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Nuclear fuel technology — Tank calibration and volume determination for nuclear materials accountancy —

Part 5:
Accurate determination of liquid height in accountancy tanks equipped with dip tubes, fast bubbling rate

Technologie du combustible nucléaire — Étalonnage et détermination du volume de cuve pour la comptabilité des matières nucléaires —

Partie 5: Détermination précise de la hauteur de liquide dans une cuve bilan équipée de cannes de bullage, bullage rapide

Reference number
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Foreword

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ISO 18213-5 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 5, *Nuclear fuel technology*.

ISO 18213 consists of the following parts, under the general title *Nuclear fuel technology — Tank calibration and volume determination for nuclear materials accountancy*:

- *Part 1: Procedural overview*
- *Part 2: Data standardization for tank calibration*
- *Part 3: Statistical methods*
- *Part 4: Accurate determination of liquid height in accountancy tanks equipped with dip tubes, slow bubbling rate*
- *Part 5: Accurate determination of liquid height in accountancy tanks equipped with dip tubes, fast bubbling rate*
- *Part 6: Accurate in-tank determination of liquid density in accountancy tanks equipped with dip tubes*

Introduction

ISO 18213 deals with the acquisition, standardization, analysis, and use of calibration data to determine liquid volumes in process tanks for accountability purposes. This part of ISO 18213 is complementary to the other parts, ISO 18213-1 (procedural overview), ISO 18213-2 (data standardization), ISO 18213-3 (statistical methods), ISO 18213-4 (slow bubbling rate) and ISO 18213-6 (in-tank determination of liquid density).

The procedure presented herein for determining liquid height from measurements of induced pressure applies specifically when a fast bubbling rate is employed. A similar procedure that is appropriate for a very slow bubbling rate is given in ISO 18213-4.

Measurements of the volume and height of liquid in a process accountancy tank are often made in order to estimate or verify the tank's calibration or volume measurement equation. The calibration equation relates the response of the tank's measurement system to some independent measure of tank volume.

Beginning with an empty tank, calibration data are typically acquired by introducing a series of carefully measured quantities of some calibration liquid into the tank. The quantity of liquid added, the response of the tank's measurement system, and relevant ambient conditions such as temperature are measured for each incremental addition. Several calibration runs are made to obtain data for estimating or verifying a tank's calibration or measurement equation. A procedural overview of the tank calibration and volume measurement process is given in ISO 18213-1. An algorithm for standardizing tank calibration and volume measurement data to minimize the effects of variability in ambient conditions that prevail during the measurement period is given in ISO 18213-2. The procedure presented in this part of ISO 18213 for determining the height of calibration liquid in the tank from a measurement of the pressure it induces in the tank's measurement system is a vital component of that algorithm.

In some reprocessing plants, the volume of liquid transferred into or out of a tank is determined by the levels of two siphons. The high level corresponds to the nominal volume, and the low level to the heel volume. If the transfer volume cannot be measured directly, then it is necessary to calibrate this volume (as described in the previous paragraph) because the difference between the actual volume and that used for inventory calculations will appear as a systematic error.

The ultimate purpose of the calibration exercise is to estimate the tank’s volume measurement equation (the inverse of the calibration equation), which relates tank volume to measurement system response. Steps for using the measurement equation to determine the volume of process liquid in the tank are presented in ISO 18213-1. The procedure presented in this part of ISO 18213 for determining the height of process liquid in a tank from a measurement of the pressure it induces in the tank's measurement system is also a key step in the procedure for determining process liquid volumes.

Nuclear fuel technology — Tank calibration and volume determination for nuclear materials accountancy —

Part 5: Accurate determination of liquid height in accountancy tanks equipped with dip tubes, fast bubbling rate

1 Scope

This part of ISO 18213 specifies a procedure for making accurate determinations of liquid height in nuclear-materials-accountancy tanks that are equipped with pneumatic systems for determining the liquid content. With such systems, gas is forced through a probe (dip tube) whose tip is submerged in the tank liquid. The pressure required to induce bubbling is measured with a manometer located at some distance from the tip of the probe. This procedure applies specifically when a fast bubbling rate is employed.

A series of liquid height determinations made with a liquid of known density is required to estimate a tank's calibration equation (see ISO 18213-1), the function that relates the elevation (height) of a point in the tank to an independent determination of tank volume associated with that point. For accountability purposes, the tank's measurement equation (the inverse of its calibration equation) is used to determine the volume of process liquid in the tank that corresponds to a given determination of liquid height.

