



FUEL GAS ENERGY METERING

Transmission Measurement Committee Report No. 5



OPERATING SECTION
AMERICAN GAS ASSOCIATION
1515 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22209

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ARLINGTON, VA



FUEL GAS ENERGY METERING
TRANSMISSION MEASUREMENT COMMITTEE REPORT NO. 5
(Revised)

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Transmission Measurement Committee
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PREFACE

Technical publications of the American Gas Association's Measurement Committee generally stem from work accomplished within the framework of one of its standing task groups. The work may be a joint effort of the membership of the sponsoring task group, or it may be accomplished more or less single handedly by one of the members. Accomplishments arising from such efforts are reviewed by the Measurement Committee Steering Group. Where work is thought to materially improve the scope, accuracy and/or efficiency of gas measurement practices, the information is reduced to practical report form.

With the cooperation of A.G.A. Headquarters' staff such reports of the Measurement Committee are printed and publicized as a matter of information, but not as standards or recommendations. Reports of this nature are always subject to subsequent revision with the progression of time and additional research or indication of inadequacy. This is true since the A.G.A. Measurement Committee is a standing body, continuously working to increase skills and knowledge in its specific area of investigation. Thus note must be taken of the title of each report and its date of issue.

This Report on Fuel Gas Energy Metering is a project undertaken by Mr. Bruce J. Caldwell, Chairman of the Gas Quality Measurement task group of the A.G.A. Measurement Committee. The period of individual investigation leading to this publication ranged over some twenty years, all in quest of simpler means to reduce gas volumes and their mass to thermal energy equivalents.

The Measurement Committee is deeply indebted to Mr. Caldwell for the great amount of time and effort represented by this report. It is a particularly timely attempt, considering present sentiment leaning in the direction of a thermal energy unit of gas measurement. Wherever the energy content of fuel gases is a consideration this report may be expected to facilitate metering techniques, quite economically.


 Pat H. Miller, Chairman, 1967-68
 A.G.A. Measurement Committee

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INTRODUCTION

The scope of this report provides for the conversion of units of gas volume, or its mass, to energy equivalents through the use of that data associated with volume metering practices, without the necessity for analytical fractionation of hydrocarbon compounds of a mixed gas, or employment of a calorimeter.

Presented equations, tables and data are not intended to conflict with current volume metering practices. The purpose of this report is to add to the utility of meter types commonly employed by the gas industry, namely:

- (1) Orifice meters with circular orifices placed concentrically in a pipeline section, having pressure taps generally known as "flange taps" or "pipe taps".
- (2) Volume displacement meters of the rotary, diaphragm and other related types that are designed to index gas volume throughput at prevailing conditions of gas pressure and temperature.
- (3) Meters designed to measure gas weight throughput, the same being generally known as mass meters.

This report does not cover specifications relating to the selection, installation or operation of any given meter type, or tolerances of accuracy relative thereto. For information of that nature, users are referred to other publications of the A.G.A. Measurement Committee, as well as to the American Society of Mechanical Engineers, International Standards Association, other trade associations, and equipment manufacturers.

Terms and nomenclature common both to this report and Gas Measurement Committee Report No. 3 of American Gas Association are agreeable in meaning. When orifice meters are employed for energy metering, this report may be used to supplement the information in Report No. 3. Certain tables and factors peculiar to volume measurements found in Report No. 3 are omitted from this report. Those omitted have been replaced by substitute factors to facilitate energy computations. Table for physical constants (properties) for gas compounds has been omitted as these are revised from time to time by the Gas Processors Association (GPA), in Tulsa, Oklahoma. For the latest figures on these constants, please contact GPA.



SECTION I

—
ORIFICE METERING APPROACH
TO
GAS ENERGY MEASUREMENT
—

For the purposes of this section, an orifice meter is defined as an inferential device, consisting of a flat orifice disc placed concentrically in a pipe section, installed and operated to agree with current recommendation of the American Gas Association.

SECTION I-1

VOLUME AND MASS

The orifice meter is basically both a volume meter and a mass meter, and is so recognized in American Gas Association orifice metering reports, although these publications have placed most emphasis upon its use for volume metering. Calling upon the nomenclature of A.G.A. Gas Measurement Committee Report No. 3, we find:

- (1) Volume flow/hr. $Q_h = C' (h_w P_f)^{.5}$
(2) Mass flow/hr. $W_h = C'' (h_w \gamma)^{.5}$

Greatest difference to be noted between the two basic orifice equations lies with a measure of absolute static pressure (P_f) for volume measurements and gas specific weight (γ) for mass measurements. Specific weight requirements in the second equation presuppose use of a densitometer to compute mass flow. Yet, in the absence of a densitometer, volume flow (Q) is readily converted to weight flow units, following equation 3.

$$(3) \quad U_m = Q \times G \times (0.076173 + 0.000772G - 0.000535 Xi)$$

where,

U_m = Units of mass, pounds, totalized or rate flow per unit of time.

