The Accuracy of Open Channel Flow Measurements in Industry

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Abstract Open channel flow measurements are largely used in the process industry to measure waste water discharge. Most measurements use open channel venturi or weir as the measuring device. Demands for sound measurement accuracy from process control, environmental quality systems and environmental protection authorities are constantly increasing.

Indmeas has for years been engaged in quality maintenance of the waste water flow measurements of the Finnish process industry. The basis of quality maintenance is repeated field calibrations. The reference value for an open channel flow is determined by using a radioactive tracer and the dilution method. The quality assurance of the method is obtained in the field by regular comparisons against the accredited transit time tracer method. The calibration results, altogether more than 700, give a representative picture of the accuracy of noncalibrated open channel flow measurement positions, on the critical parts of the measurement chains and on the accuracy level that can be reached by reasonable efforts.

The most critical part in the open channel measurement chain is the water level measurement that is most often carried out by using either a pressure or an ultra sound measurement. Both have their own operational limits and maintenance problems. Measurement stability may also be disturbed by sludge sedimentation on the channel bottom. Other uncertainty components are most often constant with time and can therefore be removed by a field calibration.

Experience has shown that a measurement uncertainty level of +- 5 % can be reached in a fairly straightforward manner by using field calibrations.

Keywords: flow measurement; waste water; accuracy; field calibration; quality assurance

1. Introduction

Good and verified measurement accuracy has become a common requirement in industrial waste water flow measurements. The requirement originates from the needs of process control, commercial interests and by environmental protection objectives.

Where treatment chemicals are dosed into the flow accuracy is needed to maintain optimal dosing. Commercial interests come into the picture when waste water treatment has been outsourced and the treatment is charged according to the flow measurement. Environmentally motivated accuracy requirements originate from the industry´s own environmental quality systems and from the environmental protection authorities. ISO 14000 and EMAS require verification of the discharge measurement results. As to measurement quality the systems in this case have proved to be somewhat inefficient because an industrial plant can define its target accuracy level qualitatively and freely choose the verification method. In Finland there is a recommendation given by the environmental protection authorities for a maximum measurement uncertainty of +- 5 %. A corresponding quantitative recommendation exists in a few other European countries too.

2. Waste water flow measurements

The majority of the waste water flows of industry are measured in open channels by using venturis or weirs. The flow value is obtained by measuring the water level upstream from the measurement device and by calculating the flow from the theoretical discharge equation. The water level is measured by using ultra sound, a pressure transducer or a bubble pipe. The optimal choice between these methods depends on the characteristics of the measurement position.

Waste water flows in pipes are most often measured by using magnetic flow meters. In large diameter pipes the number of ultra sound meters seems to be increasing rapidly.

A small number of waste water flow measurements are carried out in pipes only partly filled with water. The flow is determined by calculating it from the measured values for water level and flow velocity.

3. The quality maintenance based on field calibrations

Indmeas has participated in the quality assurance work related to waste water flow measurements at a number of industrial plants. The field flow calibrations carried out by Indmeas[1] have been the basis for the work. The reference value for the flow through the measurement position is determined on site by using the field calibration method. This reference value is compared with the simultaneous flow value given by the measurement position. In the field calibration the whole measurement chain is controlled up to the final flow value of the plant automation system. The procedure gives not only the total measurement error of the final flow value but also reveals the possible error components distributed along the whole measurement chain. By using this information the error components can be corrected at points where they have originated.

For the field calibrations of open channel flow measurements Indmeas uses the dilution method. A tracer solution with a known radiotracer concentration is injected at a constant rate into the flow. Downstream where the tracer has been mixed thoroughly over the flow cross section a continuous sample is taken into the measurement chamber for measurement of the diluted tracer concentration. The reference value of the flow is obtained by dividing the tracer injection rate by the dilution ratio. The reference flow value is typically measured over 10 – 15 minutes which assures the correct timing in the comparison even in the case of a strongly varying flow and different delays in the reference value and the position value measurements. The uncertainty of the field calibration depends on the calibration conditions, the flow characteristics and the calibration procedure parameters and is determined individually for each case. A typical result in open channel flow measurement calibrations has been 1 – 2 %.

The dilution method is used in partially filled pipes and also for normal pipe flows if sediment layers are suspected to exist on the inner surfaces of the pipe.