2 Physical principles involved

The methodology in this part of ISO 18213 is based on measurements of the difference in hydrostatic pressure at the base of a column of liquid in a tank and the pressure at its surface, as measured with a bubbler probe inserted into the liquid. Specifically, the pressure, P, expressed in pascals, exerted by a column of liquid at its base is related to the height of the column and the density of the liquid, in accordance with Equation (1)[1]:

$$P = gH_{\mathrm{M}}\rho_{\mathrm{M}} \quad (1)$$

where

H_{M} is the height of the liquid column (at temperature T_{m}), in m;

ρ_{M} is the average density of the liquid in the column (at temperature T_{m}), in kg/m^3;

g is the local acceleration due to gravity, in m/s^2.

For a liquid of known density, ρ, Equation (1) can be used to determine the height, H, of the column of liquid above a given point from (a measurement of) the pressure, P, exerted by the liquid at that point. Therefore, process tanks are typically equipped with bubbler probe systems to measure pressure. Components of a typical pressure measurement system (see Figure 1) are discussed in detail in ISO 18213-1, together with a description of the procedural aspects of a typical calibration exercise.

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1) The subscript "M" is used to indicate the value of a temperature-dependent quantity at the temperature T_{m}.

In practice, it is not absolute pressure that is measured, but rather the difference in pressure between the bottom and the top of the liquid column. Gas is forced through two probes to measure this differential pressure. The tip of one probe (the long or major probe) is located near the bottom of the tank and immersed in the liquid. The tip of the second probe (reference probe) is located in the tank above the liquid surface.

Various factors can affect the accuracy of the height determinations that follow from Equation (1). Temperature variations potentially have the greatest effect, especially on the comparability of two or more measurements (such as those taken for calibration), primarily because liquid density changes with temperature. Moreover, differences between actual pressures at the tip of the probes and observed pressures at the manometer can result from the buoyancy effect of air, the mass of gas in the probe lines, flow resistance, and the effects of bubble formation and release at the tip of the probes. A general algorithm for standardizing pressure measurements that compensates for temperature variations and other measurement factors is presented in ISO 18213-2. For the case in which pressure measurements are made with a fast bubbling rate, details of the pressure-to-height calculation step of this standardization algorithm are presented in Clause 4 of this part of ISO 18213. Analogous calculations that apply for a slow bubbling rate are given in ISO 18213-4. Procedures for estimating the uncertainty of the resulting height determinations are given in ISO 18213-3.

3 Required equipment, measurement conditions, and operating procedures

The pressure measurements to which this part of ISO 18213 applies are made either to calibrate a tank or to determine the volume of process liquid it contains. The same equipment, operating procedures, and standardization steps are used for both purposes. The elements of a pressure measurement system for determining the liquid content of a process tank are described in detail in Clause 4 of ISO 18213-1:2007. Measurement conditions and operating procedures for making pressure measurements to determine liquid height are described in detail in Clause 6 of ISO 18213-1:2007.

4 Determination of height from measurements of pressure

As noted in Clause 2, several factors can affect the accuracy of the calculation for determining height from pressure based on Equation (1). Adjustments that compensate for these factors are identified in this clause. See References [6] and [8].

If the effect of atmospheric pressure is taken into account, the fundamental relationship for determining liquid height from pressure is obtained from Equation (1), in accordance with Equation (2)[2]:

$$gH_{1,\mathrm{M}}\rho_{\mathrm{M}} = P_1(H) - P(H_{1,\mathrm{M}} + H) \tag{2}$$

where

- g is the local acceleration due to gravity;
- ρ_{M} is the average density of liquid in the tank;
- $H_{1,\mathrm{M}}$ is the height of the column of liquid in the tank above the tip of the bubbling (major) probe;
- $P_1(H)$ is the pressure at the tip of the bubbling probe (at elevation H above reference point r_1);
- $P(H_{1,\mathrm{M}} + H)$ is the ambient pressure minus off-gas pressure at the liquid surface in the vapour space [at elevation $(H_{1,\mathrm{M}} + H)$ above reference point, r_1].

2) The subscript “1” is used in this part of ISO 18213 to indicate quantities that refer to the major probe (see Figure 1). The steps for standardizing data from a second probe are completely analogous.

It is convenient to take the bottom of the tank or the tip of the measuring (major) probe as the primary reference point. If the bottom of the tank is selected as the primary reference point, then $H = \varepsilon$ in the nomenclature of Figure 1. If the tip of the measuring probe is selected as the primary reference point, then $H = 0$. Under the latter convention, Equation (2) can be written in accordance with Equation (3):

$$gH_{1,\mathrm{M}}\rho_\mathrm{M} = P_1(0) - P(H_{1,\mathrm{M}}) \tag{3}$$

where

$P_1(0)$ denotes the pressure at the tip of major probe;

$P(H_{1,\mathrm{M}})$ denotes the ambient pressure minus off-gas pressure at the liquid surface.

