Optical analysis of air release in a liquid flow behind an orifice

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Motivation

Hydraulic systems, cavitation and air release

> Cavitation in hydraulic systems can lead to:
  > Erosion
  > Vibration & noise
  > Alteration of hydraulic liquids
  > Chocked flow phenomena
  > Efficiency losses vs. acoustic decoupling
  > **Air release** (each liquid contains air)

Notes:

> Cavitation can not be avoided in general – it has to be controlled (focus on erosion)
> The same is valid for air release
> Cavitation occurs on small time & spatial scales (ns, μs / nm, μm)
> But: Air release occurs on larger time & spatial scales than cavitation (ms, s, h or days in some cases / μm, mm)
Motivation

Air release in hydraulic systems

- Degassed air leads to bubbles in the liquid:
  - **Change of liquid properties**
    - Density
    - Bulk modulus
    - Speed of sound
    - Viscosity
  - **Change of hydraulic system properties**
    - Mass flow
    - Generated forces
    - Eigen-frequencies
    - Vibration & noise

Research objectives*:

Cavitation  →  Degassing  →  Dissolving of air  →  Modelling

\[ \frac{\partial \rho}{\partial t} + \frac{\partial \rho v}{\partial z} = 0 \]


Note: Compression -> hot bubbles -> Diesel lightening

Suction and compression phase in a cylinder of a high pressure piston pump
Experiments

Experimental setup

2 fluid tanks
Gear pump
Pressure transducers
Temperature transducers
Mass flow meter
Stopcocks
Flow channel
4 Optical accesses

\( p_{\text{in}} = 75 \text{ bar} \)
\( P_{\text{out}} = 3.0 \text{ bar} \)

\( \phi = 0.2 \text{ mm} \)
\( l = 2 \text{ mm} \)
Experiments

Optical setup - shadowgraphy

- **Flash light**: NanoLite
- **Flow Channel**: 1 mm x 1 mm
- **Objective**: B.Halle, f=100 mm
- **Camera**: PCO 2000, 2048 x 2048

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Results

Choked flow - air release

Inlet pressure: 50 bar & 75 bar
Distance throttle - optical access: 100 mm
Fluid: V1404

Choked flow curve

Bernoulli curve

Pressure drop (p_in-p_out) [bar]

m² [g/(s)²]

P_in=50 bar
P_in=75 bar
P_out = 4.9 bar
P_out = 4.0 bar
P_out = 3.3 bar
P_out = 2.5 bar

Ø = 8 mm

75 bar, tube
75 bar, channel
50 bar, tube
50 bar, channel
Results

Bubble recognition & characterization

1. Image preparation

2. Segmentation of bubble images
   - Hough-Transformation ➔ spherical bubbles
   - Image binarization ➔ spherical and non-spherical bubbles

3. Determination of bubble size
   - Determine intensity profile for round bubble images
   - Determine bubble radius at half intensity level

4. Size correction
   - Determine optical scale
   - Size correction using the contrast

\[ I := \frac{I_B + I_{\text{min}}}{2} \rightarrow r_i \]
Results

Degassing – results

→ Distance: 100 mm
→ Liquid is saturated with air at atmospheric pressure:

\[ c_g = 1.03 \times 10^{-3} \text{ mol/mol} \]

\[ p_b = p_l + \frac{2\sigma}{r_b} \]

\[ \xi := \frac{n_l \cdot c_g}{n_g} \times 100 \]

\[ n_l = (V_{channel} - \sum V_{bubbles}) \frac{\rho_l}{M_l} \]

\[ n_g = \sum \frac{p_b V_b}{RT_l} \]
Results

Bubble size distribution – 100 images

- Inlet pressure: 75 bar
- Inlet pressure: 50 bar

Bubble size distribution

- Bubble diameter [μm]
- Number of bubbles

Inlet pressure: 75 bar
- p_out = 2.53 bar
- p_out = 3.10 bar
- p_out = 3.87 bar
- p_out = 4.46 bar

Inlet pressure: 50 bar
- p_out = 2.49 bar
- p_out = 3.07 bar
- p_out = 3.88 bar
- p_out = 4.47 bar
Conclusion

Present Work & Results for V1404 and stated conditions

- Gas bubbles in hydraulic systems affect system behavior significantly
- Degassing of air is strongly linked to cavitation
- Degassing occurs only at choked flow conditions
- Degassing is very sensible to outlet pressure; approx. exponential correlation
- Number and size of bubbles depend on in- and outlet pressure conditions

Future Work

- Variation of air content in liquid (air content in tank)
- Variation of orifice dimensions and geometry (D/L)
- Modelling of air release in hydraulic systems
Thank you!