However, Indmeas mostly calibrates pipe flow measurements in full pipes using the accredited tracer pulse transit method by which a radioactive tracer pulse is injected into the flow. After the tracer pulse has been mixed over the flow cross section its velocity is measured on a suitable straight pipe section by using radiation detectors mounted on the pipe. The pulse velocity multiplied by the pipe inner cross section gives the flow reference value, which is compared with the simultaneous flow value given by the flow meter. The smallest calibration uncertainty stated in the accreditation decision is 0.8 %. The calibration uncertainty is determined case by case. In waste water pipe flow measurement calibrations it is usually 1 – 1.5 %.

4. The actual measurement accuracy in industrial waste water flow measurements

Indmeas has carried out altogether more than 700 field calibrations for industrial waste water flow measurements using the methods described above. Most of the calibrations have been carried out according to quality assurance agreements between industrial plants and Indmeas. Calibration objects have mainly been large waste water discharge measurements for the Finnish forestry industry. The calibration results have been carefully documented in the database of Indmeas. The database gives the possibility to draw statistical conclusions on the industry's initial measurement uncertainty and on its improvement in the course of quality assurance work. The database also contains statistical information on the main error components in the measurement chains.

Fig. 1 presents the distribution of the total measurement errors observed in the first field calibrations of open channel venturi measurements. The distribution accordingly represents the measurement uncertainty level which industry reaches by using its own normal installation and maintenance routines. Only about one third of the first calibration measurements fulfilled the recommendation for a maximum of +- 5 % measurement uncertainty. Significantly large measurement errors were often encountered.

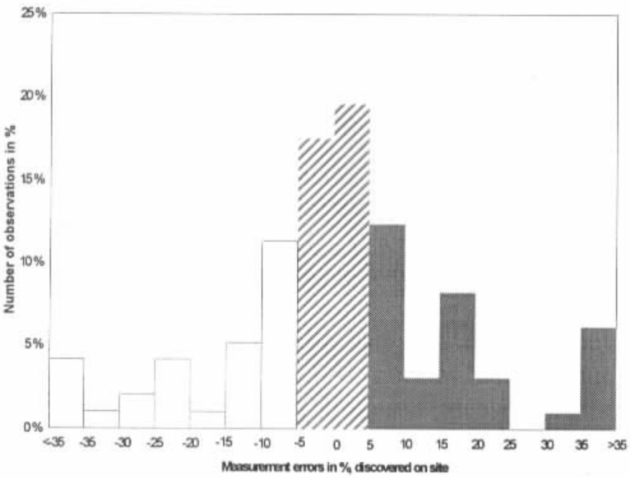

Fig. 1. The error distribution observed in the first calibrations of open channel venturi measurements. The number of observations is 97

Fig. 2 presents the statistical measurement stability of venturis. This is estimated by using the recalibration results. Fig. 2 also represents the statistical mean measurement uncertainty after starting the quality assurance work. More than 80 % of the venturi measurements have been inside the authority recommendation of +- 5 %. It should be noted that these figures are also mean values taken over all recalibrations of the same position. In an average measurement position the measurement accuracy tends to improve further along recalibrations due to the adjusting of maintenance work according to the observations in recalibrations.

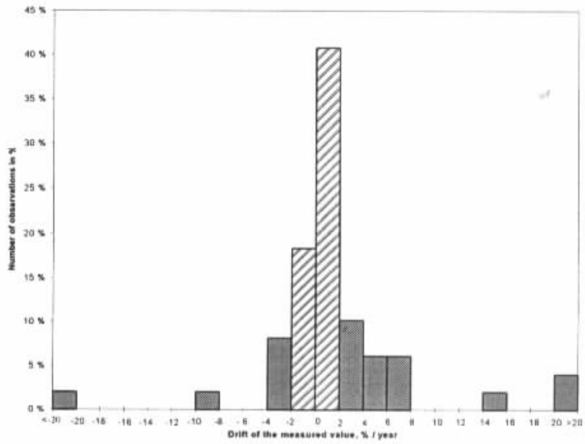

Fig. 2. The statistical stability of venturi measurements. The number of observations is 49.

Weir measurements, although fewer in number, have very similar error statistics. In the first calibrations 33 % of weir measurement errors were inside +- 5 % and in recalibrations 87 %.

