Deltares

Enabling Delta Life

Fundamentals of Urban Drainage CT-4491

Pressurised systems

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Content

Pumping stations in systems

Capacity problems in pressurised wastewater systems

- clogged pump
- gas pockets in inverted siphons

Hydraulic design guidelines for pressurised wastewater systems

- Pump pit
- Pumping station
- Pipeline

Pumping stations in systems

Learning goal

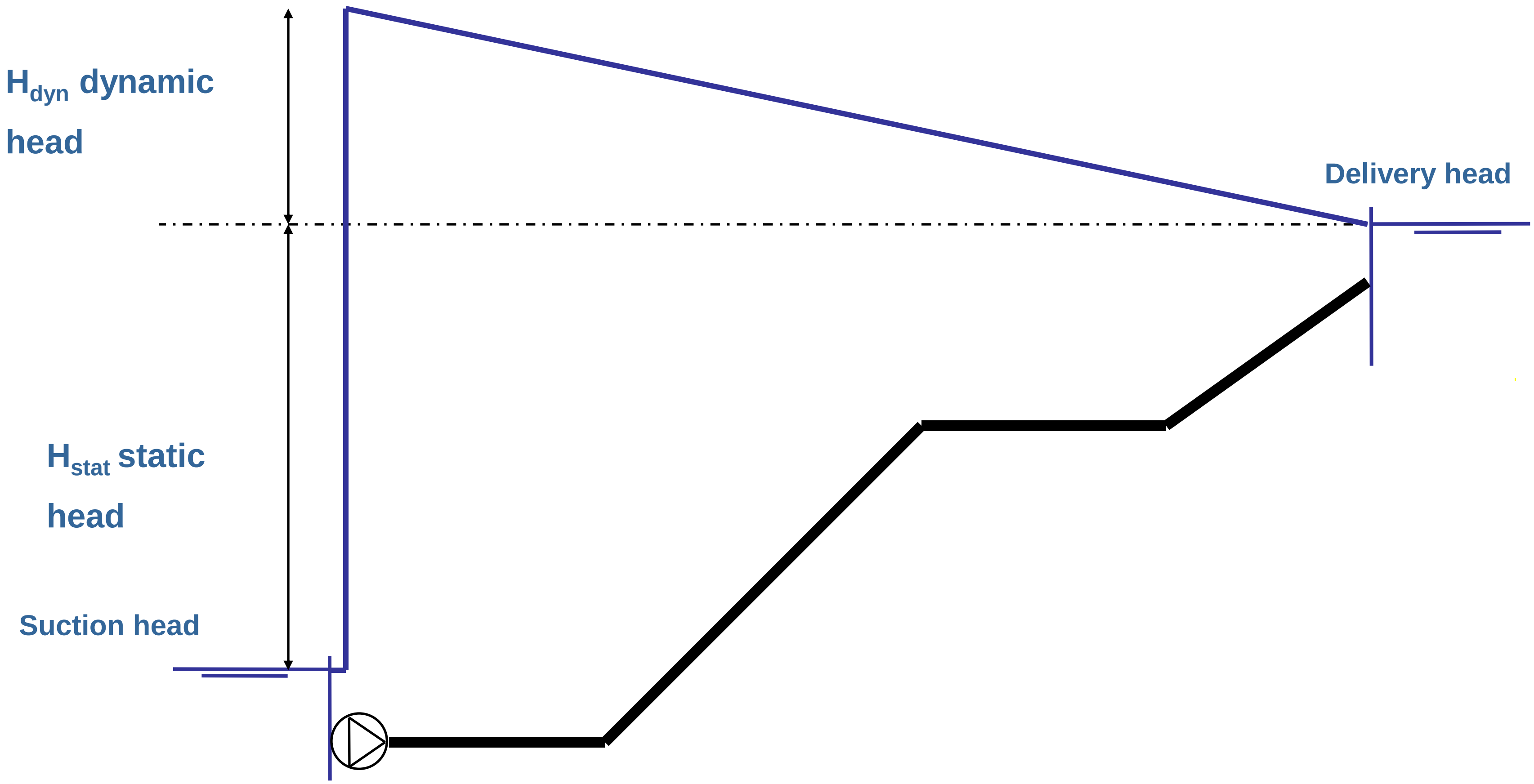
- Understand the interaction between system and pumping station

- Characterise the system, independently of the pumps
  - > System characteristic
  - > Static head, suction head, delivery head
  - > Dynamic head

- Characterise the pump(s), independently of the system
  - > Pump capacity curve, Q-H curve
  - > Pump head

- Combine the system characteristic and pump curve(s) to find the duty point(s)

