Temperature Compensated (Net) Volume Directly from Mass Flow Meters

April 2011

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Objective and Background

- Proposed Objectives from industry:
  - Meet measurement needs for net volume
    - Net volume at 60 °F from mass meter
    - Net volume at 60 °F from truck scale weighing
  - Weights and Measures recognition
  - Environmental Protection Agency (EPA) recognition
- Submitted by representatives from Renewable Fuels Association (RFA)
  - Proposal received by NIST February 2011

Introduction

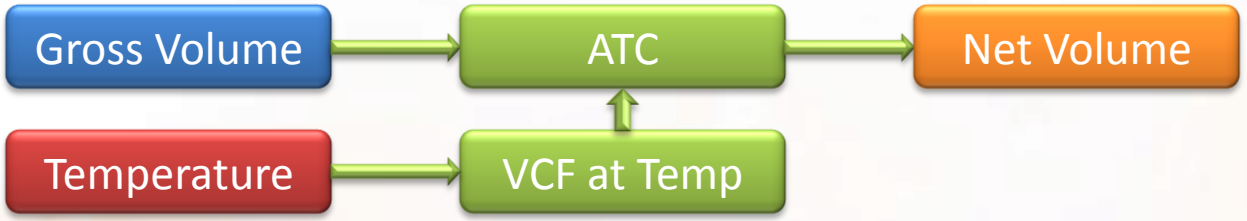
- Automatic Temperature Compensated (ATC) Volume, or "Net Volume", units are covered in NIST Handbook 44 (HB44):
  - Liquid-Measuring Devices (LMD) Code [3.30.]
  - Vehicle-Tank Meter (VTM) Code [3.31.]
  - LPG and Anhydrous Ammonia (LPG) Code [3.32.]

- NTEP certifies mass flow meters for both:
  - Mass units
  - Gross Volume units (separate evaluation)

- Mass Flow Meter Code [3.37.] does not address Net Volume Units
  - Mass flow meter must use gross volume and ATC to meet LMD, VTM, and LPG requirements for net volume
  - Proposed solution: Addition of Net Volume Units to Mass Meter Code

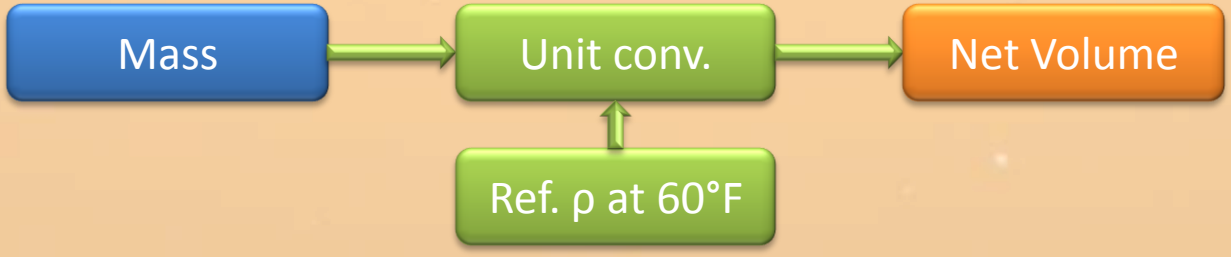
Two Ways to Measure Net Volume

- **Starting from Gross Volume:** $V_{60°F} = V_T \times VCF(T)$



  - Applies a Volume Correction Factor (VCF) to gross volume
  - Requires a temperature measurement

- **Starting from Mass:** $V_{60°F} = \frac{M_T}{\rho_{60°F}} = \frac{M_{60°F}}{\rho_{60°F}}$
  - Mass does not change with temperature $M_T = V_T \times \rho_T = M_{60°F} = V_{60°F} \times \rho_{60°F}$



  - Applies the Reference Density ($\rho_{60°F}$) to mass
  - No temperature measurement required

VCF and Reference Density ($\rho_{60°F}$)

- VCF is a function
  - Fluid
  - Temperature
- $\rho_{60°F}$ is a constant
  - One per fluid

$$VCF(T) = \frac{V_{60°F}}{V_T} = \frac{\rho_T}{\rho_{60°F}}$$

Source of VCF: API MPMS Chapter 11 May 2004

(VCF≡C_{TL} from Section 11.1.3.2)

