Monitoring of the interface movement of a bubbling dip tube by the pressure signal

G. Janssens-Maenhout*, L. Dechamp, P. Grassi
Institute for the Protection and the Security of the Citizen, Nuclear Safeguards Unit
Joint Research Centre Ispra, Via E. Fermi 1, TP 421, I-21020 ISPRA (VA), Italy;
tel: +39 0332 78 5831; +39 0332 78 5076; fax: +39 0332 78 9216;
* docent University of Ghent, Nuclear Technology
e-mail: greet.maenhout@jrc.it; luc.dechamp@jrc.it, piergiorgio.grassi@jrc.it

Abstract

In accountancy tanks of reprocessing facilities the pneumercator known as dip tube technique is commonly used for level measurements, because the pneumercator measurement system has a high resolution and the dip tubes are robust and easy in maintenance. The traditional pneumercator consists in three dip tubes of steel with a flat end and different lengths, all connected to the same air flow supply. The liquid level is measured by means of the hydrostatic head at the bubbling tip of the immersed dip tube.

Registering precisely the pressure at the dip tube's tip with a high measurement data rate (10kHz) allows to monitor the dynamics of the bubble interface. Each step in the bubble formation process can be followed. The total bubble build-up is unambiguously determined with the pressure signal.

The special case at the condition of air supply with small gas flow rate, called slower bubbling mode, shows promising results for practical applications. The performance and efficiency of this level measurement technique in this new mode for verifying the status of the dip tube's tip is positively compared with those of other techniques.

1. Introduction

The inventory of accountancy tanks in reprocessing facilities is commonly monitored with the level of the acid radioactive solutions measured by the dip tube technique. Accountancy tanks in reprocessing facilities are equipped with at least three but commonly five or even more up to seven steel tubes, all of different lengths. They are all connected to the same air flow supply with separate air flow regulators for the fine tuning. The tube contributes actively to the level or density measurements when she is dipping into the solution, unless she is measuring the reference pressure in the tank.

In the minimal configuration of three dip tubes, there are:

(i) the level dip tube, which is the longest one,

(ii) the density dip tube, which ends on a well-defined probe separation distance S above the level dip tube

(iii) and the reference dip tube, which never dips into the solution.

In most cases absolute pressures at the dip tube's bubbling tip, respectively p_L, p_D and p_R are measured by three separate pressure transducers, although also the differential configuration exists where two pressure transducers measure p_L-p_R and p_L-p_D. For the real-time level monitoring, the differential pressure configuration is traditionally utilized, whereas for calibration and recalibrations the absolute pressure configuration is preferred.

The density r_L is then derived by

$$r_L = (p_L - p_D)/(gS) \qquad (1)$$

and the level l by

$$l = (p_L - p_R)/(r\ g) \qquad (2)$$

and the volume is derived with the measured level and temperature, utilizing the calibration curve of the tank $V(l, T)$.

2. Bubble formation at the tip of the dip tube

Registering precisely the pressure at the dip tube's tip with a high measurement data rate (10kHz) allows monitoring of the bubble interface . Each step in the bubble formation process can be followed. This bubble formation process is coupled with a pressure variation of several Pa, which is not negligible. With a high speed camera a sequence of bubble formations has been visualized and the associated pressure signal has been interpreted. In Fig. 1 an example is given of the pressure recorded with 10 kHz during the complete formation process of one single bubble until detachment is reached, as shown in the camera pictures, taken with a rate of up to thousand frames per second.