System characteristic



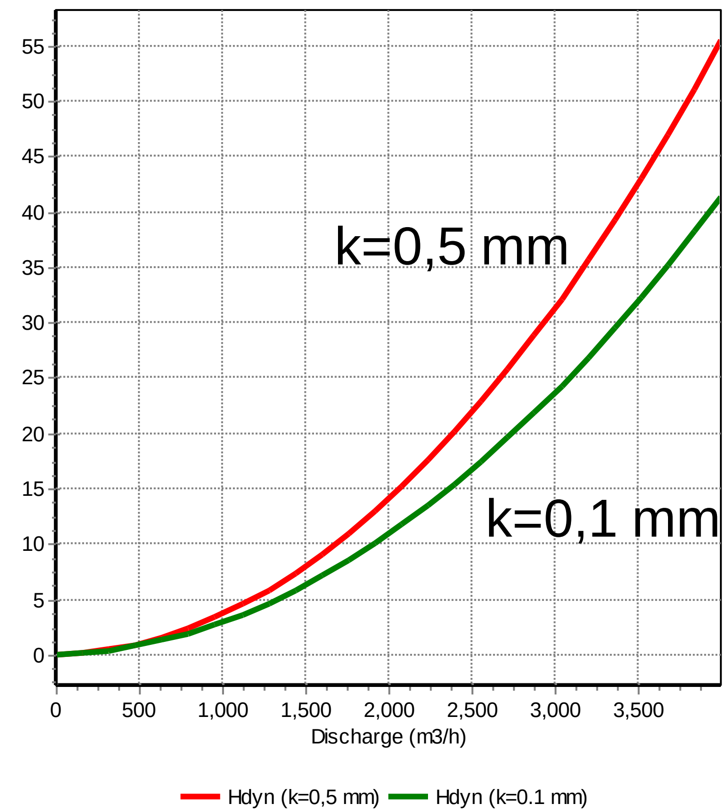
System characteristic

Definition:: static + dynamic head as function of discharge Q

$$\Delta H = H_{st} + \left(\lambda \frac{L}{D} + \xi \right) . \frac{v^2}{2g}$$

$$= H_{st} + \left(\lambda \frac{L}{D} + \xi \right) . \frac{\left(\frac{Q}{A} \right)^2}{2g}$$

$$= H_{st} + \frac{8}{g \pi^2} \left(\lambda \frac{L}{D^5} + \frac{\xi}{D^4} \right) . Q^2 = H_{st} + C\, Q^2$$



Factors affecting the system characteristic

Static head factors (H_{stat})

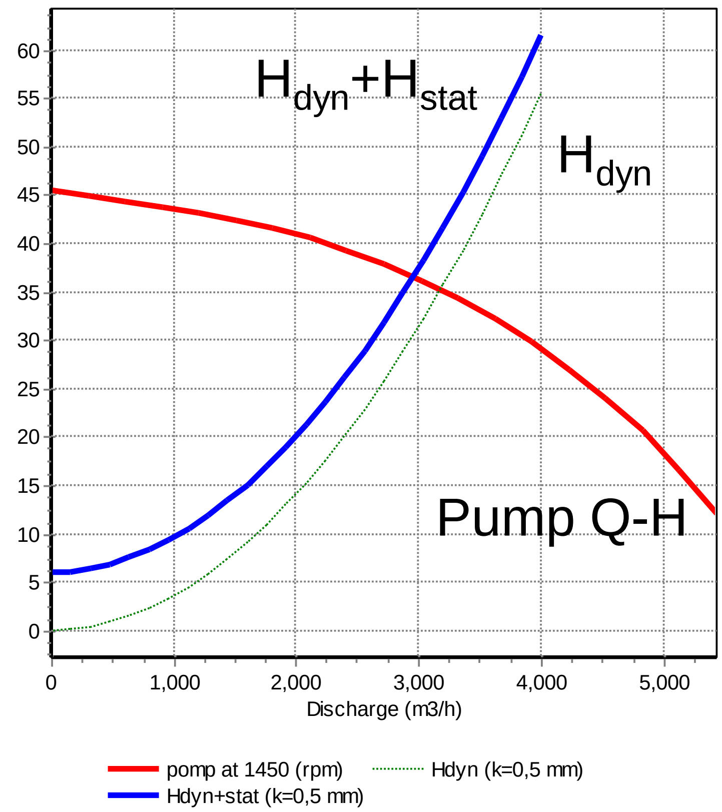
- Suction head
- Delivery head

Dynamic head factors (H_{dyn})

- Control valves
- Wall roughness
- Other pumping stations in the same wastewater transportation system

Pump and system characteristic

- Pump curve is supplied by manufacturer
- Intersection of pump curve and system characteristic is the duty point



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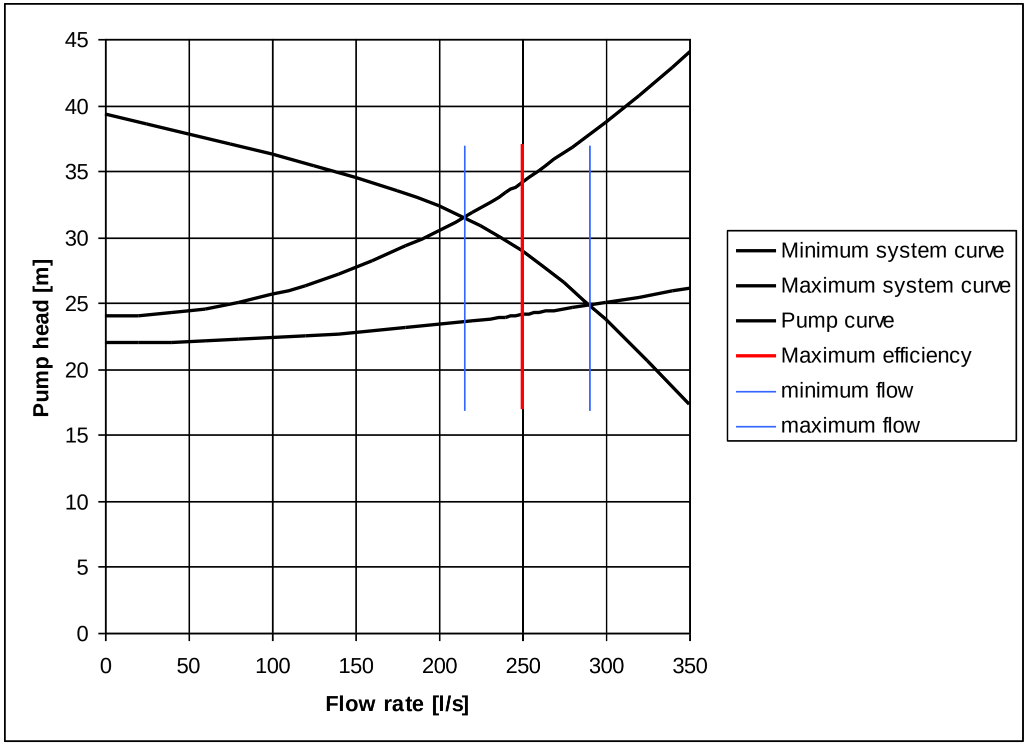
Pump and system characteristic

