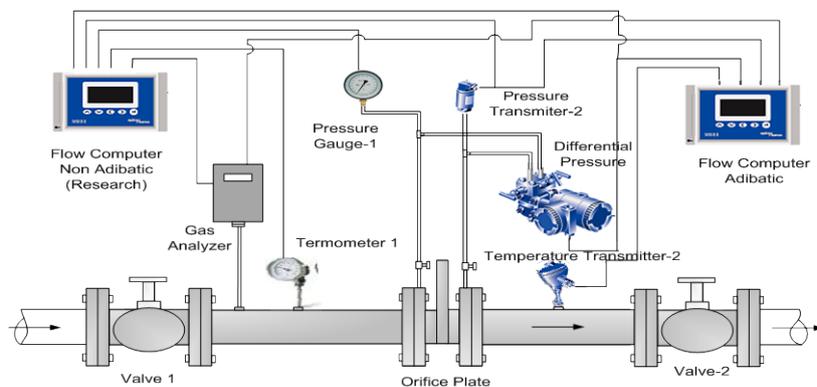


Figure 1. Instrumentation System Used In The Experiment

The data needed for calculation of uncertainty is operational conditions given by Table 3.

3.3. Procedure

The methodology used in this research follows the procedure from Joint Committee for Guide in Metrology: Guide the expression of uncertainty measurement procedure can be explained as described below:

- Retrieval of dimension data or orifice meter size in one of the calibration laboratories in charge of metrology activities.
- Data collection of operating conditions such as temperature, pressure, gas composition and other operating data in the orifice meter installation take place in one of the Oil and Gas Company.
- Perform sensitivity coefficients mathematical modeling of each component function from energy equation.
- Perform uncertainty calculations both analytical and empirical of each component function from energy balance equation based on the certificate, calibration results and orifice meter installation operating conditions.
- Perform combined and stretch uncertainty calculation which is the multiplication of the combined uncertainty with the coverage factor (k) and confidence level of 95%.
- Conduct an analysis of stretch uncertainty value compared with the technical requirements that have been issued by organizations in charge of traceability and standards.

Table 3. Orifice Meter Installation and Operating Condition Parameters

Parameter	Unit	Quantity
Orifice diameter (d)	mm	44.91
Pipe Diameter (ID)	mm	163.02
Beta ratio (β)	-	0.275488
Upstream pressure	Psig	0 ~ 435.49
Pressure Difference	in H2O	0 ~ 9.66
Reference Temperature	K	273.20
Upstream Temperature	K	298.80
Downstream Temperature	K	298.50
Environment temperature	K	298.2~313.2K
Sun intensity	micron	0.5 (max)
Fluid flow rate	Mmscfd	1.2158 (max)
(Hv) Gas Composition A	Btu/Scf	1000
(Hv) Gas Composition B	Btu/Scf	1041.8
(Hv) Gas Composition C	Btu/Scf	1071.4
(Hv) Gas Composition D	Btu/Scf	1062

4. Calculation Results and Discussion

4.1. Sensitivity Coefficient and Combined Enthalpy Uncertainty (u_c)

Referring data from Table 2 and Table 3 are used to calculate the sensitivity coefficient value and the uncertainty value of the function component from the energy equation

The sensitivity coefficient of enthalpy equation shown in equation (7) is a function of the ideal gas constant (R) and the constant of a natural gas component (A). Because of the enthalpy uncertainty is substantially influenced by temperature (T).Therefore, the value of enthalpy uncertainty is taken from the temperature uncertainty (u_T)that obtained froma calibration certificate with value of 0.0012. By using $R = 3.814 \text{ J/mol.K}$, the sensitivity coefficient and enthalpy uncertainty are shown below (Table 4).