ρ_T = density at temperature T

$\rho_{60°F}$ = density at 60°F (Constant)

VCF and $\rho_{60°F}$ are related

Both are properties of the fluid

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Some LMD, VTM, LPG Requirements <u>Not</u> Necessary with $\rho_{60°F}$ Method

- Temperature measurement at meter
- Additional (uncompensated) test drafts
- Additional calculations and entries
- Less accurate gross volume from a mass meter

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Categories of Mass Flow Meters

- **Direct Mass (e.g. Coriolis, Thermal)**
  - Most are unaffected by changes in density
- **Mass with Automatic Density Correction**
  - Density based correction (e.g., Turbine or Positive Displacement Meters with Densitometer)
  - Pressure/Temperature correction (e.g., Differential Pressure with P+T Compensation)

Methods for Determining Net Volume

From Gross Volume and Temperature (LPG example)

- Calculation: $V_{60°F} = V_T \times VCF(T)$
  - $V_{60°F}$ = Volume corrected to 60°F (Net Volume)
  - V_T = Gross volume at temperature T
  - VCF_T = Volume Correction Factor at temperature T
  - Source of VCF: API MPMS Table 24C
    - ρ_T = density at temperature T
    - $\rho_{60°F}$ = density at 60°F (Constant)

$$VCF_T = \frac{V_{60°F}}{V_T} = \frac{\rho_T}{\rho_{60°F}}$$

- Sources of Uncertainty Using Direct Gross Volume

Device (ATC Meter Reading)

- Volume measurement
  - Impacted by Volume Calibration
  - Checked by uncompensated drafts

ATC
- Device temperature measurement
- Applied VCF
- Fluid composition variation effects on VCF

Reference (Prover)

- Prover volume reading
- Prover temperature measurement
- VCF for Prover volume reading (compensated drafts)
- Fluid composition variation effects on VCF
- Correction factors for temperature effects on Prover expansion/contraction
- Prover pressure reading
- Correction factors for pressure effects on Prover expansion/contraction
- Traceable temperature measurement at device (Thermo well)
- Correction for change in temperature from device to Prover (uncompensated drafts)

Methods for Determining Net Volume

From Gross Volume and Temperature (LPG example)

- Calculation: $V_{60°F} = V_T \times VCF(T)$
  - $V_{60°F}$ = Volume corrected to 60°F (Net Volume)
  - V_T = Gross volume at temperature T
  - VCF_T = Volume Correction Factor at temperature T
  - Source of VCF: API MPMS Table 24C
    - ρ_T = density at temperature T
    - $\rho_{60°F}$ = density at 60°F (Constant)

$$VCF_T = \frac{V_{60°F}}{V_T} = \frac{\rho_T}{\rho_{60°F}}$$

- Sources of Uncertainty Using Mass Meter Volume

Device (ATC Meter Reading)

- Volume measurement
  - Impacted by Mass AND Density calibration
  - Checked by uncompensated drafts

ATC
- Device temperature measurement
- Applied VCF
- Fluid composition variation effects on VCF

Reference (Prover)

- Prover volume reading
- Prover temperature measurement
- VCF for Prover volume reading (compensated drafts)
- Fluid composition variation effects on VCF
- Correction factors for temperature effects on Prover expansion/contraction
- Prover pressure reading
- Correction factors for pressure effects on Prover expansion/contraction
- Traceable temperature measurement at device (Thermo well)
- Correction for change in temperature from device to Prover (uncompensated drafts)

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Methods for Determining Net Volume

From Direct Mass and Ref. Density (LPG example)

- **Calculation:** $V_{60°F} = \frac{M_T}{\rho_{60°F}} = \frac{M_{60°F}}{\rho_{60°F}}$
  - $V_{60°F}$ = Volume corrected to 60°F (Net Volume)
  - M_T = Mass at temperature T = Mass at 60°F
  - $\rho_{60°F}$ = density at 60°F (Constant)

$$M_T = V_T \times \rho_T = M_{60°F} = V_{60°F} \times \rho_{60°F}$$

- **Sources of Uncertainty Using Direct Mass Meter**

Device

- Mass measurement
  - Impacted only by Mass Calibration
  - Checked by compensated drafts
- Applied $\rho_{60°F}$
- Fluid composition variation effects on $\rho_{60°F}$