Each pumping station has to cope with a range of system curves, due to

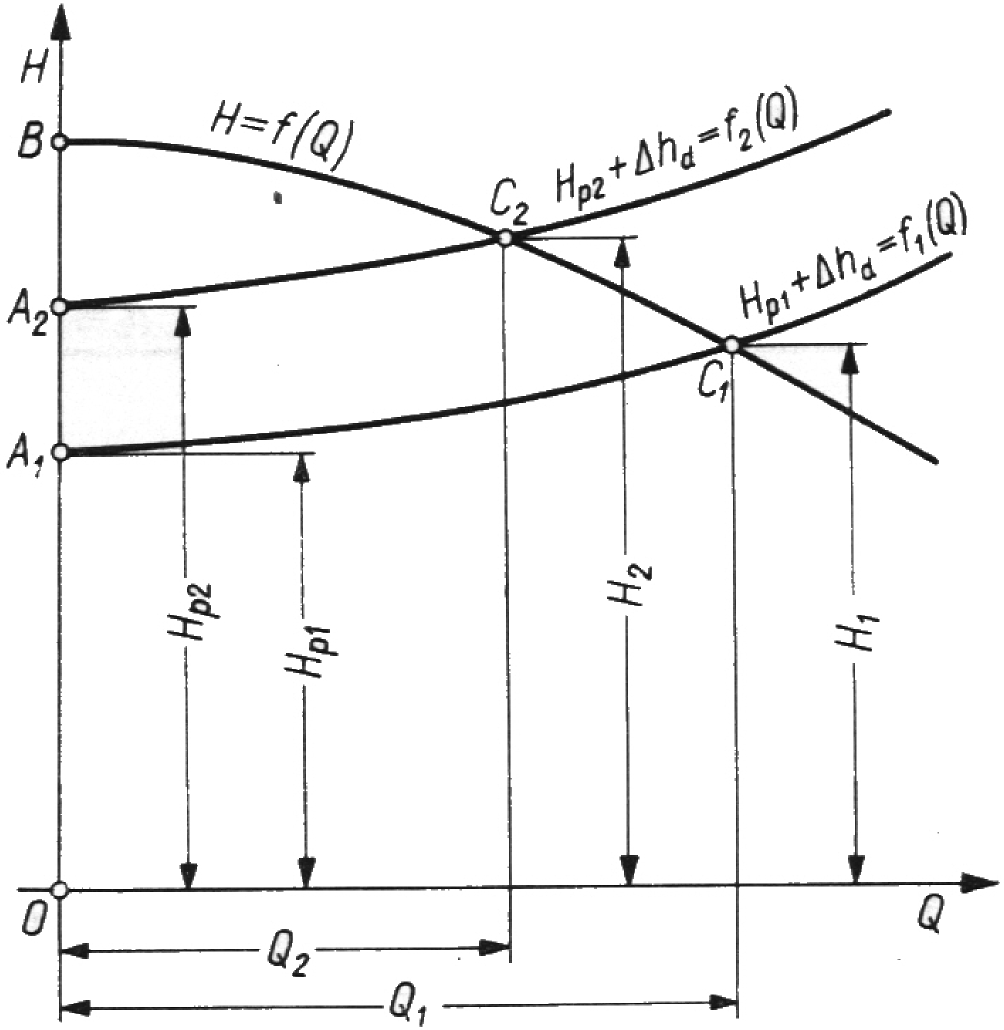
- Other pumping stations
- Increased wall friction in time
- Gas pocket accumulation