Table4. Calculation of Ideal Enthalpy Uncertainty

Component	Formula (X)	Heat Capacity Constant				ΔT K	$c_{\Delta T}$ J/mole.K	$u_{\Delta T}$ K	$c_{\Delta T}^2 \cdot u_{\Delta T}^2$ J/mole
		XA	XB	XC	XD				
Methane	CH ₄	1.40	0.749	-1.78E-06	0	-0.3	11.67	0.0012	0.00019644
Ethane	C ₂ H ₆	0.08	0.001	-4.07E-07	0	-0.3	0.68	0.0012	6.82229E-07
Propane	C ₃ H ₈	0.06	0.001	-4.81E-07	0	-0.3	0.55	0.0012	4.36606E-07
Iso-butane	C ₄ H ₁₀	0.01	0.0003	-9.55E-08	0	-0.3	0.11	0.0012	1.79155E-08
n-butane	C ₄ H ₁₀	0.02	0.0003	-1.19E-07	0	-0.3	0.173	0.0012	4.34702E-08
Iso-pentane	C ₅ H ₁₂	0.01	0.0001	-5.50E-08	0	-0.3	0.079	0.0012	9.19164E-09
n-pentane	C ₅ H ₁₂	0.006	0.00012	-3.80E-08	0	-0.3	0.055	0.0012	4.40546E-09
Pseudo hexane	C ₆ H ₁₄	0.014	0.00025	-7.89E-08	0	-0.3	0.11	0.0012	2.012E-08
Pseudo heptane	C ₇ H ₁₆	0	0	0	0	-0.3	0	0.0012	0
Carbon Dioxide	CO ₂	0.089	1.71E-05	0	-1897.48	-0.3	0.74	0.0012	7.9722E-07
Nitrogen	N ₂	0.0009	1.77E-07	0	1.2	-0.3	0.007	0.0012	9.17329E-11

Calculation result of combined uncertainty of enthalpy

0.0001984 Joule/mol

By using the same method, the sensitivity coefficient and combined uncertainty is shown in Table 5. From Table 5, it can be deduced that the total combined uncertainty of enthalpy is influenced by the factors:

uncertainty of ideal enthalpy; uncertainty of real pressure; uncertainty of generalized correlation coefficient; uncertainty of critical temperature; and uncertainty of real temperature.

Table 5. Calculation of Total Uncertainty of Enthalpy (H) in Orifice Meter

Empirical and Analytical Equation		Combined Uncertainty(u_c)				Information
Sensitivity Coefficient	Uncertainty	Chemical Composition Gas A	Chemical Composition Gas B	Chemical Composition Gas C	Chemical Composition Gas D	
$c_{\Delta H_1}$	$u_{\Delta T}$	1.984E-4	2.445E-4	2.374E-4	2.344E-4	Certificate
c_{Pr}	u_{pr}	7.793E-11	1.973 E-11	3.017E-11	4.975E-11	Certificate
c_{B^o}	u_{B^o}	2.462E-10	2.927E-10	2.820E-10	2.820E-10	Calculation
c_{ω}	u_{ω}	6.152E-10	7.355E-10	7.078E-10	7.078E-10	Calculation
c_{T_C}	u_{T_C}	1.026-11	1.152E-11	1.113E-11	1.113E-11	Certificate
c_{Tr}	u_{Tr}	2.100E-08	2.488E-08	2.394E-08	2.394E-08	Certificate
u_c		0.0001984	0.0002445	0.0002374	0.000234	Calculation
U		0.0003968	0.000489	0.0004748	0.000469	Calculation

From the tabel, we can see that the natural gas of B has the largest uncertainty (0.000489Joule/mole (8.59 x 10⁻⁷ Mmbtud)) and the natural gas of A has the smallest uncertainty (0.000396 Joule/mole (6.95 x 10⁻⁷ Mmbtud)).Relation between the density and compressibility is explained on Figure 1. According to

Figure 1(a), the natural gas of B has the smallest density of 23.285 kg/m³and the largest compressibility factor of 0.938.The natural gas composition of A has the largest density of 27.245 kg/m³ and the smallest compressibility factor of 0.9114. The Natural gas Bhasproperties close to the ideal gas.