Q = Volume, cubic feet at 14.73 psi, 60°F, totalized or rate flow per unit of time.

G = Gas specific gravity, related to the molecular weight of air (28.9644)

Xi = Volume fraction of contained inert gas compounds.

SECTION I-2
EQUATION DERIVATION AND CALCULATION PROCEDURES
ORIFICE METERED VOLUME AND ENERGY

Where there is need to compute and tabulate both volume and energy, A.G.A. Gas Measurement Committee Report No. 3 is recommended for Volume Computation Purposes. As a second step to convert volume to its energy equivalent, Section II of this manual should be consulted. Here are found factors to express gas energy per unit of volume. These energy conversion factors only apply, however, to volume units under a pressure of 14.73 psi and 60°F. If orifice metered volumes are first expressed at bases other than 14.73 psi and 60°F a secondary volume conversion is required (to 14.73 psi, 60°F) to compare with energy tables of Section II.

$$(4) \quad U_v = Q \times (P_b/14.73) \times (520/T_b)$$

U_v = Unit of volume, cubic feet at 14.73 psi, 60°F.

Q = Cubic feet of gas at any other base conditions.

P_b = Any other pressure base, psia.

T_b = Any other temperature base, °Rankine

It will be noted that factors of Section II are dovetailed to displacement metering. As such, several of these factors are not required for orifice metered volume to energy conversions. Equation 5 reflects those certain factors required.

$$(5) \quad U_e = U_v \times E_v \times F_{ue}$$

where,

U_e = Desired units of gas energy, totalized or rate per unit of time.

E_v = Energy per unit volume, Gross Btu per cubic foot at 14.73 psi, 60°F.

F_{ue} = Energy conversion factor, Btu to other energy units.
(Table II-B).

The number of steps required to develop factor E_v depends upon the composition of a gas. If a gas consists singly of mixed hydrocarbon compounds, knowledge of specific gravity alone is required to predict its thermal energy (Btu) per unit of volume (cubic foot).

SECTION I-2

(Cont'd)

$$(6) \quad E_v = V_g \quad (\text{See Table II-E})$$

where,

$$V_g = (1571.5 \times \text{specific gravity}) + 144$$

Where a gas mixture contains other than hydrocarbon compounds, factor E_v must be adjusted to account for their presence.

$$(7) \quad E_v = V_g - \sum V_{\text{adj} \dots n} \quad (\text{Tables II-E thru II-M})$$

While the extent of this work is broad enough to cover all fuel gases, both natural and manufactured, supplementary data, in addition to specific gravity, may likely be limited to nitrogen and carbon dioxide in determining values of E_v for natural gases. This is not to state, however, other energy diluents are not sometimes encountered. Provided tables reflect their accountability.

SECTION I-3

EQUATION DERIVATION AND CALCULATION PROCEDURE

ORIFICE METERED VOLUME, MASS AND ENERGY

Where an orifice meter is used to simultaneously meter volume, mass and energy, or mass and energy to exclusion of volume, Section III of this manual should be used to supplement A.G.A. recommendations pertinent to volume measurements.

In the instance of Volume-Mass-Energy determinations by orifice meter, Equation 1 (from A.G.A. Report No. 3) should be used to compute gas volumes. The weight of the volume is found by added reference to Equation 3; thermal energy following by further reference to Section III of this publication.

In the instance of Mass-Energy determinations by orifice meter, many calculation conveniences are to be realized through first employment of Equation 2 to compute gas weight. This recommendation, however, is predicated upon the availability of a densitometer to sense specific weight (γ) of a gas. In the absence of density sensing equipment, Equation 3 may be used to compute gas weight, followed by reference to Section III of this work.

Section III outlines the conversion of the weight of gas to equivalent units of energy. The tables and data of the section are applicable both to the readout of true mass meters or mass computed from orifice metering data. Here are found tables and formulae to facilitate conversion of mass to energy.

$$(8) \quad U_e = U_m \times E_m \times F_{ue}$$

U_e = Desired units of energy, totalized or rate flow per unit of time.