Suction level variation

H_{stat} varies

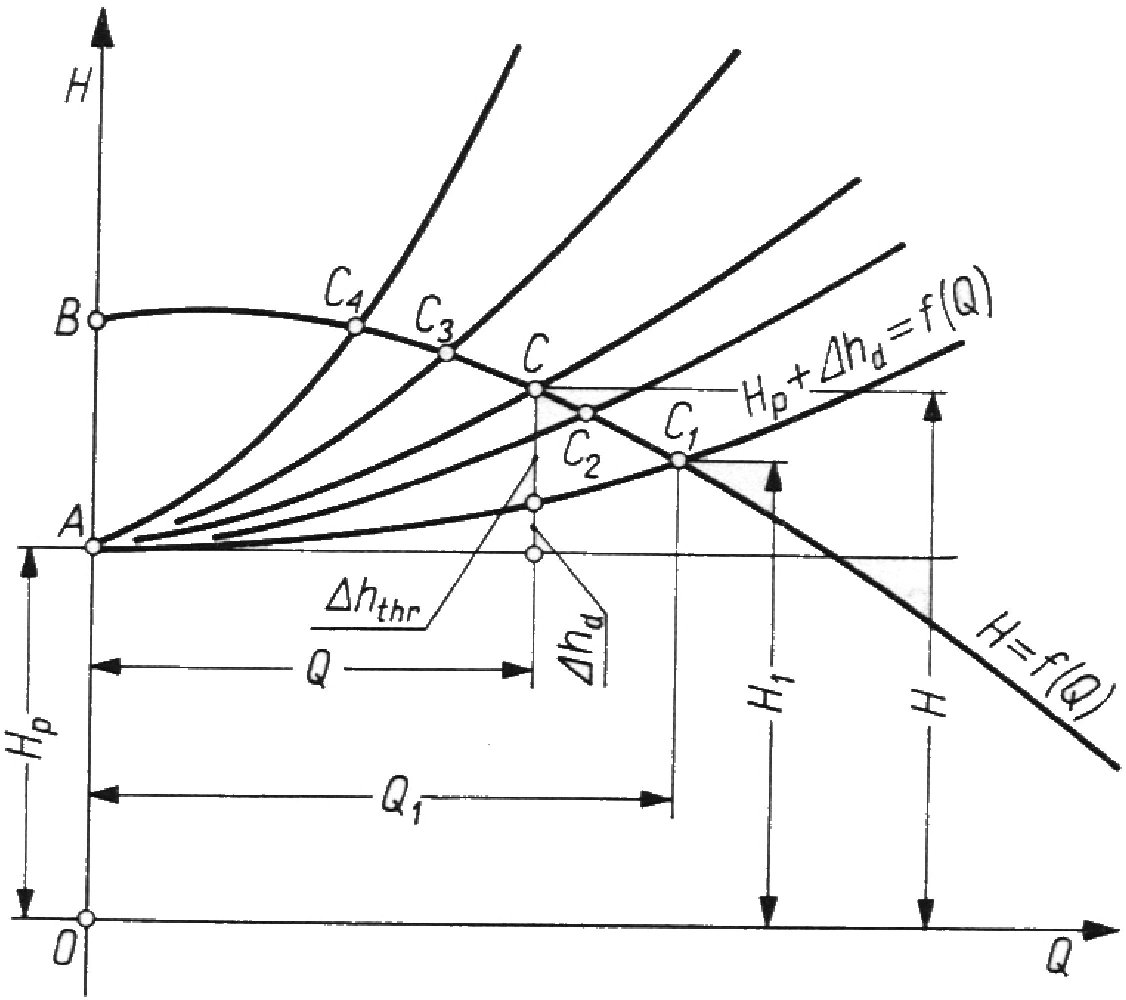
System curve shifts vertically



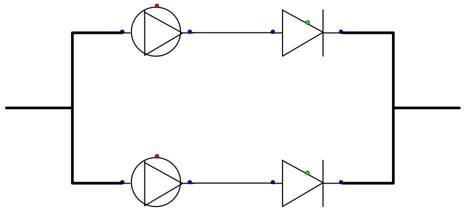
Influence of wall friction / control valve

H_{dyn} varies

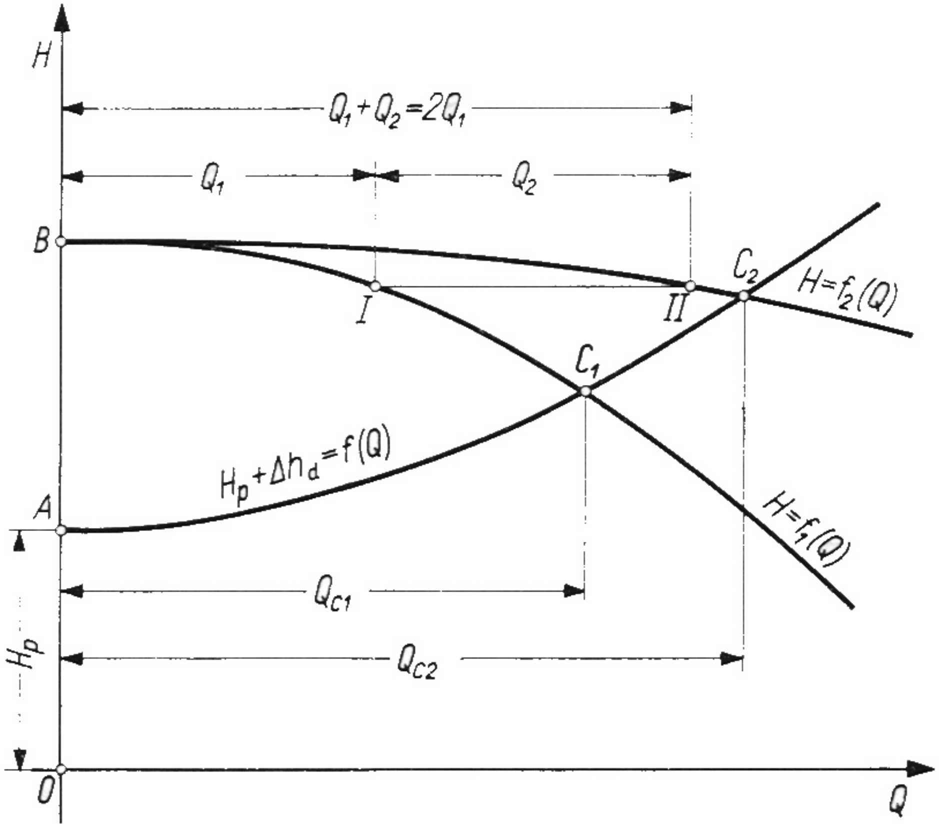
System curve gradient varies



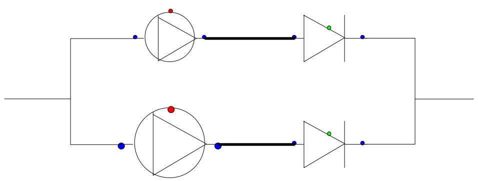
Combining pump curves (parallel)

