Air pocket removal from downward sloping pipes

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Background of Joint Industry Project CAPWAT

- CAPacity loss
- waste WATer mains
- Air accumulation in downward sloping sections
- Consequences
  - Energy losses
  - More maintenance
  - More investments
  - Unreliable transport capacity

- CAPWAT project 2003 – 2010
  - Water boards, pump manufacturer, consultants, Stowa, RIONED
  - Deltares, DUT
Facility in Hoek van Holland (video)
Key questions of CAPWAT

- What is required water velocity to move an elongated air pocket?
- How long should a certain water velocity be maintained to break down an air pocket?
- What are feasible mitigating measures?
- Need for practical guidelines
Approach for air pocket removal model

- Validated numerical model for steady air discharge
  - Geometry: Pipe diameter, pipe angle, length of slope
  - Operation: water discharge, gas pocket length, absolute pressure
- Assume no air inflow, then air outflow ......
  - reduces gas pocket length/head loss
  - reduces absolute pressure
  - may increase water discharge or reduce pump speed
- Integration in time yields
  - Evolution of gas pocket length and head loss,
  - Required water volume for head loss reduction
Air discharge highly varies due to gas pocket length.

Measured differential pressure, $\Delta p$ [bar]

Liquid flow number, $F_w$ [-]

$$F_w = \frac{v_{sw}}{\sqrt{gD}}$$
Assumptions for air pocket removal model

- Water is at normal depth under air pocket(s)
- Air pocket length and head loss are linearly related
- Air expansion is isothermal
- Air expansion in upstream section is neglected

- Validation experiments
  - $F_w = 0.63; 0.75$ and $0.94$
Experiment at 25 l/s, 0.86 m/s, $F_w = 0.63$
Model performance

- Experiment Fw = 0.63
- Experiment Fw = 0.72
- Experiment Fw = 0.94
- Model Fw = 0.63
- Model Fw = 0.72
- Model Fw = 0.94

Differential pressure [bar] vs. Time [s]
Conclusions and discussion

• Reasonable performance
  • required time and
  • water volume for air pocket removal

• However,
  • Air discharge is over-predicted for very large air pockets
  • If multiple air pockets are present ($F_w > 0.6$), pressure recovery in hydraulic jumps should not be neglected.
Range of applications

- Air pocket removal in inverted siphons
- Air pockets behaviour in hydropower bottom outlets
- Air pockets behaviour in stormwater storage tunnels

Questions?

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Approach – scientific track

- Lab measurements of co-current air-water flow in downward sloping pipes
  - Pipe diameter, pipe angle, air-water discharge ratio, equilibrium gas pocket length, absolute pressure
- Experiments at large-scale facility at WWTP
  - Length of sloping reach, water quality
  - 3 series of experiments
    > Clean water
    > Water with detergents
    > Untreated wastewater
## Overview of air-water flow experiments

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Key results - Flow regimes

- **Flow regimes**
  - **No accumulation**: one long air pocket and hydraulic jump; maximum head loss
  - **Transition multiple pockets**: multiple hydraulic jumps; intermediate head loss
  - **Elongated air pockets move downstream; no head loss**

\[ \frac{v_w}{(gD)^{1/2}} \]

*downward pipe angle, \( \theta \) [%]*
Approach – practical track

- 3 progress meetings / workshops per year
  - Input for Handbook
- Handbook on hydraulic design & operation of pressurised wastewater mains
  - Editorial Board from participants
  - Input from scientific track
- First release 2010, update 2011 (Dutch)
Table of Contents
1. Preface
2. Design of wastewater transportation systems
3. Pipeline design
4. Pumping station design
5. Transient events
6. Review of integrated system
7. Design considerations to maintain the hydraulic capacity
8. Commissioning of the system
9. Monitoring the hydraulic capacity
10. Literature.
Possible air management measures

- Pump stop procedure (soft-stop)
- Raise switch-off level
- Vertical deflection plate in pump pit
- Include pigging facility (Y-piece)
- Reduce diameter of inverted siphon

- See paper for more
CAPWAT applications

- **Wastewater engineering**
  - Design – minimise air-entrainment into pipeline
  - Operation – prevent capacity issues and excessive energy consumption
  - Operation – compute water volume to breakdown air accumulation

- **Stormwater storage tunnels and hydropower stations**
  - Better understanding of air pocket motion
  - Prevent blow-back events
  - Proper venting

- **Two-phase flow applications**
  - Downwardly inclined pipe as efficient separator
  - Possibly improve slug prediction models
• **Measured variables**
  - Air discharge (controlled)
  - Water discharge (controlled)
  - Differential pressure
  - Absolute upstream pressure
  - Water temperature
  - Air pocket characteristics (length, max. height)

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**Diagram:**
- Hydraulic grade line (HGL)
- Gas accumulation
- Hydraulic jump
- Reference plane
- $p_1$, $v_{sw}$, $y_1$, $v_{w1}$
- $p_2$, $v_{w2}$, $y_2$