Modelling of multiphase flow measurements in Coriolis flowmeters: Status, cross-disciplinary applications and future developments

5. Modeling and inverse problems

Nils Basse[1]

[1] RISE Research Institutes of Sweden

Abstract

Multiphase flow measurement is challenging for most flowmeter technologies, including Coriolis flowmeters. Significant research efforts are ongoing to address both two- [1] and three-phase [2] flows. Modern techniques such as artificial neural networks have been employed to make progress [3].

Developments in multiphase flow measurements using Coriolis flowmeters is rapidly evolving and it is timely to present a status of recent modelling efforts. These will be compared to experiments and simulations to create a research roadmap.

Theoretical modelling of two-phase flow, also known as the “bubble theory”, can be traced back to [4], with the complete theory only being publicly available in 2014 [5]. The measurement error is due to an effect named “phase decoupling”, where the motion of the two phases becomes decoupled and violates the common center-of-mass motion assumed for single-phase fluids. This error exists both for mass flow and density measurements; for gas-liquid mixtures, it is particularly severe and leads to significant damping which may cause complete measurement failures [6].

In addition to phase decoupling, other error and damping mechanisms can play a role, e.g. effects due to compressibility [7]. This implies that multiple effects must be treated simultaneously, see e.g. [8] for an example.

The bubble theory has been applied to other scientific fields such as the bias flow aperture theory, where a turbulent jet and vortex shedding can be interpreted as an acoustic manifestation of two-phase flow [9]. Sound propagation and attenuation in aerosols and hydrosols has been analysed with an amended version of the bubble theory, which is another cross-disciplinary application [10].

The future for modelling of multiphase flow in Coriolis flowmeters can be approached using a multipronged strategy, where one path is to work on the underlying assumptions of the bubble theory [5,11]. Another path is to improve the modelling of several physical effects at once, perhaps with less accuracy of the individual contributions but with better overall accuracy.

This modelling work is referring to two-phase flow; there is an even wider range of questions to address for three-phase flow.

For all types of multiphase flow modelling, measurement uncertainty has to be analysed as an integral part of the research to enable statements with a solid foundation.

References

[1] M. Henry et al. Two-phase flow metering of heavy oil using a Coriolis mass flow meter: A case study. Flow Meas. Instrum. Vol. 17, 2006, 399-413

[2] M. Henry et al. Coriolis mass flow metering for three-phase flow: A case study. Flow Meas. Instrum. Vol. 30, 2013, 112-122

[3] S. Bahrami et al. Application of artificial neural network to multiphase flow metering: A review. Flow Meas. Instrum. Vol. 97, 2024, 102601

[4] J. Hemp and G. Sultan. On the theory and performance of Coriolis mass flowmeters. In: Proceedings of the international conference on mass flow measurement, IBC technical services, 1989, 1–38

[5] N.T. Basse. A review of the theory of Coriolis flowmeter measurement errors due to entrained particles. Flow Meas. Instrum. Vol. 37, 2014, 107-118

[6] N.T. Basse. Coriolis flowmeter damping for two-phase flow due to decoupling. Flow Meas. Instrum. Vol. 52, 2016, 40-52

[7] J. Hemp and J. Kutin. Theory of errors in Coriolis flowmeter readings due to compressibility of the fluid being metered. Flow Meas. Instrum. Vol. 17, 2006, 359-369

[8] D.L. Gysling. Accurate mass flow and density of bubbly liquids using speed of sound augmented Coriolis technology. Flow Meas. Instrum. Vol. 91, 2023, 102358

[9] N.T. Basse. On the analogy between the bias flow aperture theory and the Coriolis flowmeter “bubble theory”. Flow Meas. Instrum. Vol. 71, 2020, 101663

[10] N.T. Basse. Application of the amended Coriolis flowmeter ‘‘bubble theory’’ to sound propagation and attenuation in aerosols and hydrosols. Flow Meas. Instrum. Vol. 77, 2021, 101875

[11] S. Wernli et al. Coriolis massflow measurement errors due to inhomogeneous entrained particles: An analytical model. Flow Meas. Instrum. Vol. 103, 2025, 102847