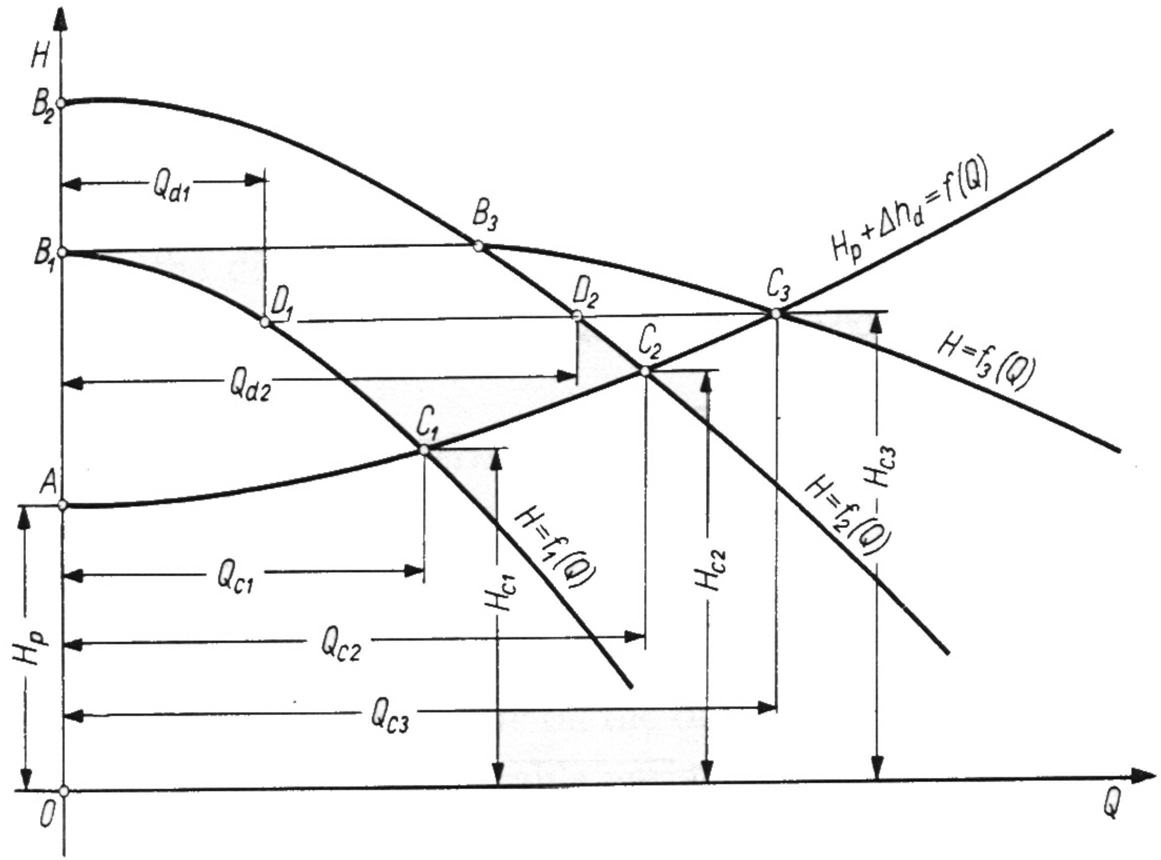


- Sum pump Q at each pump H
- Flow rate at duty point does not double with 2nd pump



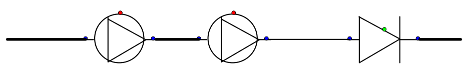
Combining pump curves (parallel, different capacity)