U_m = Units of mass, pounds avoirdupois.

E_m = Energy-mass ratio, dekaTherm per pound mass.

F_{ue} = Energy conversion factor, dekaTherm to desired Thermal energy units.

The development of factor E_m is approached with knowledge of gas specific gravity and contained non-hydrocarbon compounds. In absence of hydrocarbon diluents, specific gravity alone suffices to predict factor E_m .

SECTION I-3
(Cont'd)

(9) $E_m = M_g$ (See Table III-C)

where,

$$M_g = 0.020350 + (0.001970/G)$$

In the presence of significant concentrations of non-hydrocarbon compounds, factor E_m must be adjusted to recognize energy dilution or enrichment; ordinarily dilution.

(10) $E_m = M_g - \sum \text{Adj.} \dots_n$ (Tables III-D thru III-K)

Energy adjustments to account for non-combustibles in solution, are usually limited to carbon dioxide and nitrogen in the instance of natural gases. Yet other diluents may be encountered in significant concentration to become accountable. Tables III-E through III-K reflect various concentrations and their energy dilution (or enrichment) equivalents.

SECTION I-4
EQUATION DERIVATION AND CALCULATION PROCEDURE
ORIFICE METERED ENERGY - 'DATE METHOD'

Although knowledge of gas mass may not be needed, it remains that the most convenient and direct approach to energy measurements by orifice meter follows the employment of a specific weight sensing densitometer and use of Equation 2, followed by reference to Section III of this work. However, where Equation 2 cannot be used in the absence of a densitometer, and there are no added requirements for computing either volume or mass, it is not necessary to call upon either Equations 1 or 3. The conventional (volume) orifice meter equation can be modified to directly produce units of energy, without prior determination of volume or its mass. For want of better terminology, this calculation procedure may be qualified as a Direct Approach To Energy by orifice meter.

The direct approach to energy by orifice meter, hereinafter conveniently termed 'DATE METHOD', involves no greater number of calculation factors than are found in the conventional (volume) calculation equation presented in A.G.A Gas Measurement Committee Report No. 3. However, three of the Report No. 3 factors are not required for energy calculations; namely F_{pb} , F_{tb} and F_g .

Basic orifice factors (F_p) of Report No. 3 are qualified with a pressure base of 14.73 psi and a temperature base of 60°F. Conversion of volume to energy commences from this premise, without need for factors F_{pb} and F_{tb} . Factor F_g having dimensions of $(1/G)^{.5}$, is coupled with G of Equation 3, to become $(G)^{.5}$.

$$(11) \quad \dots\dots\dots G \times (1/G)^{.5} = G^{.5}$$

By rewriting Equation 3 to reflect Equation 11, Equation 12 is obtained.

$$(12) \quad \dots\dots\text{Lbs. of gas} = (Q/F_g) \left[.076173G^{.5} + .000772G^{1.5} - Xi(.000535G^{.5}) \right]$$

where,

Q = Cubic feet at F_p conditions of 14.73 psi, 60°F.

Xi = Volume fraction inert compounds.

SECTION I-4
(Cont'd)

With reference to Section III of this work, DekaTherm per pound of hydrocarbon gas carries dimensions represented by Equation 9. By merging the conventional (volume) orifice meter equation (A.G.A. Report No. 3) with Equations 9 and 12, an energy equation (13) for mixed hydrocarbon gases, providing dekaTherm readout, may be written for the orifice meter.

$$(13) \quad \dots dT/\text{Hour} = \left[(.001 F_b) F_r Y F_{gr} F_{pv} F_m (h_{wp})^{.5} \right] \left[1.551642 G^{.5} + 0.015710 G^{1.5} + \left(\frac{.150061}{G^{.5}} \right) \right]$$

The summation found by the second bracketed part of Equation 13 is designated Factor G_{em} . Obviously, the factor is associated with specific gravity, to account for both the energy of a gas and the effect of specific gravity on meter manometers with flow across an orifice. Manual users should think of Factor G_{em} (Table I-A) as a substitute for Factor F_g , when energy resolutions are desired of an orifice meter equation is lieu of volume.

$$(14) \quad \dots G_{em} = \left[1.551642 G^{.5} + 0.015710 G^{1.5} + \left(\frac{.150061}{G^{.5}} \right) \right]$$