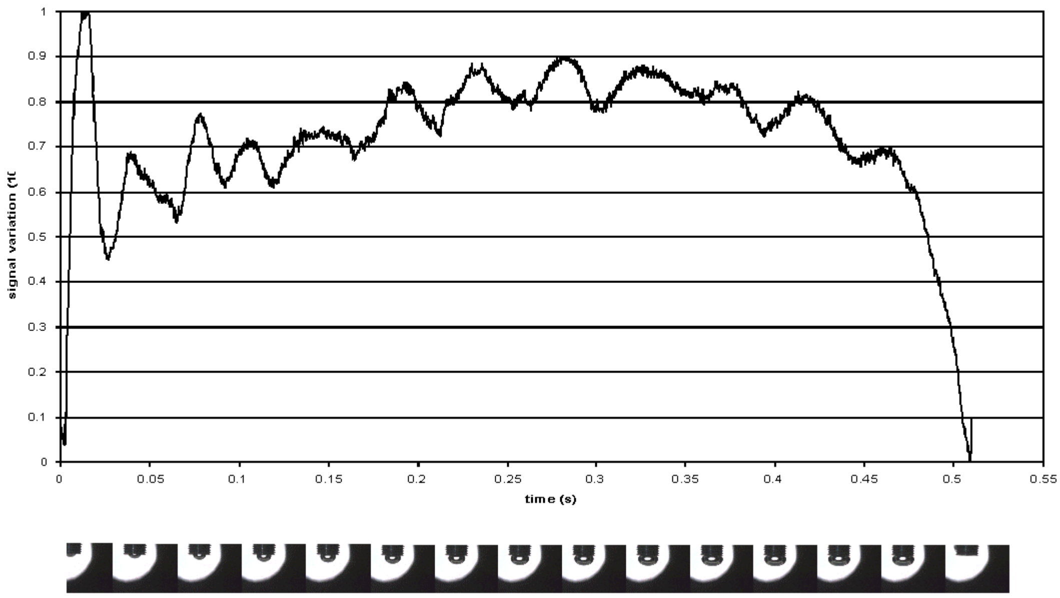


Fig. 1: Visualization of a bubble formation sequence until detachment with camera.

The pressure signal shows the strong oscillation of the gas/liquid-interface after the detachment of a bubble, alternately inside and outside at the exit or tip of the dip tube. Then the dynamic bubble growth is gradually performed by a steadily increasing pressure build-up with small dynamic steps, which may correspond to the bubble oscillation. The pressure increase corresponds to the expansion of the gas/liquid-interface downwards the dip tube's tip. The total pressure build-up during the bubble growth can be unambiguously determined.

After the maximum height z (for the given air flow rate) is reached, the bubble starts enlarging (with increasing bubble diameter D_B), increasing its volume V without enhancing the mean internal pressure. In the contrary the bubble contracts in the vertical direction slightly to expand more in the horizontal direction and a pressure decrease is noticed. The bubble with a large width D_B becomes instable, and the bubble detachment is finally induced.

The most important point is the bubble detachment, because this is directly linked to the bubbling frequency.

Both the amplitude as well as the frequency of the periodical pressure signal depend on the gas flow rate and on the maximum bubble volume *V*. According to Georgescu (2001) the maximum bubble volume *V*, which is reached at the moment of detachment can be well derived with the mean detachment bubble diameter or so-called Sauter diameter S_B in the relationship of Tate:

$$(r_L - r_G)gV = p\ S_B s \qquad (3)$$

if a quasi-static detachment occurs. This equation expresses that under quasi-static conditions, which are only fulfilled in the limited case of very small gas flow rate the Archimedes force with the density difference r_L - r_G between the liquid and the air and the surface tension force with the surface tension σ are in balance at the point of detachment.

Up to now the slow bubbling mode, with one bubble release every 10 seconds is utilised to check the tip’s status of a dip tube with typical inner diameter varying from 4 to 6 mm. This slow bubbling mode is not applied frequently because this mode is very time consuming: with a mean for 100000 bubbles, several hours are needed.

In this paper a bubbling mode, which is much faster, with about five bubbles released in one second, defined as *slower bubbling mode* is investigated as alternative. The validity range of the slower bubbling mode to check the tip’s status efficiently was determined with one bubble release per second up to six bubbles released in a second. In less than 0.15 seconds a repetitive bubble form can not be generated with a high probablity. From one second as bubble generation time onwards no significant improvement can be seen in the repeatability of the bubble form.

3. Bubble detachment at slower bubbling mode

The detachment is mainly influenced by the dip tube’s geometry in form and size. The flat shape of the tip of the dip tube has been selected in most cases, although the flat shape leads to a random detachment at any side of the tube. Studies on other shapes of the dip tube's tip, such as performed by Uchikoshi (1996), tried to localize the detachment point by means of a cut of the dip tube under a certain angle. No significant advantage was obtained and the flat shape was preferred because it seemed to be less sensitive to a non-vertical position.

The external diameter of each dip tube is typically 10mm and the internal diameter 6mm. The O-ring of about 50 mm² is important to keep the bubble as long as possible attached. The bubble diameter starts initially with the internal diameter of 6 mm and grows until it reaches the detachment diameter D_B which remains slightly smaller than the external diameter of 10mm.