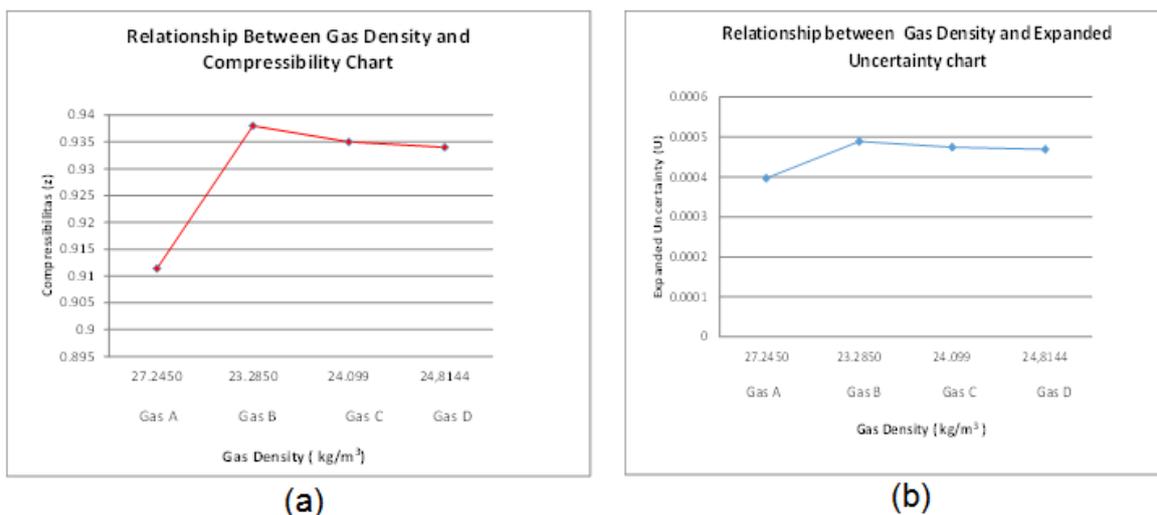


Figure 2. (a) Density Relation to Compressibility. (b) Compressibility Relation and Expanded Uncertainty

Furthermore, according to Figure 2 (b), the natural gas with large density (Gas A) within a transportation process going across a piping system, when experiencing a pressure drop. Gas components with larger density (propane, butane, and gases with heavier molecular weight) will be condensed into a liquid whereas gases with lighter phase such as methane and ethane will pass through orifice meter. From Table 2, it can be explained that light phase gases passing the orifice meter. The natural gas composition of A has light phase of 89.96% and natural gas with B composition has a light phase of 94.85%. Both of the gases can be seen that if the amount of light phase gases passing the orifice meter is larger, its uncertainty value is also larger.

4.2. Accuracy and Precision

The calculation results for all kind of gas compositions show that the largest value of expanded uncertainty is the natural gas with B composition (8.59×10^{-7} Mmbtud ($\pm 8.59 \times 10^{-8}\%$)). This value is smaller than the calculation result from previous research that resulted of expanded uncertainty of enthalpy value based on adiabatic condition is $\pm 0.25\%$. (Paul J. La Nasa et al, 2002). This calculation result shows that the calculation of enthalpy uncertainty in a non-adiabatic condition give better precision and accuracy.

According to the organization of legal metrology, the uncertainty value should be smaller than one-third ($1/3$) of the Maximum Permissible Error (MPE). If the magnitude of Maximum Permissible Error is $\pm 0.50\%$, the magnitude of uncertainty shouldn't be more than 0.1667% . The total uncertainty of enthalpy in a non-adiabatic condition is 8.59×10^{-7} Mmbtud ($\pm 8.59 \times 10^{-8}\%$), which means this value is still smaller than required (0.1667%). This also means that the energy measurement result in a non-adiabatic condition method is acceptable and can be proposed as a new method of calculating the total natural gas energy using orifice meter.

5. Conclusion

The calculation of total uncertainty of enthalpy in a non-adiabatic condition has been developed from the

calculation method of natural gas flow rate uncertainty with orifice meter based on AGA 3, 1992 [1] and Heating value (Hv) uncertainty calculation method. Total expanded uncertainty of enthalpy in this a non-adiabatic condition is calculated with 95% confidence level and coverage factor of 2 ($k=2$). This total expanded uncertainty of enthalpy is a sum of total combined uncertainty of ideal enthalpy and real enthalpy.

The calculation result of the highest total combined uncertainty of enthalpy (for B natural gas composition) is 3.86×10^{-7} Mmbtud ($3.86 \times 10^{-8}\%$) and the calculation result of expanded uncertainty is 7.73×10^{-7} Mmbtud ($7.73 \times 10^{-8}\%$). The value of this expanded uncertainty is smaller than required (0.1667%) which means the method of energy measurement result in a non-adiabatic condition is acceptable and can be proposed as a new method of calculating the natural gas total energy using orifice meter.

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