No Temp Measurement at Device
No VCF for Device

Reference (Prover)

- Prover volume reading
- Prover temperature measurement
- VCF for Prover volume reading (compensated drafts)
- Fluid composition variation effects on VCF
- Correction factors for temperature effects on Prover expansion/contraction
- Prover pressure reading
- Correction factors for pressure effects on Prover expansion/contraction
- ~~Traceable temperature measurement at device (Thermo well)~~
- ~~Correction for change in temperature from device to Prover (uncompensated drafts)~~

No Uncompensated Volume Drafts

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Methods for Determining Net Volume

From Direct Mass and Ref. Density (LPG example)

- **Calculation:** $V_{60°F} = \frac{M_T}{\rho_{60°F}} = \frac{M_{60°F}}{\rho_{60°F}}$
  - $V_{60°F}$ = Volume corrected to 60°F (Net Volume)
  - M_T = Mass at temperature T = Mass at 60°F
  - $\rho_{60°F}$ = density at 60°F (Constant)

$$M_T = V_T \times \rho_T = M_{60°F} = V_{60°F} \times \rho_{60°F}$$

- **Sources of Uncertainty Using Mass Meter with Automatic Density Correction**

Device

- Mass measurement
  - Impacted by Volume Calibration AND Auto Density Correction
  - Checked by compensated drafts
- Applied $\rho_{60°F}$
- Fluid composition variation effects on $\rho_{60°F}$

No Temp Measurement at Device
No VCF for Device

Reference (Prover)

- Prover volume reading
- Prover temperature measurement
- VCF for Prover volume reading (compensated drafts)
- Fluid composition variation effects on VCF
- Correction factors for temperature effects on Prover expansion/contraction
- Prover pressure reading
- Correction factors for pressure effects on Prover expansion/contraction
- ~~Traceable temperature measurement at device (Thermo well)~~
- ~~Correction for change in temperature from device to Prover (uncompensated drafts)~~

No Uncompensated Volume Drafts

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HB44 Code Requirements

- Mass Flow Meter Code (3.37.) does not address temperature compensated volume
  - Must use LMD (3.30.), VTM(3.31.), or LPG/NH_3 (3.32.)

- Several requirements prevent use of the $\rho_{60°F}$ method

Requirements Preventing $\rho_{60\,°F}$

- Devices with ATC must provide means during testing for temperature measurement with a traceable thermometer
  - 3.30. LMD wholesale: (S.2.6. and S.2.7.4.)
  - 3.31. VTM: (S.2.5.5.)
  - 3.32. LPG and NH_3: (S.2.5.)
- Testing of devices that use ATC require both compensated and uncompensated drafts (some devices can display simultaneously)
  - 3.30. LMD wholesale: (N.4.1.1. and T.4.)
  - 3.31. VTM: (N.4.1.3. and T.2.1.)
  - 3.32. LPG and NH_3: (N.4.1.1. and T.4.)
- Wholesale LMD with ATC must include both gross volume and temperature on invoices
  - 3.30. LMD wholesale: (UR.3.6.1.2.(b))

Conclusions

- Mass flow meters can measure Volume at 60 °F ($V_{60\,°F}$)two different ways
  - ATC using VCF(T) correction tables
    - Best method for gross volume meters
    - VCF's derived from temperature, $\rho_{60°F}$, and Coefficient of Thermal expansion (CTE) of the fluid
  - Using $\rho_{60°F}$
    - Best method for direct mass flow meters
    - $\rho_{60°F}$ is a property of the fluid
    - Testing can be simplified with the $\rho_{60°F}$ method
- Direct mass flow meters with density/volume can use either method
- Mass flow meters with auto density correction can use either method
- Mass Flow Meter Code does not currently address $\rho_{60°F}$ method

Proposal:

Address $\rho_{60°F}$ method for Net Volume Units in Mass Meter Code

Eliminate the requirements unique to ATC method

- No requirement to take temperature measurement at the device during testing
- No requirement to record uncompensated drafts
- No requirement to compare compensated and uncompensated drafts for difference tolerance
- No requirement to include uncompensated volume and temperature on invoices

Will result in better accuracy for mass meters without the requirement to behave as a gross volume meter

Questions?