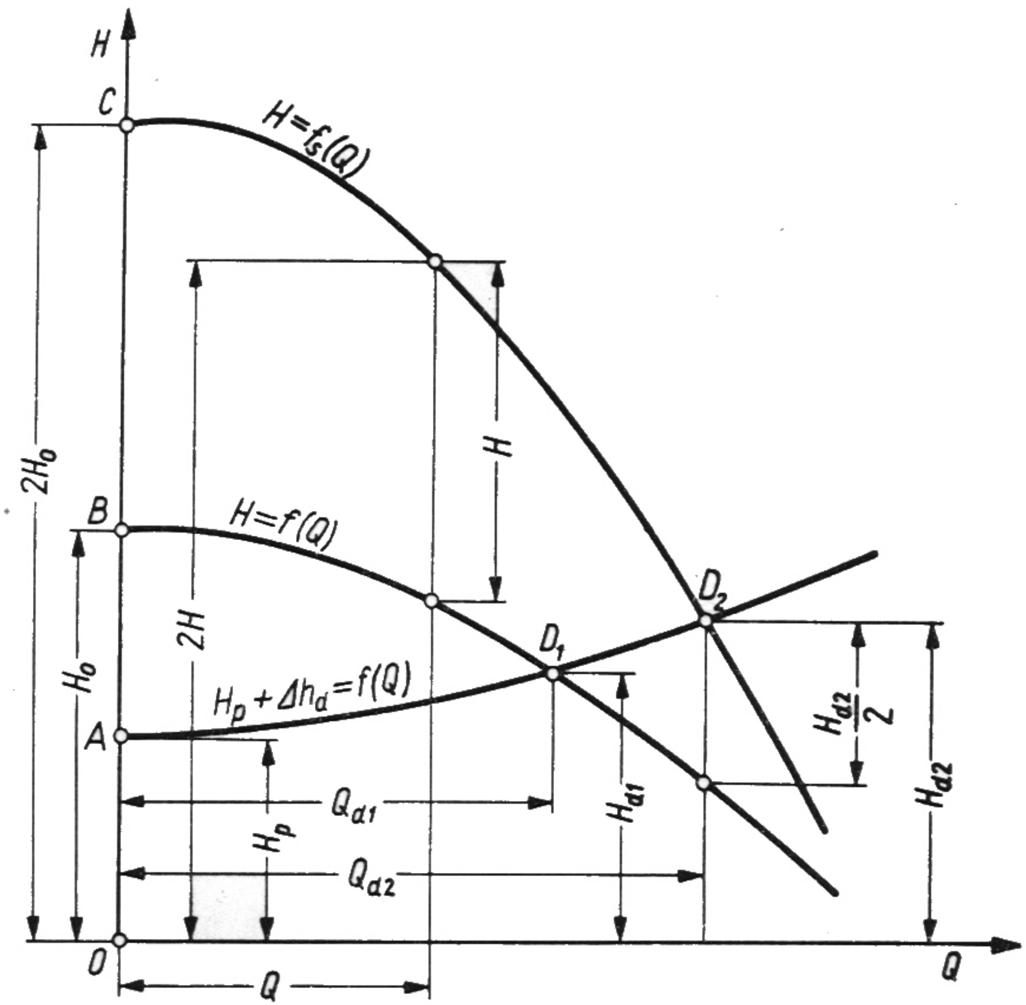


- Sum pump Q at each pump H

Multistage pump (serial)



- Sum pump H at each pump Q



Learning goals

- Capacity problems pressurised wastewater mains
  - Understand consequences of insufficient capacity
  - Identify possible causes
  - Basic understanding of air in pipelines

Consequences of capacity problems

Increased power consumption

- 30% increase measured, if capacity reduction is acceptable
- 10000 ton CO_2 , 3 M€ per year

Financial claims after floods

Increased maintenance costs

- Pigging operations

Extra investments infrastructure

Increased CSO volume

Causes of reduced capacity

Partially blocked pump impeller

- Pump vibration

Unpredictable capacity reductions (90% of cases)

- gas- and air pockets
  - > air intake by pumps
  - > local pipe draining at pump after pump trip
  - > draining air vessel
  - > degassing during transport
  - > biochemical processes

Steadily growing capacity reductions (10%)

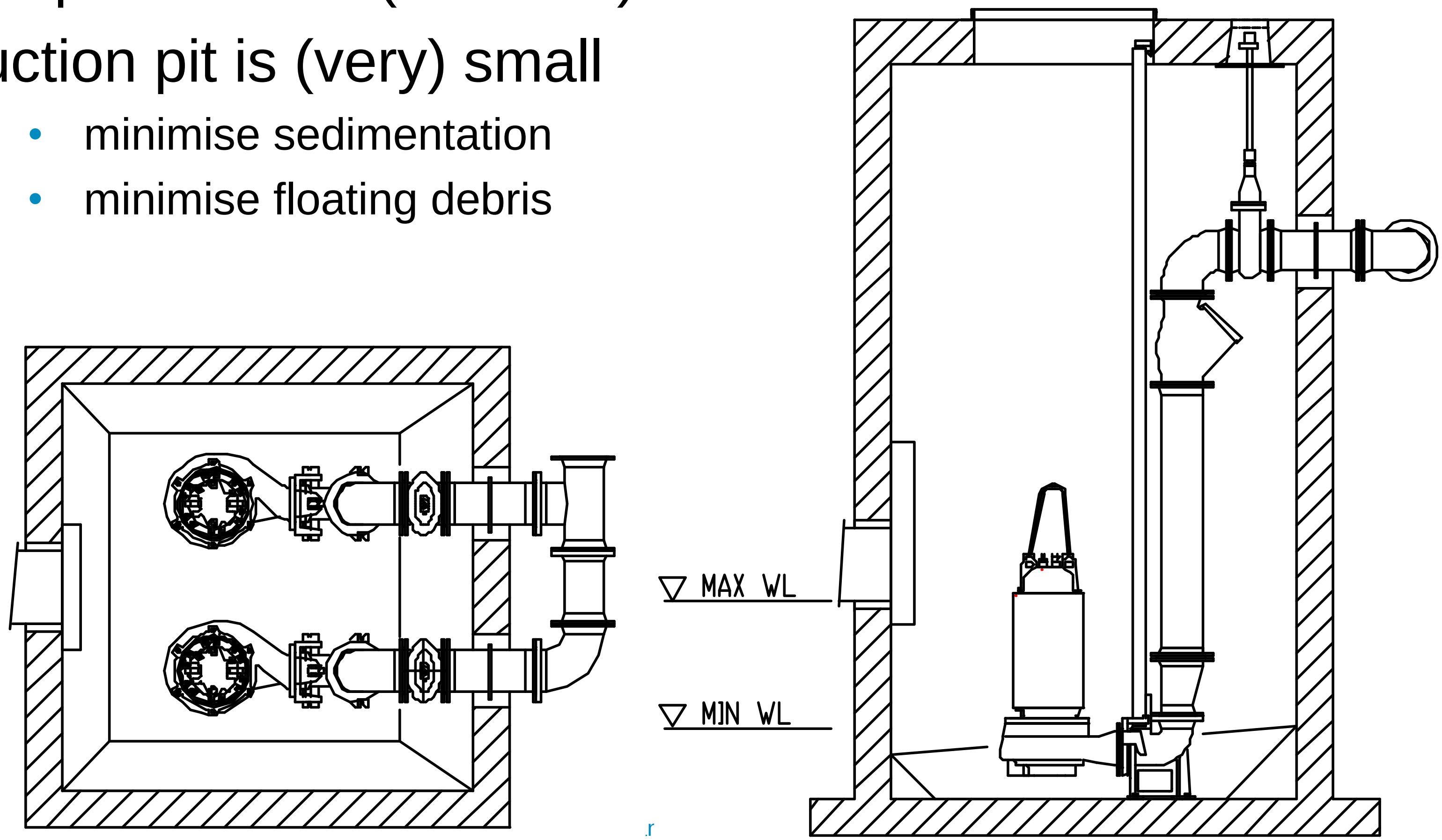
- pipe wall deterioration
- biofouling / scaling