As noted in Clause 2, it is not possible to directly measure the quantities in Equation (1), nor is it possible to directly measure the quantities in Equation (3). In practice, the difference in pressure between the major probe and the reference probe, in accordance with Equation (4), is measured by a manometer located at some elevation, E_1, above the primary reference point (see Figure 1).

$$\Delta P_1 = P_1(E_1) - P_\mathrm{r}(E_1) \tag{4}$$

However, the pressure at the tips of the major and reference probes may differ from the pressure measured at the manometer because of

— the mass of gas in the pressure lines,

— differences in the densities of gas (air) in the pressure lines and in the vapour space,

— flow resistances in the pressure lines,

— the effects of bubble formation at the tip of the major probe, and

— surface tension and pressure associated with the formation of bubbles at the tip of the major probe.

Equations (5), (6) and (7) give the basic relationships among these factors. Equation (5) gives the pressure at the tip of the major probe:

$$P_1(0) = gH_{1,\mathrm{M}}\rho_\mathrm{M} + g(E_1 - E_\mathrm{r} - H_{1,\mathrm{M}})\,\rho_{\mathrm{a,s}} + P_\mathrm{r}(E_1 - E_\mathrm{r}) \tag{5}$$

where

g is the local acceleration due to gravity;

ρ_M is the average density of liquid in the tank;

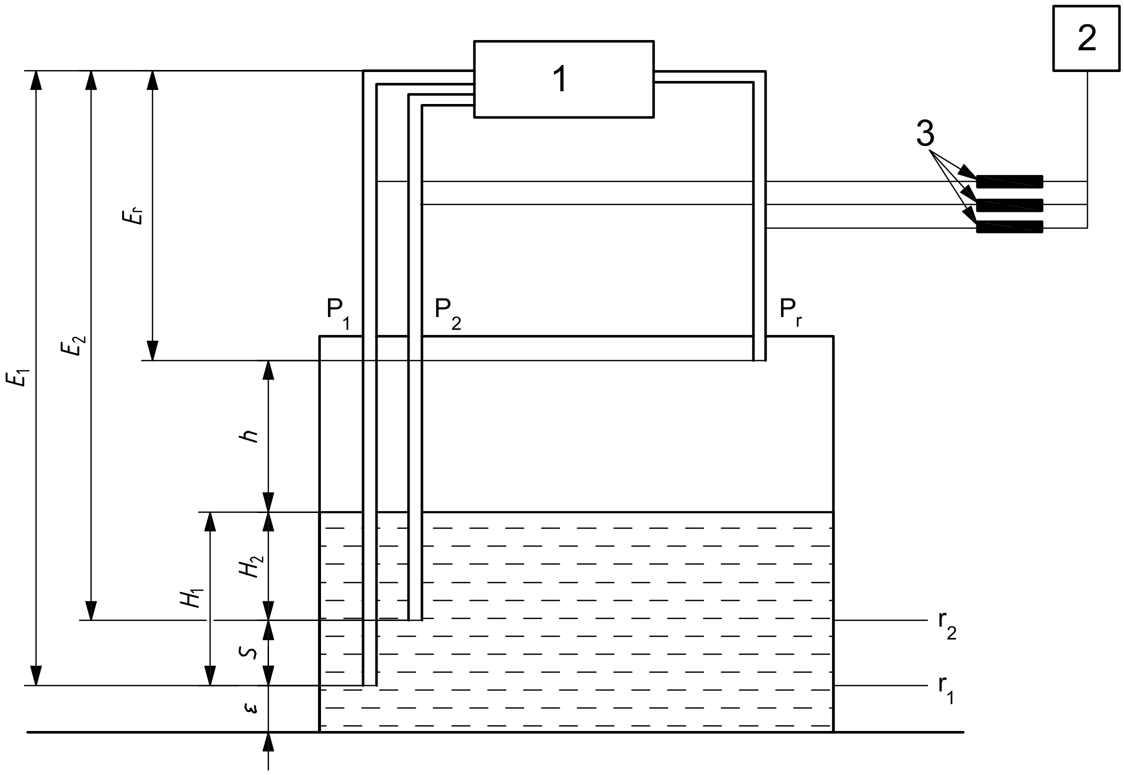
$H_{1,\mathrm{M}}$ is the height of liquid in the tank relative to the primary reference point, r_1, (the tip of the major probe);

E_1 is the elevation of the manometer above the primary reference point, r_1;

E_r is the elevation of the manometer above the tip of the reference probe;

$\rho_{\mathrm{a,s}}$ is the average density of air in the tank above the liquid surface at the prevailing pressure (atmospheric pressure minus off-gas pressure).

