FLOW MEASUREMENT AND CONTROL IN THE PRESENCE OF BUBBLES

Authors: Karl Anderson, George Gonnella, Lisa Pilati-Warner

Introduction

Integrated Circuit cleaning operation chemistries, such as ammonium hydroxide and hydrogen peroxide, produce bubbles as they degrade. The presence of bubbles in these chemistries makes fluid measurement a challenge, as it introduces noise into the flow measurement and control process. Bubbles are naturally occurring. Therefore, tolerance to the presence of bubbles is a requirement for accurate flow measurement.

The most prominent technologies for measuring and controlling flow in high-purity cleaning operations are Ultrasonic (ULS) and Differential Pressure (DP). The purpose of this paper is to analyze and present the performance differences between these two technologies in the presence of bubbles.

Flow Measurement Principle of Operation

Ultrasonic Technology

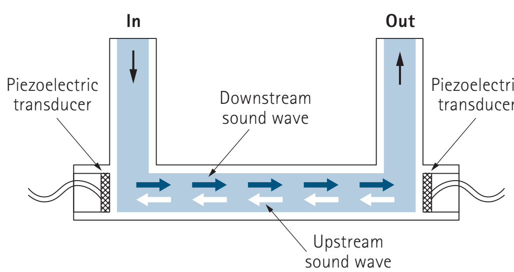

Figure 1

Ultrasonic flow technology measures the velocity of a fluid through a tube using ultrasonic waves to calculate volume flow. Two piezoelectric transducers, one mounted at each end of the flow tube, send and receive ultrasonic waves alternately. The waves increase or decrease their velocity with the flow stream, producing a difference in transit time. This difference in transit time is proportional to the velocity of the fluid. The velocity with the known internal volume of the flow tube is calculated to produce volumetric flow.

When a bubble is introduced in the flow tube, the ultrasonic wave is attenuated. In extreme cases, the ultrasonic wave is blocked by the bubble. Different methods are employed to compensate for the attenuation. For example, relative signal strength of the ultrasonic wave is used when calculating transit time. Another example is suspending flowmeter output while the bubble is in the flow tube.

Differential Pressure Technology

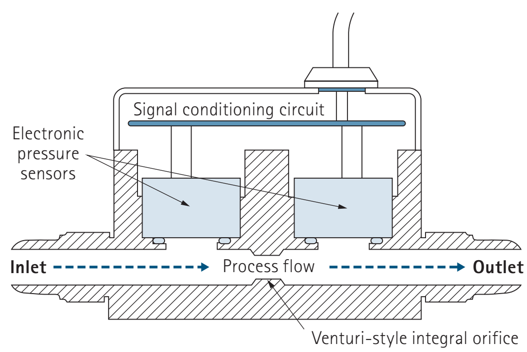

Figure 2

Differential pressure flow measurement incorporates two pressure sensors separated by a venturi-style orifice in the process flow path. The orifice in the flow stream creates a differential pressure between the two sensors that is proportional to fluid flow rate. The higher the flow velocity, the greater the differential pressure measured.

DP technology design is inherently more tolerant to the presence of bubbles in the liquid media. When liquid media passes through the integral orifice it is accelerated. The bubble moves through so quickly that no discernible deviation in differential pressure measurement occurs.

Test Procedure

Symbol	Specifications
V1	N_2 to Tank A and Bubbles line valve
V2	Flow to UUT valve
V3	Flow from UUT to Beaker valve
V4	Vent valve
V5	Gas flow to water line valve
V6	Gas regulator
G1	Gas pressure gauge
G2	Gas pressure gauge
G3	Bubbles pressure gauge
G4	Vent gauge
UUT	Unit Under Test (flow controller)
REF	Reference flowmeter

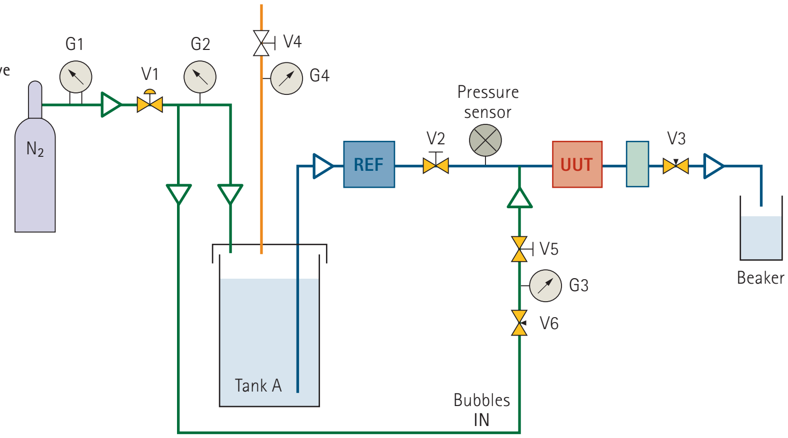

Figure 3

One DP technology based flow controller and two Ultrasonic technology based flow controllers, all with a flow range capability up to 500 milliliters, were tested. (A flow controller is a flowmeter with integrated valve and control electronics.). The two ultrasonic flow controllers were each from a different manufacturer. Each flow controller unit-under-test (UUT) was installed in a horizontal orientation in the setup described in Figure 3. Two test methods were executed using this test setup. To measure actual flow, a higher accuracy reference flowmeter was installed upstream of the bubble injection point to ensure no direct bubble influence. The test media was deionized water with 10% and 40% bubble concentration flowing at 45 psig.

Test Results

Bubble Effects on Flow Accuracy

In the first test method, the UUT Flow Setpoint was varied between 10% Full Scale and 100% Full Scale, according to the flow program in Figure 4. A data acquisition instrument was used to record the flow signal.

