Standard Practice for Determining a Flow-Proportioned Average Property Value (FPAPV) for a Collected Batch of Process Stream Material Using Stream Analyzer Data[1]

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INTRODUCTION

The determination of an average property value that is representative of a batch of petroleum product collected and isolated in a tank or vessel has always been a challenge. Historically, the industry practice has been to follow the appropriate procedures prescribed in Practices D 4057, D 5842, or D 4177 to extract one sample (or a limited few, taken from top, middle, and bottom) from the tank or vessel after the content is mixed by any of several means to ensure the material is homogeneous prior to sample extraction. The extracted sample is then sent to a laboratory for analysis. Depending on the property and its criticality, the average property value can also be obtained by independently analyzing each of the top, middle, and bottom samples and the results averaged, or, the three tank samples are mixed and testing for the property is performed on the mixture.

With the introduction of in-line blending and process stream analysis in the 1960s, the potential for real-time delivery to a pipeline, barge, ship, or tank car compartment was envisioned.

To determine the average property value that is representative of a batch of product from a blend or process stream, two approaches have been developed and implemented. One depends on the use of a composite sampler, a vessel into which a sample of the flowing process or blended product stream is introduced at a flow-rate proportional to the flow-rate of the product stream (Practice D 4177). This sample, collected over the period of time required to generate the batch quantity of product, is then analyzed using a primary test method in the laboratory. Multiple laboratory analyses on one or more aliquots of composite sample can be averaged to provide a more precise estimate of the property value than a single analysis.

A second technique utilizes the results produced by on-line, at-line, or in-line analytical measurement systems that continually test material from the process or in-line blended stream for the desired property as it flows to a collection tank, pipeline, or shipping compartment. To determine the average property value of all the material collected (or shipped) at any time during the production process, a unique real time flow-proportioned averaging technique evolved. By appropriate selection of a production time period or cycle, the average property value for the collected (or shipped) material at any time in the production or shipment cycle is obtained by recursively calculating a flow-proportion average using all available property values from the analytical measurement system and the measured incremental quantity of product flow associated with each cycle. The determination of this flow-proportioned average property value is the subject of this practice.

1. Scope

1.1 This practice covers a technique for calculating a flow-proportioned average property value (FPAPV) for a batch of in-line blended product or process stream material that is collected over time and isolated in a storage tank or vessel, using a combination of on-line or at-line measurements of the property and flow rates.

1.2 The FPAPV methodology uses regularly collected on-line or at-line process analyzer measurements, flow, and assessment of other appropriate process measurements or values, to calculate a flow-proportioned average property value in accordance with flow quantity units of material produced.

1.3 When the collecting vessel contains a heel (retained material prior to receipt of the production batch), both the

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property value and quantity of the heel material can be pre-determined and factored into the calculation of the FPAPV for the new batch.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 3764 Practice for Validation of Process Stream Analyzers [2]

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products[2]

D 4177 Practice for Automatic Sampling of Petroleum and Petroleum Products[2]

D 5842 Practice for Sampling and Handling of Fuels for Volatility Measurement[3]

D 6299 Practice for Applying Statistical Quality Assurance Techniques to Evaluate Analytical Measurement System Performance[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *analysis cycle time*, *n*—the period of time required to properly obtain and analyze a representative sample of the process stream material.

3.1.2 *flow-proportioned average property value (FPAPV)*, *n*—the average property value of the collected material in the tank or vessel, calculated by using the flow-proportioned average technique described in the practice of all measurements performed on aliquots of the material while it is flowing into the tank or vessel.

3.1.2.1 *Discussion*—The term *property* as used in this practice can be the physical, chemical, or performance property measurements as provided by on-line, at-line analyzer systems, or, can be the deviation of such measurements from a desired value.

3.1.2.2 *Discussion*—The FPAPV can include a value contributed by material (commonly referred to as a tank heel) present in the collection tank or vessel before the start of delivery of the current process stream material.

3.1.3 *fit-for-use*, *n*—a product, system, or service that is suitable for its intended use.