To this point gases have been treated as pure hydrocarbon mixtures, without attempts to account for any likely contained non-hydrocarbon and their effect on thermal energy determinations. Section III (Mass Metering) carries both formulae and tables (III-D through III-K) necessary to adjust for non-hydrocarbon compounds. Once the adjustment factor is found, it should hold for subsequent calculations except where gases are comingled in varying proportions. Experience reflects tolerable inert compound percentage consistency where gas is metered at a wellhead or from a common production reservoir.

$$(15) \quad \dots F_a = \left[1 - 0.007X \right] \left[1 - \left(\frac{M_{cd} + M_n + M_o + M_{he} + M_{cn} + M_{hs} + M_w - M_{by}}{M_g} \right) \right]$$

where,

F_a = Adjustment factor for non-hydrocarbon constituents.

X = Volume fraction inert compounds.

SECTION I-4
(Cont'd)

In Equation 15, $(1-0.007X)$ serves to adjust Equation 3, by accounting for the contribution of inert compounds to Boyle's Law deviation and, in turn, its contribution to gas weight per cubic foot. The remaining portion of Equation 3 represents adjustment for energy dilution due to the presence of non-hydrocarbons in solution, with hydrogen (M_{hy}) excepted. Hydrogen tends to enrich Mass-Energy ratios. Terms 'inert compounds' (non-combustibles) and 'non-hydrocarbon compounds' are not necessarily synonymous. Hydrogen, carbon monoxide and hydrogen sulfide are non-hydrocarbons, yet they are combustibles.

Equations 16 and 17 outline the basic orifice meter 'DATE' calculation procedure.

$$(16) \quad \dots\dots U_e = O_e (h_w p_f)^{.5}$$

where,

U_e = Desired units of energy, totalized or rate flow per unit of time.

O_e = Orifice energy flow constant

$$(17) \quad \dots\dots O_e = \left[(.001 F_b) \times F_r \times Y \times F_{tf} \times F_{pv} \times F_m \right] \left[G_{em} \times F_a \times F_{ue} \right]$$

where,

F_{ue} = Units of energy conversion factor, dekaTherm to other energy units. (Table III-B)

Equation 17 has been bracketed to segregate those factors having A.G.A. Committee Report No. 3 reference from the newer nomenclature carrying energy connotations. It will be noted Factor $(.001 F_b)$ represents a three place decimal offset to produce MCF in lieu of cubic feet. Otherwise, that first bracketed portion of equation 17 is equal to C' (Report No. 3) save for deletion of three factors; namely, F_{tb} , F_{pb} and F_g . In substitution are found Factors G_{em} , F_a and F_{ue} .

TABLE 1-A
VALUES of GEM

ORIFICE METERING SPECIFIC GRAVITY VALUES
(DATE' CALCULATION PROCEDURE)