The first term on the right-hand side of Equation (5) represents the pressure exerted by the liquid in the tank above the tip of the major probe; the second term represents the pressure exerted by the air in the tank between the surface of the liquid and the tip of the reference probe; and the last term represents the pressure at the tip of the reference probe.



NOTE This configuration is typical but other configurations are possible; see Reference [11] for examples.

Key

1 manometer

2 gas supply (N_2 or air)

3 flowmeters

Probe	Major probe	Minor probe	Reference probe
Probe designation	P_1	P_2	P_r
Reference point	r_1 (primary)	r_2 (secondary)	—
Height of liquid above reference point	H_1	H_2	—
Elevation of pressure gauge (manometer) above reference point	E_1	E_2	E_r
Elevation of reference probe above liquid surface	$h = E_1 - E_r - H_1$	$h = E_2 - E_r - H_2$	—
Elevation of reference point above bottom of tank	ε	$\varepsilon + S$ [a]	—

[a] Vertical distance (probe separation): $S = H_1 - H_2$.

Figure 1 — Elements of a typical pressure measurement system for determining liquid content

Equation (6) gives the pressure at the manometer in the major probe line:

$$P_1(E_1) = P_1(0) + \delta_1 - gE_1\rho_{g,1} + g\lambda(\rho_M - \rho_{g,1}) + 2\sigma/r_b \tag{6}$$

where

δ_1 is the pressure drop in the major probe line due to the gas flow resistance;

$\rho_{g,1}$ is the average density of gas in the major probe line at the prevailing pressure;

λ is the distance of the lowest point of the bubble below the tip of the major probe;

σ is the surface tension for the liquid and gas;

r_b is the radius of curvature of the bubble at its lowest point.

The first term on the right-hand side of Equation (6) represents the pressure at the tip of the major probe; the second term represents the pressure drop in the major probe line due to flow resistance; the third represents pressure exerted by the gas in the major probe line; the fourth term gives the pressure of a column of liquid equal in height to the average distance of the lowest point of the bubble below the tip of the major probe; and the last term accounts for the surface tension at the interface between the tank liquid and the gas in the major probe line.

Finally, Equation (7) gives the pressure, at the manometer, in the reference probe line:

$$P_r(E_1) = P_r(E_1 - E_r) + \delta_r - gE_r\rho_{g,r} \tag{7}$$

where

$\rho_{g,r}$ is the average density of gas in the reference probe line at the prevailing pressure;

δ_r is the pressure drop in the reference probe line due to gas flow resistance.

The first term on the right-hand side of Equation (7) represents the pressure at the tip of the reference probe; the next term represents the pressure drop in the reference probe line due to flow resistance; and the last term represents the pressure exerted by the gas in the reference probe.

If the expression for $P_1(0)$ given by Equation (5) is first substituted into Equation (6), and then Equation (7) is subtracted from Equation (6), the following expression is obtained for the liquid height $H_{1,M}$:

$$H_{1,M} = [\Delta P_1 + gE_1(\rho_{g,1} - \rho_{a,s}) - gE_r(\rho_{g,r} - \rho_{a,s}) + (\delta_r - \delta_1) - g\lambda(\rho_M - \rho_{g,1}) - 2\sigma/r_b]/[g(\rho_M - \rho_{a,s})] \tag{8}$$

The expression in Equation (8) for determining $H_{1,M}$ from the measured differential pressure, ΔP_1, includes adjustments that compensate for all the factors identified in this clause. The expression is valid at the measurement temperature, T_m.

The accuracy of height determinations obtained by means of Equation (8) is limited by how well the density of the measured liquid is determined at the prevailing temperature. It is also important to note that $H_{1,M}$ is the height of the liquid in the tank only at the measurement temperature, T_m. In particular, $H_{1,M}$ is not the height of the same liquid at some other temperature.

Some of the effects identified in Equation (8) may be quite small. Whether or not they must be taken into account depends on the capability of the tank's measurement system (e.g. manometer) and required measurement accuracy. An algorithm for estimating the quantities in Equation (8) is given in Annex A. In general, these quantities should be measured whenever possible. However, under normal operating conditions, use of the suggested default values instead of actual measurements will provide acceptable results in nearly all situations.