Air entrainment by the pumps

Sewer outflow always above pump start level (max WL)

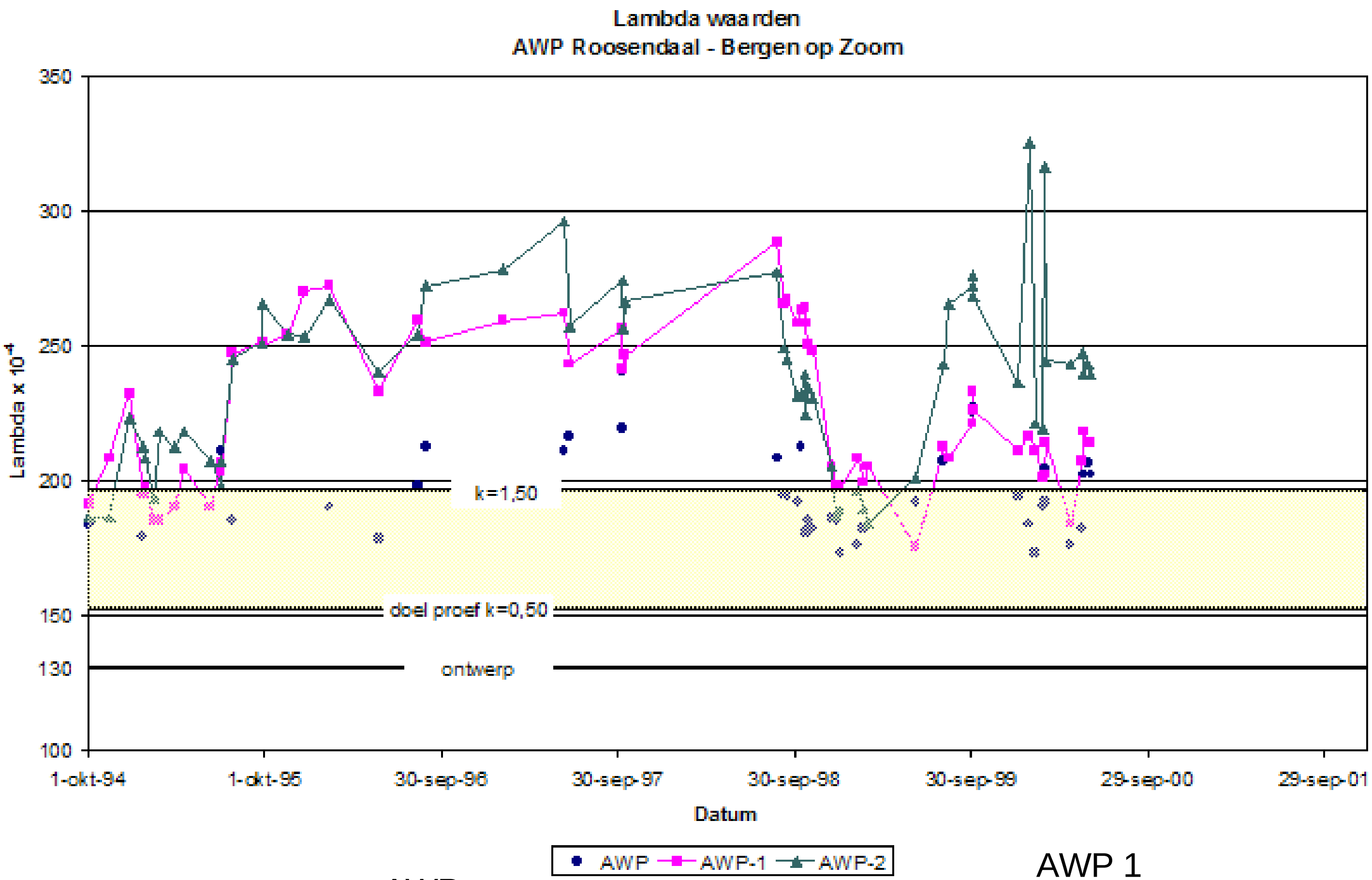
Suction pit is (very) small

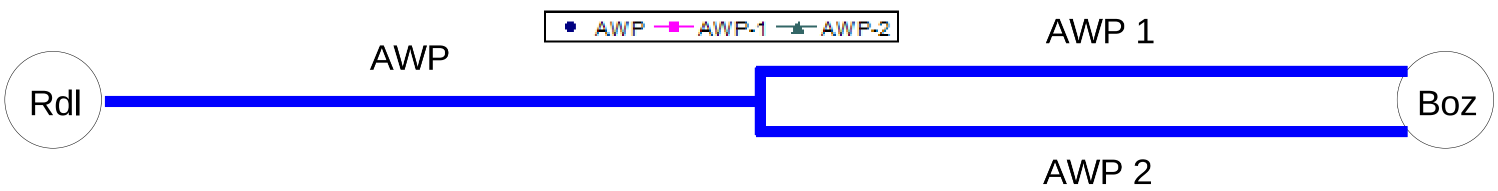
- minimise sedimentation
- minimise floating debris