SPECIFIC GRAVITY	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.550	1.359479	1.360358	1.361237	1.362116	1.362994	1.363871	1.364749	1.365626	1.366502	1.367378
.560	1.368254	1.369129	1.370003	1.370878	1.371751	1.372625	1.373498	1.374370	1.375242	1.376114
.570	1.376985	1.377856	1.378727	1.379597	1.380466	1.381335	1.382204	1.383072	1.383940	1.384807
.580	1.385674	1.386541	1.387407	1.388273	1.389138	1.390003	1.390868	1.391732	1.392595	1.393458
.590	1.394321	1.395184	1.396045	1.396907	1.397768	1.398629	1.399489	1.400349	1.401208	1.402067
.600	1.402926	1.403784	1.404642	1.405499	1.406356	1.407213	1.408069	1.408925	1.409780	1.410635
.610	1.411489	1.412343	1.413197	1.414050	1.414903	1.415755	1.416607	1.417459	1.418310	1.419161
.620	1.420011	1.420861	1.421711	1.422560	1.423409	1.424257	1.425105	1.425952	1.426799	1.427646
.630	1.428492	1.429338	1.430184	1.431029	1.431874	1.432718	1.433562	1.434405	1.435248	1.436091
.640	1.436933	1.437775	1.438617	1.439458	1.440299	1.441139	1.441979	1.442818	1.443657	1.444496
.650	1.445334	1.446172	1.447010	1.447847	1.448684	1.449520	1.450356	1.451191	1.452027	1.452861
.660	1.453696	1.454530	1.455363	1.456197	1.457029	1.457862	1.458694	1.459525	1.460357	1.461188
.670	1.462018	1.462848	1.463678	1.464507	1.465336	1.466165	1.466993	1.467821	1.468648	1.469475
.680	1.470302	1.471128	1.471954	1.472779	1.473604	1.474429	1.475254	1.476078	1.476901	1.477724
.690	1.478547	1.479370	1.480192	1.481013	1.481835	1.482656	1.483476	1.484296	1.485116	1.485936
.700	1.486755	1.487573	1.488392	1.489210	1.490027	1.490845	1.491661	1.492478	1.493294	1.494110
.710	1.494925	1.495740	1.496555	1.497369	1.498183	1.498996	1.499809	1.500622	1.501435	1.502247
.720	1.503058	1.503870	1.504681	1.505491	1.506301	1.507111	1.507921	1.508730	1.509539	1.510347
.730	1.511155	1.511963	1.512770	1.513577	1.514384	1.515190	1.515996	1.516801	1.517607	1.518411
.740	1.519216	1.520020	1.520824	1.521627	1.522430	1.523233	1.524035	1.524837	1.525639	1.526440
.750	1.527241	1.528041	1.528842	1.529641	1.530441	1.531240	1.532039	1.532837	1.533635	1.534433
.760	1.535231	1.536028	1.536824	1.537621	1.538417	1.539212	1.540008	1.540803	1.541597	1.542392
.770	1.543186	1.543979	1.544772	1.545565	1.546358	1.547150	1.547942	1.548733	1.549525	1.550315
.780	1.551106	1.551896	1.552686	1.553475	1.554265	1.555053	1.555842	1.556630	1.557418	1.558205
.790	1.558992	1.559779	1.560566	1.561352	1.562138	1.562923	1.563708	1.564493	1.565277	1.566061
.800	1.566845	1.567629	1.568412	1.569195	1.569977	1.570759	1.571541	1.572322	1.573104	1.573884
.810	1.574655	1.575445	1.576225	1.577004	1.577783	1.578562	1.579341	1.580119	1.580897	1.581674
.820	1.582452	1.583228	1.584005	1.584781	1.585557	1.586333	1.587108	1.587883	1.588658	1.589432
.830	1.590202	1.590980	1.591753	1.592526	1.593299	1.594071	1.594843	1.595615	1.596386	1.597157
.840	1.597928	1.598699	1.599469	1.600239	1.601008	1.601777	1.602546	1.603315	1.604083	1.604851
.850	1.605619	1.606386	1.607153	1.607920	1.608686	1.609452	1.610218	1.610983	1.611748	1.612513
.860	1.613278	1.614042	1.614806	1.615569	1.616333	1.617096	1.617858	1.618621	1.619383	1.620145
.870	1.620906	1.621667	1.622428	1.623188	1.623949	1.624709	1.625468	1.626227	1.626986	1.627745
.880	1.628504	1.629262	1.630019	1.630777	1.631534	1.632291	1.633048	1.633804	1.634560	1.635316
.890	1.636071	1.636826	1.637581	1.638335	1.639090	1.639843	1.640597	1.641350	1.642103	1.642856
.900	1.643608	1.644361	1.645112	1.645864	1.646615	1.647366	1.648117	1.648867	1.649617	1.650367
.910	1.651116	1.651866	1.652614	1.653363	1.654111	1.654859	1.655607	1.656355	1.657102	1.657849
.920	1.658595	1.659341	1.660087	1.660833	1.661579	1.662324	1.663069	1.663813	1.664557	1.665301
.930	1.666045	1.666788	1.667532	1.668274	1.669017	1.669759	1.670501	1.671243	1.671984	1.672726
.940	1.673466	1.674207	1.674947	1.675687	1.676427	1.677166	1.677906	1.678644	1.679383	1.680121
.950	1.680859	1.681597	1.682335	1.683072	1.683809	1.684546	1.685282	1.686018	1.686754	1.687489
.960	1.688225	1.688960	1.689694	1.690429	1.691163	1.691897	1.692631	1.693364	1.694097	1.694830
.970	1.695562	1.696295	1.697027	1.697758	1.698490	1.699221	1.699952	1.700683	1.701413	1.702143
.980	1.702873	1.703602	1.704332	1.705061	1.705789	1.706518	1.707246	1.707974	1.708702	1.709429
.990	1.710156	1.710883	1.711610	1.712336	1.713062	1.713788	1.714513	1.715239	1.715964	1.716689
1.000	1.717413									

$$GEM = 1.551642 G^{.5} + 0.015710 G^{1.5} + \frac{(0.150061)}{(G^{.5})}$$