The bubble at its maximum size can be assumed to be an ellipsoide, which is symmetrically around the vertical axis with width D_B and with distance *z* from the tip of the dip tube until the sattle point of the liquid-gas unterface. With the balance of Eq. 1 the distance z below the dip tube's tip is determined by

$$zD_B^2(r_L - r_G)g = 6S_B s \qquad (4).$$

The distance *z* can be measured by the maximum pressure variation. If the maximum bubble width D_B is assumed to reach the outer diameter of the dip tube without exceeding it, then the Sauter diameter S_B can be estimated with Eq. 3 and the volume *V* can be calculated with Eq. 1. The derived maximum bubble volumes for the different pressure measurements are in agreement with the results of Platzer et al. (1985). Moreover, Janssens-Maenhout et al. (2003) have demonstrated with electrical conductivity experiments that at the detachment point no water was covering the whole metal O-ring area of the steel tip.

This let us also conclude that the quasi-static assumptions are acceptable and that the pressure does not only record the bubble form but also the geometry of the tip. The air bubbling causing up and down movements of the solution in the lowest part of the dip tube can cause drying out of the thin liquid films. Hence precipitation of salts of the concentrated solution occurs and solid particles deposit on the internal wall of the dip tube. Clogging of dip tubes is partially anticipated by installation of instrument air humidifiers after the air flow meter on the air supplying line. However the status of the dip tube's tip remains to be surveyed in order to keep the pressure measurements accurate.

An overview of clogging models and guidelines are given by Perez Paricio (2001). In artificial groundwater recharge systems the pressure build-up by clogging is modeled in large extend. One of the empirical models is given by Olsthoorn et al (1983) and relates the pressure buildup by clogging *Dp* with a reference flow rate (based on the calculated reference velocity and the difference in original pressure and flow rate at starting conditions (index s) and end conditions (index e), simplified represented as:

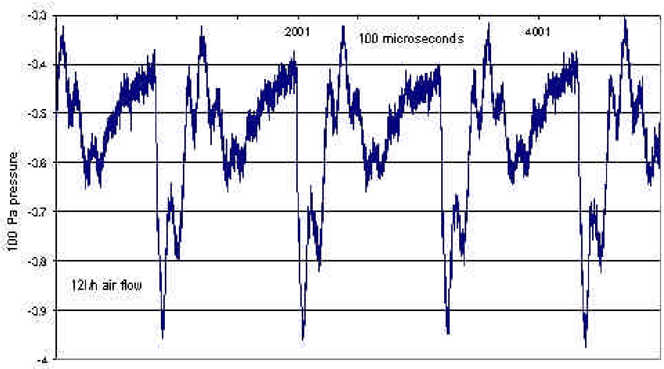
$$\Delta p = Q_0 \left(\frac{p_e}{Q_e} - \frac{p_s}{Q_s} \right) \qquad (5)$$

In our application this relation was not utilized because the objective was not to survey the degradation over a certain period but to survey the tip's status at any time.

4. Method to check the status of the dip tube's tip

A method for checking the tip's status by recording accurately the bubble interface movement in slower bubbling mode has been investigated in detail. Experiments have been carried out with different gas flow rates, simulating the clogging of a 6 mm dip tube at a given air flow supply.

A histogram was made with the pressure signal and showed the expected distribution, which differs from an ideal Gaussian profile. The pressure histogram served to find the most meaningful pressure value, which is directly related to the detachment bubble diameter. The histogram also showed clearly the influence of the gas flow rate on the pressure signal, can be observed by the differences between Fig. 2 and Fig. 3.



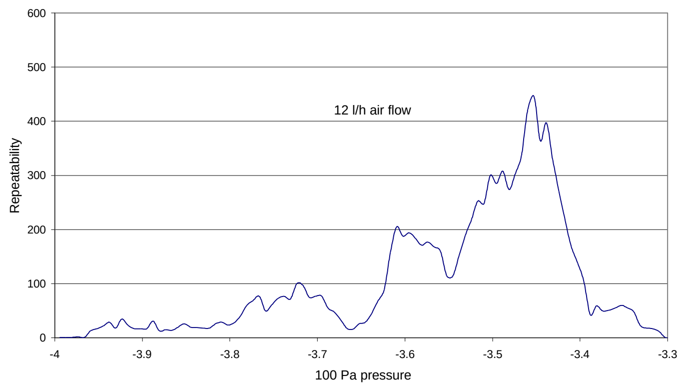


Fig. 2: Fast bubbling mode: pressure signal and repeatability.
Different bubble types can be distinguished:
(i) a larger bubble measured with a mean FWHM of about 15Pa (which corresponds to a mean distance *z* of the bubble into water of about 1.5mm[1]).