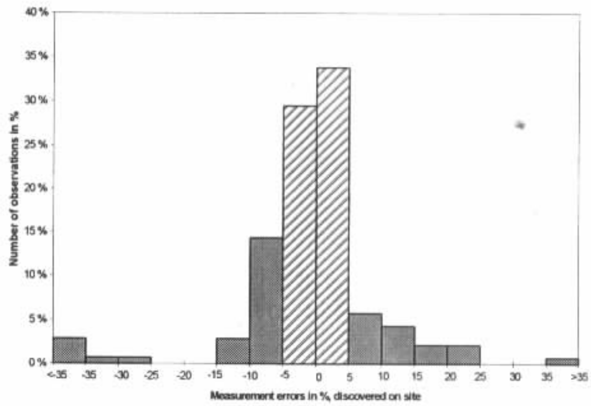

Fig. 3. The error distribution observed in the first calibrations of magnetic full pipe flow measurements. The number of observations is 139.

Fig. 3 presents the error distribution from the first calibrations for magnetic flow meters measuring full pipe flow. 65 % of magnetic measurements had an error less than +- 5 %. In recalibrations, see Fig. 4, the corresponding percentage had increased to 91 %.

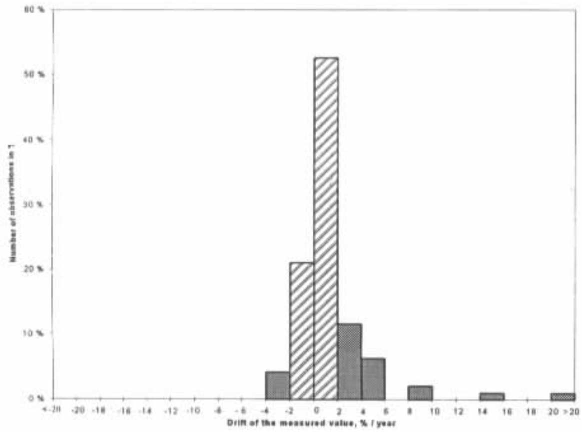

Fig. 4. The statistical stability of magnetic full pipe flow measurements. The number of observations is 95.

Ultrasound meters measuring full pipe flow have been mainly clamp-on meters installed in large diameter pipes. The number of measurement positions for which calibration data exists is only a quarter of that of magnetic measurements. In the first calibrations 55 % of ultra sound measurement errors were within +- 5 %. In the very few recalibrations carried out so far the statistical measurement accuracy was somewhat worse. This was due to the dominating share of repeated recalibrations in a few exceptionally problematic measurement positions when searching for a feasible measurement method for them.

5. The main factors affecting measurement accuracy

In open channel measurements an improper or inaccurately adjusted level measurement is the most important factor affecting both the flow measurement accuracy and stability. The accuracy demands in level measurements have on average actually increased due to the decrease of waste water discharges from industrial plants. Many measurement installations have become over dimensioned but are still used as they are for the flow measurement.

Installation errors of flow calculation equations in the plant automation systems may cause large errors in flow values. However, these types of errors are not frequent and they are eliminated in the first field calibration. The error components due to dimensional tolerances of venturi and weir structures are generally small and constant and can be corrected by the first calibration.

Sediment accumulation on the bottom of an open channel measurement is a well known and easily detectable error source. Its significance, however, is nowadays much smaller than earlier. Progress is attributed to decreased solids in waste waters and more responsible and effective measurement maintenance measures that have been generally adopted.

Both in magnetic and ultra sound flow measurements the most frequent reason for large measurement errors has been the entrained or separated gas phase in the flow. The existence of significant gas amounts affecting the flow measurement can be detected in a field calibration by density measurements with a small collimated gamma source and a radiation detector. The several measurement difficulties encountered when using clamp-on ultra sound meters for waste waters in large pipe diameters indicate that much more experience must be collected before this application area can be regarded as well established.

6. Conclusions

The statistics from field calibration results show that nowadays the flow in full pipes is measured significantly more accurately than in open channels. The difference is obviously partly explained by the fact that the water quality in pipe flows makes it on average easier take measurements. Another contributing factor is that the installation of pipe flow meters is well standardized routine process compared with that of open channel positions where much more responsibility is left to the user. In principle open channel measurements are not more inaccurate but demand more carefulness in planning, construction and maintenance. On the other hand the user can, by using straight forward measures, control the stability of the open channel measurement fairly easily.

Comprehensive experience, however, shows that irrespective of the flow type and flow measurement equipment chosen it is very difficult for the industry, when using its own methods, to reach an uncertainty level of +- 5 % in waste water flow measurements. The only known effective means to reach this target level is to use a quality assurance system based on reliable field flow calibrations.

References

[1] Kuoppamäki R. *Quality Maintenance of Flow Measurements in Industry, Flomeko '2000, The International Conference on Flow Measurement,* June 4-8, 2000, Salvador, Brazil