3.1.4 *linearly mixable*, *adj*—a property is deemed to be linearly mixable in a mass or volume measurement unit if the property of the mixed material can be calculated from the quantities and properties of the materials used to produce the mixture.

3.1.4.1 *Discussion*—The general equations describing this linearly mixable attribute are as follows:

$$P_{MIXED} = \frac{A_1 \cdot P_1 + A_2 \cdot P_2 + A_3 \cdot P_3 + A_4 \cdot P_4 + \ldots + A_N \cdot P_N}{A_1 + A_2 + A_3 + A_4 + \ldots + A_N} \quad (1)$$

$$A_{MIXED} = A_1 + A_2 + A_3 + A_4 + \ldots + A_N \quad (2)$$

where:

A_N = quantity of material N,
P_N = property of material N,
P_{MIXED} = property of mixed material, and
A_{MIXED} = quantity of mixed material.

3.1.4.2 *Discussion*—The material being mixed can be from the same process stream over time.

4. Significance and Use

4.1 Contractual or local regulation, or both, permitting, the FPAPV calculated according to this practice can be used to represent the average property of the quantity of material collected.

4.2 Due to the averaging and appropriate weighting of analysis results, the FPAPV estimate of the property for the collected material is expected to be more representative and more precise than an estimate based on a small number of analyses on a few samples.

4.3 If the measured property value can be used to predict another property value through the use of an appropriate correlation equation, the FPAPV can also be used as a suitable prediction of that property.

4.4 The most recently updated FPAPV can be used to represent the property of the material currently accumulated in the tank or vessel for process control or material, or both, disposition decisions.

5. General Requirements

5.1 The analytical and flow measurement instrumentation systems shall be installed in compliance with the principles set forth in API TP-550.[5]

5.2 The property being measured shall be linearly mixable within the range of the property measurements used to calculate FPAPV, and with respect to the quantity units (volume or mass).

5.3 The integrity of the design, physical components and assemblies of both the analytical measurement system (inclusive of the sampling subsystem), and the instrumentation for flow quantity measurement shall be determined and documented at the time of commissioning and at regular intervals thereafter. Factors to be addressed shall include, but not be limited to, the following:

5.3.1 The sampling system design and operation shall ensure a sample representative of the process stream is delivered to the applicable process stream analyzer.

5.3.2 The process stream shall have dynamics such that the analytical measurement system result used for FPAPV calculation at the end of each analysis cycle time shall be representative of the property of the material produced during that time period.

5.3.3 Analyzer functions shall be in proper condition to produce accurate property measurement results.

5.3.4 During the calculation of FPAPV, inferential or other validation strategies shall be in place to ensure the analytical

[2] *Annual Book of ASTM Standards*, Vol 05.02.
[3] *Annual Book of ASTM Standards*, Vol 05.03.
[4] *Annual Book of ASTM Standards*, Vol 05.04.

[5] Part II Process Stream Analyzers, *Manual on Installation of Refinery Instruments and Control Systems*, available from American Petroleum Institute, 1220 L St. NW, Washington, DC 20005–8197.

measurement system results are representative of the material in the process stream. The effectiveness of these strategies shall be supported by data.

NOTE 1—Examples of these strategies can include, but are not limited to, the following: monitoring of appropriate system parameters to ensure each sample is representative of the manufacturing process stream being analyzed; continuous comparison of an *expected* value of the stream measured versus actual result; monitoring for unusually large or unusually small changes of analytic data; monitoring of key analytical instrumentation parameters.

5.3.5 Fit-for-use condition of the flow quantity measurement instrumentation shall be regularly verified using suitable equipment and apparatus.

5.4 The analytical measurement system shall be commissioned, validated, and thereafter regularly monitored using a suitably designed internal quality assurance program that meets the appropriate requirements and criteria of Practice D 3764 and the techniques of Practice D 6299.

NOTE 2—It is recommended that a statistician be consulted to ensure the proper application of Practices D 6299 and D 3764.