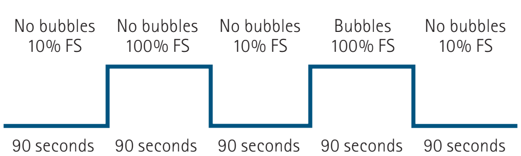

Figure 4

10% BUBBLES

The graph in Figure 5 displays the actual flow of each UUT, as measured by the reference flowmeter, at 500 milliliters per minute (100% Full Scale) with 10% bubble content. The Differential Pressure technology based flow controller produced the least amount of noise and had little shift in accuracy. Ultrasonic Supplier A showed low noise, however displayed a significant shift in accuracy. Ultrasonic Supplier B showed both high noise and shift in accuracy.

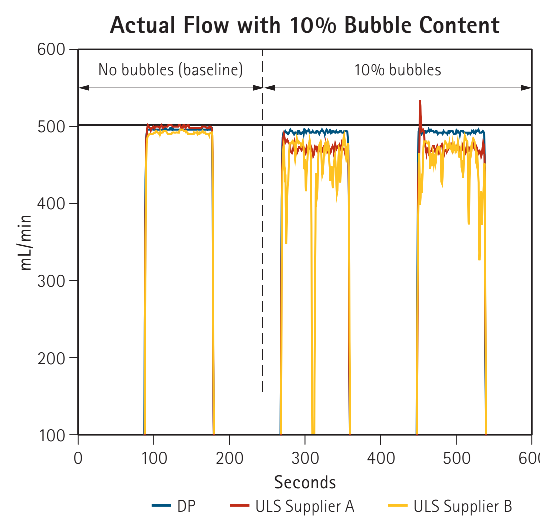

Figure 5

40% BUBBLES

The graph in Figure 6 displays the actual flow of each UUT, as measured by the reference flowmeter, at 500 milliliters (100% Full Scale) per minute with 40% bubble content. The Differential Pressure technology based flow controller produced the least amount of noise and a shift in accuracy. Ultrasonic Supplier A and Ultrasonic Supplier B both displayed high noise and a significant shift in accuracy.

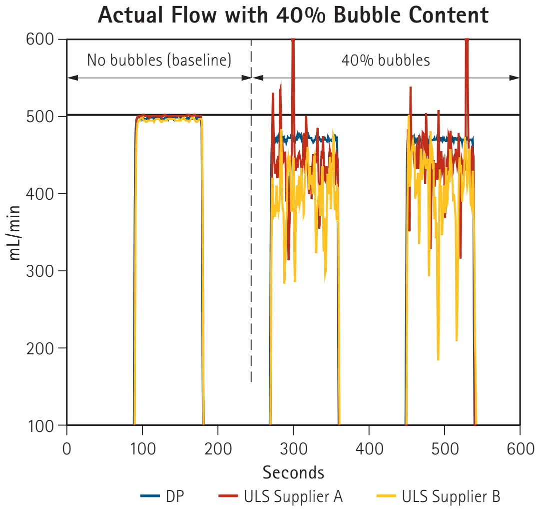

Figure 6

Bubble Effect on Totalized Volume

In the second test method, measuring batch dispense accuracy, a setpoint of 500 milliliters per minute was applied for 60 seconds. The volume of media was collected in a beaker and compared to the area under the curve (totalized volume) of the dispense. This was completed three times each for the two different bubble levels, 10% and 40%. The results of each series of three runs were averaged.

The graph in Figure 7 displays the averaged totalized volume error and standard deviation from the three runs. The flow controller utilizing Differential Pressure technology displayed the best accuracy in the presence of 10% bubbles, with 2% reading error. It also displayed the best repeatability for both bubble levels.

Ultrasonic Supplier A and Ultrasonic Supplier B displayed 4% or greater reading error in both bubble levels. Both Ultrasonic units displayed wider variability of results (poor repeatability).

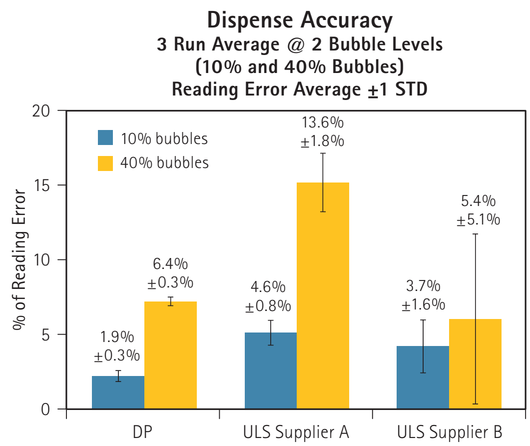

Figure 7

Conclusions

The ideal fluid measurement condition is no bubbles, however some chemistries naturally produce bubbles. In bubble prone chemistries, DP technology demonstrates superior performance for flow measurement. DP technology is more accurate (up to 2 times better) for both levels of bubble concentrations tested. In addition, it is more repeatable (up to 12 times better) than the two ULS units tested.

When using bubble prone chemistries, Differential Pressure based flowmeters and flow controllers are a better choice to achieve the best possible accuracy and repeatability. Accuracy and repeatability translate into tighter process control. Tighter process control delivers optimized consumables and higher yields.

ENTEGRIS, INC.
Corporate Headquarters | 129 Concord Road | Billerica, MA 01821 USA
Customer Service Tel. +1 952 556 4181 | Customer Service Fax +1 952 556 8022
In North America 800 394 4083 | *www.entegris.com*

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