On two-phase flow models for Coriolis flowmeters

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Introduction

• a Coriolis flowmeter measures flowrate by force.
• play as a ‘real’ mass flowmeter.
• multi-purpose measurement by one meter.

Based on Baker: Flow Measurement Handbook, 2nd Ed. CUP
## Errors of Coriolis flowmeters in multiphase flow

*(Test data)*

<table>
<thead>
<tr>
<th>Author</th>
<th>Coriolis meter installation</th>
<th>Fluids</th>
<th>Void fraction</th>
<th>Max. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skea and Hall</td>
<td>Straight, Curved</td>
<td>Oil+N2</td>
<td>6% N₂, 9% N₂, Max. 15%</td>
<td>-15%, +5% 0.3%(small)</td>
</tr>
<tr>
<td></td>
<td>3 others</td>
<td>Water in oil, Oil in water</td>
<td></td>
<td>Not work</td>
</tr>
<tr>
<td>Wang et al</td>
<td>Vertical</td>
<td>Liquid and gas CO₂</td>
<td>0~70%</td>
<td>-16%~2%</td>
</tr>
<tr>
<td></td>
<td>Horizontal</td>
<td></td>
<td></td>
<td>-4%~14%</td>
</tr>
<tr>
<td>Michael et al</td>
<td>normal</td>
<td>High viscous oil N₂</td>
<td>0~90%</td>
<td>±2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±5%</td>
</tr>
<tr>
<td>Liu et al</td>
<td>U type</td>
<td>air, water</td>
<td>0~35%</td>
<td>0~ -25%</td>
</tr>
<tr>
<td>B B Tao et al</td>
<td>U type, horizontal</td>
<td>Gas, water</td>
<td>0~25%</td>
<td>2%~ -22%</td>
</tr>
<tr>
<td>Weinstein</td>
<td>U type, up/down</td>
<td>Gas, water</td>
<td>0~8%</td>
<td>Up: -15%, down: 12%</td>
</tr>
</tbody>
</table>
Models for Coriolis flowmeters in multiphase flow

• 2003  Hemp and Hoi: bubble model – solid sphere
• 2006  Hemp and Kutin: compressibility, well mixed
• 2007  Gysling: aeroelastic model
• 2008  Weistain Ph D thesis: phase decouple, relative speed
• 2014  Wang and Baker: detailed Review of Coriolis flowmeter
• 2016  Basse: damping

• 2001  Liu at el: neural network for signal
But works still being done to improve the models we were trying to look at how multiphase flows affect a Coriolis flowmeter.
Experiment - 1 : Bubble rising in still water
• **Bubble shape** - flexible flat instead of solid sphere shape changes while moving
• Bubble motion – spiral instead of straight, caused by flat bubble shape
• bubble induced vibration
• Standard deviation of bubble flow induced vibration

<table>
<thead>
<tr>
<th>Gas flowrate (L/min)</th>
<th>0.4</th>
<th>0.8</th>
<th>1.2</th>
<th>1.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard deviation</td>
<td>0.053</td>
<td>0.083</td>
<td>0.148</td>
<td>0.235</td>
</tr>
<tr>
<td>with uncertainty</td>
<td>±0.003</td>
<td>±0.002</td>
<td>±0.035</td>
<td>±0.067</td>
</tr>
</tbody>
</table>

induced vibration increases with gas void fraction
Experiment - 2: water-air flows
• Flows induced vibration
• water flow with/without external vibration
water flow and water-air flow under external excitation
• Water-air flow under vibration – 1st modal damping
• Damping - 2\textsuperscript{nd} modal
In modeling

- Transverse vibration of a Coriolis flowmeter in water-air flow may be described by this simplified equation:

\[ M \frac{d^2 x}{dt^2} + C \frac{dx}{dt} + Kx = F_0 \sin(\omega t) + F_1 + F_2 \]

- \( M \) - total mass including water and ‘added mass’ of air;
- \( C \) - total damping including structure, fluids, phase interaction
- \( K \) – structure stiffness mainly
- \( F_0 \sin(\omega t) \) - external excitation
- \( F_1 \) – Coriolis force
- \( F_2 \) – water+ air flows induced transverse force

- [Green] - almost known
- [Blue] - known to some extent
- [Red] - hard to predict
Bubble shape

• Relative motion/’decouple’ makes bubble shape changes. Solid sphere bubble model seems not real. ‘Added mass’ depends on the shape.
• A flat bubble with added mass coefficient can be up to 0.97. It is larger than 0.5 as given to sphere bubble.
• Unable to give a correct ‘added mas’s causes error of models.
Damping of flow

• Existence of bubbles in water causes extra vibration damping.
• The damping ratio is proportional to void fraction of the air for both vibration modals (1\textsuperscript{st} and 2\textsuperscript{nd})
• Damping suppresses vibration amplitude especially near resonance region, and makes a small shift of resonance frequency.
• Unknown damping may cause error in flowrate measurement
Bubble motion

- Bubbles travel in non-straight way, this induces transverse vibration additional to external excitation, the later is applied by the flowmeter.
- The induced vibration may cause error in flowrate measurement
flowmeter structure

• Structure of the flowmeter has its intrinsic vibration response property. This is called transfer function.

• Flow induced vibration and external excitation will go through the transfer function to output signal.

• Poor structure design may amplify bubble induced vibration
Some thing missing?

- Phase distribution and bubble interaction are not considered in above equation.
- They are hard to measure and to describe mathematically.
Possible ways to do improvement

• With good understanding of principles of the meters in multiphase flow:
  Do numerical computation using commercial software for a better design.

• For existing meters:
  Do more measurements (induced vibration, multi-frequency excitation, additional sensors), then do signal analysis

  further work to do
Summary

• We review works on theoretical models for Coriolis flowmeters used in multiphase flows

• We do experiments on bubble rising in still water and on water-air two-phase flow, with/without external vibration

• It is found:
  1) bubbles cannot be taken as solid spheres
  2) bubbles moving in water induce transverse vibration
  3) bubbles in water induce vibration damping
• Also, difficulties in giving a good model for a Coriolis flow meter in two-phase flow are discussed.

• Further work to improve the theoretical model to reduce measurement errors are suggested.
References


[12] Zhang XZ: Damping of vibrating pipe conveying water-air flow and its effect on Coriolis flow meter, SICE2016, Tsukuba, Japan
Thank you for your time
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