5.5 The final FPAPV shall be calculated based on fit-for-use data obtained from at least 90 % of the material collected.

5.6 For measurement systems that are operated in batch mode in synchronization with the manufacturing process (that is, started up and shut down with the manufacturing process), the statistical control status of the FPAPV measurement system shall be validated in accordance with Practice D 6299 (or equivalent) at least once for each batch, preferably in the beginning. The frequency of in-statistical-control validation when the manufacturing process is active shall commensurate with the established stability of the measurement system.

5.7 The fit-for-use condition shall be initially validated with at least 15 data points using the approach described in Practice D 6299 for "Measurement System Bias Estimated from Multiple Measurements of a Single Check Standard". In this case, the *difference* between test results from aliquots of material that are obtained and analyzed with the measurement process (test method) that the FPAPV is intended to represent versus the actual calculated FPAPVs are assessed. This validation shall be subsequently carried out as part of a statistical quality assurance program meeting the requirement and guidelines of Practice D 6299 for system stability.

NOTE 3—It is recommended that a statistician be consulted to ensure the proper application of Practice D 6299.

5.8 If the FPAPV is used to predict another property value through the use of a correlation equation, the correlation equation shall be validated in accordance with Practices D 3764, D 6299, or other appropriate statistically equivalent techniques.

6. FPAPV Calculation

6.1 Determination of the flow-proportioned average property value is as follows:

6.1.1 If the collecting tank or vessel contains a residual quantity of material from a previous batch (tank heel), obtain a representative sample of that material, test it to determine an estimate of the property value of interest, and measure or estimate the quantity of the heel material. Use the heel property value, and the heel quantity as the starting values for FPAPV calculation to ensure the final FPAPV value includes the contribution from the heel material.

6.1.2 For each analysis cycle, multiply the analyzer property value result times the quantity of process stream flowing during that cycle to determine the property × flow quantity value of the latest cycle.

6.1.3 Sum the property × flow quantity values for all cycles completed through the last cycle,

6.1.4 Sum the flow quantities for all cycles completed through the last cycle.

6.1.5 Divide the sum of the property × flow quantity values by the sum of the flow quantities.

6.1.5.1 Algorithmically, the $FPAPV_i$ is recursively calculated as follows:

where:
i = current analysis cycle time period, $i \in$ integer ≥ 0,
A_i = total amount of material collected up to end of cycle time period i, in appropriate units,
P_i = analyzer property value for analysis cycle time period i (see Note 4),
$FPAPV_i$ = the FPAPV property estimate of the material collected up to end of analysis cycle period i, and
ΔA = amount of material collected between the end of (i – 1) analysis cycle time period and end of current (i) analysis cycle time period.

$$FPAPV_i = \frac{A_{i-1}\, FPAPV_{i-1} + \Delta A \times P_i}{A_{i-1} + \Delta A} \quad (3)$$

NOTE 4—A_0 and P_0 are the property value and quantity of the heel material in the collection vessel or tank.

6.1.6 See Table 1 for an example of the calculation.

7. Keywords

7.1 blending; flow proportioned average property value; heel property; process stream analyzers; quality control

TABLE 1 Sample Calculation for FPAPV

i	ΔA	A_i	P_i	$FPAPV_i$
0	0	5.3	9.85	9.850
1	9.10	14.40	10.13	10.025
2	6.17	20.57	9.95	10.001
3	10.73	31.30	10.03	10.010
4	13.83	45.13	9.97	9.999
5	13.60	58.72	9.53	9.891
6	15.20	73.92	9.80	9.872
7	3.45	77.37	10.34	9.893
8	9.30	86.67	10.07	9.911
9	13.29	99.95	10.25	9.957
10	6.74	106.69	9.85	9.950
11	7.93	114.62	9.62	9.927
12	4.93	119.55	10.48	9.950
13	4.46	124.01	10.14	9.957
14	7.07	131.08	9.93	9.955
15	7.68	138.76	10.15	9.966
16	3.65	142.40	9.54	9.955
17	8.30	150.70	10.43	9.982
18	8.79	159.49	9.43	9.951