[1] It is to be noted that the pressure oscillation has a maximum amplitude of (395-335)Pa or 6 mm water distance, which means a swapping back of the bubble interface about 3 mm into the dip tube and 3 mm outside as maximum distance from the dip tube away.

(ii) and a smaller bubble with a mean FWHM of about 10 Pa (which corresponds to a mean dipping distance z of the bubble into water of about 1 mm).

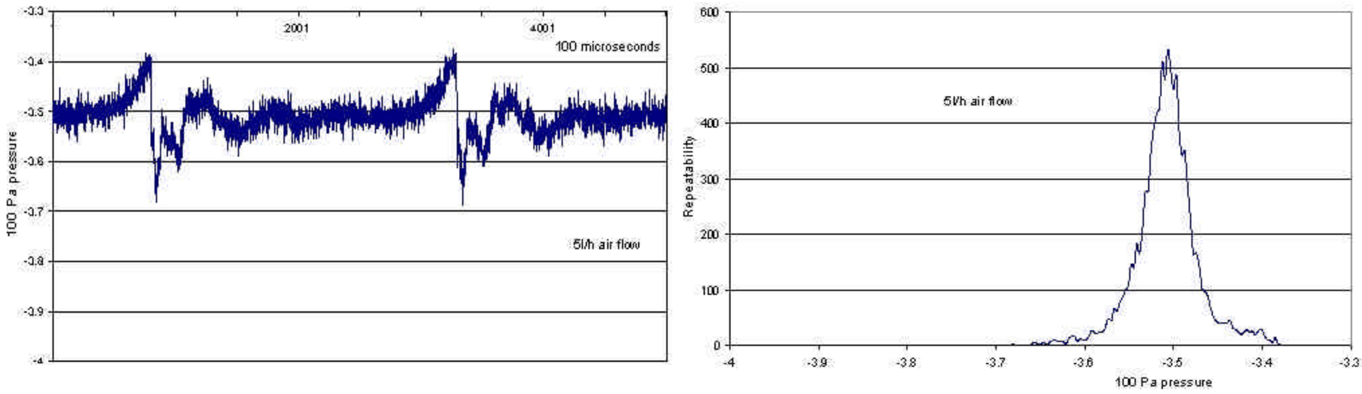


Fig. 3: Slower bubbling mode: pressure signal and repeatability (single bubble type) with a mean FWHM of 10 Pa corresponding to a mean distance z of 1 mm.

Under the condition of high gas flow rate with high bubble frequency, the histogram shows the formation of two different types of bubbles. The formation of alternating a large and a small bubble, derived with the pressure histogram was confirmed with the camera images.

Only under the condition of air supply at slower bubbling mode, a regular bubble is formed with a well-defined detachment bubble diameter, as presented in Fig. 2. The slower bubbling mode can therefore be utilized for the verification of the status of the dip tube's tip. The comparison of the experimental results for the case of a variation in gas flow rate with those for a variation in inner dip tube diameter showed that it is possible to simulate the clogging not only by reducing the opening area but by enhancing the flow rate.

With the histogram of the pressure signal, taken at high measurement data rate, the opening area A (and so clogging area) can be determined by comparing the measured bubble frequency with the calculated bubble frequency f, which is for the given gas flow rate Q and the maximum bubble volume V (given by Eq. 3 with the mean bubble detachment diameter S_B derived with the measured distance z):

$$f = \frac{Q}{V} = \frac{6Q}{p\ zD_B^2} \qquad (6)$$

It should be repeated that we assume the detachment diameter equal to the initial (and assumed unchanged) external dip tube diameter.

5. Performance of the dip tube technique

Finally the performance of the dip tube technique is compared with other techniques, such as the time domain reflectometer, the ultrasonic technique, the capacitance probe and the classical sight glass. Although all level measurement techniques are concurring, the accuracy of the bubbling dip tube technique remains under varying boundary conditions the best.

Conclusions

A method for checking the status of a dip tube's tip in real time by pressure recording have been experimentally investigated. The validity range was determined for this new slower bubbling mode, in the order of 5 *l/hr*, under which the geometry and integrity of the tip can be unambiguously controlled in an efficient and fast way.

The clogging area can be determined with the measured bubble frequency and the maximum bubble volume. The maximum bubble volume is derived with the measured maximum distance from the bubble dipping into the liquid and the mean bubble detachment diameter. Although the pressure signal visualizes clearly the dynamic bubble growth with gas/liquid interface oscillations in the slower bubbling mode, the signal can not longer be interpreted unambiguously in the fast bubbling mode.

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