Air intake by pump

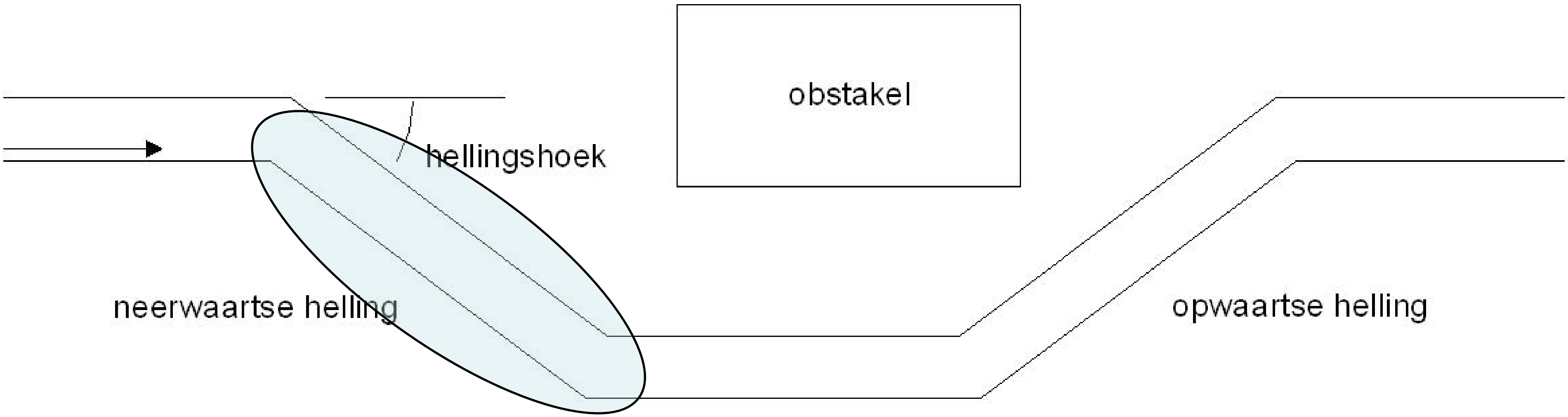
Gas pockets cause unpredictable head loss





Detail: inverted siphon

Gas pockets grow in the top of inverted siphons at DWF

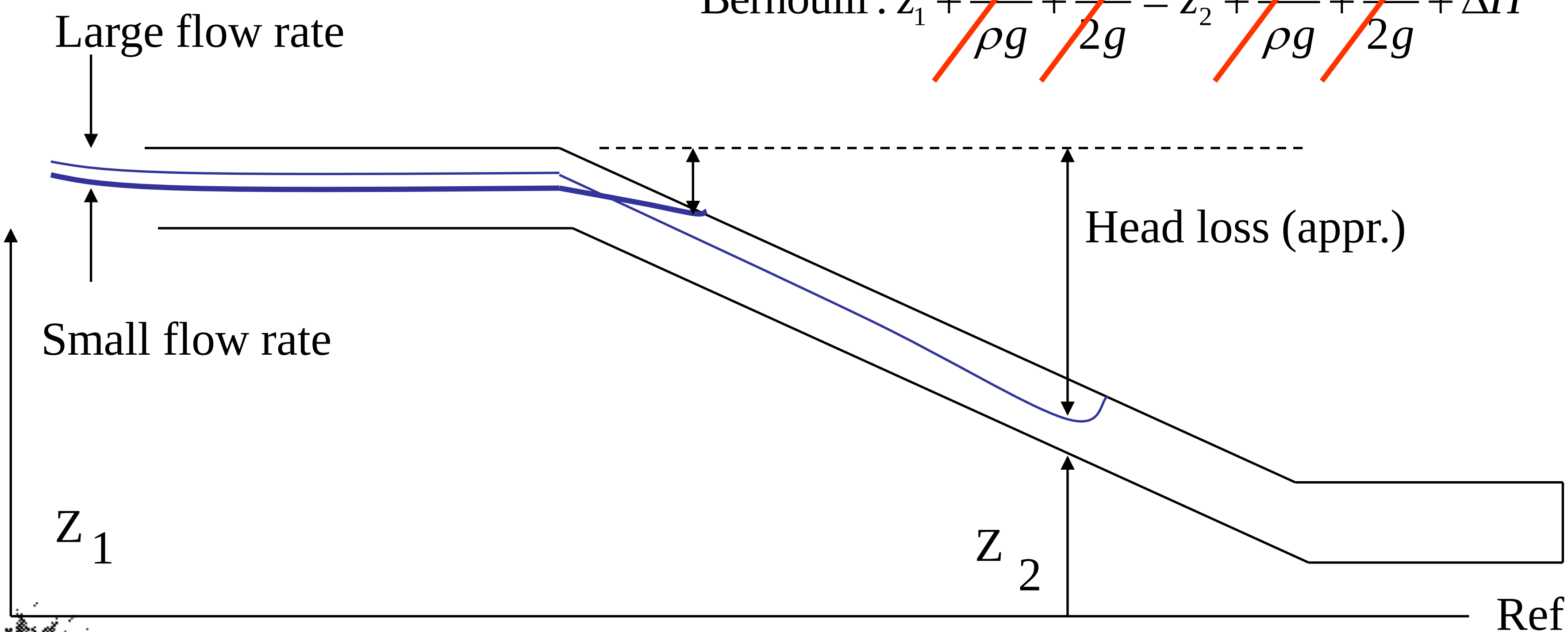


Drilled pipe in urban area (The Hague)

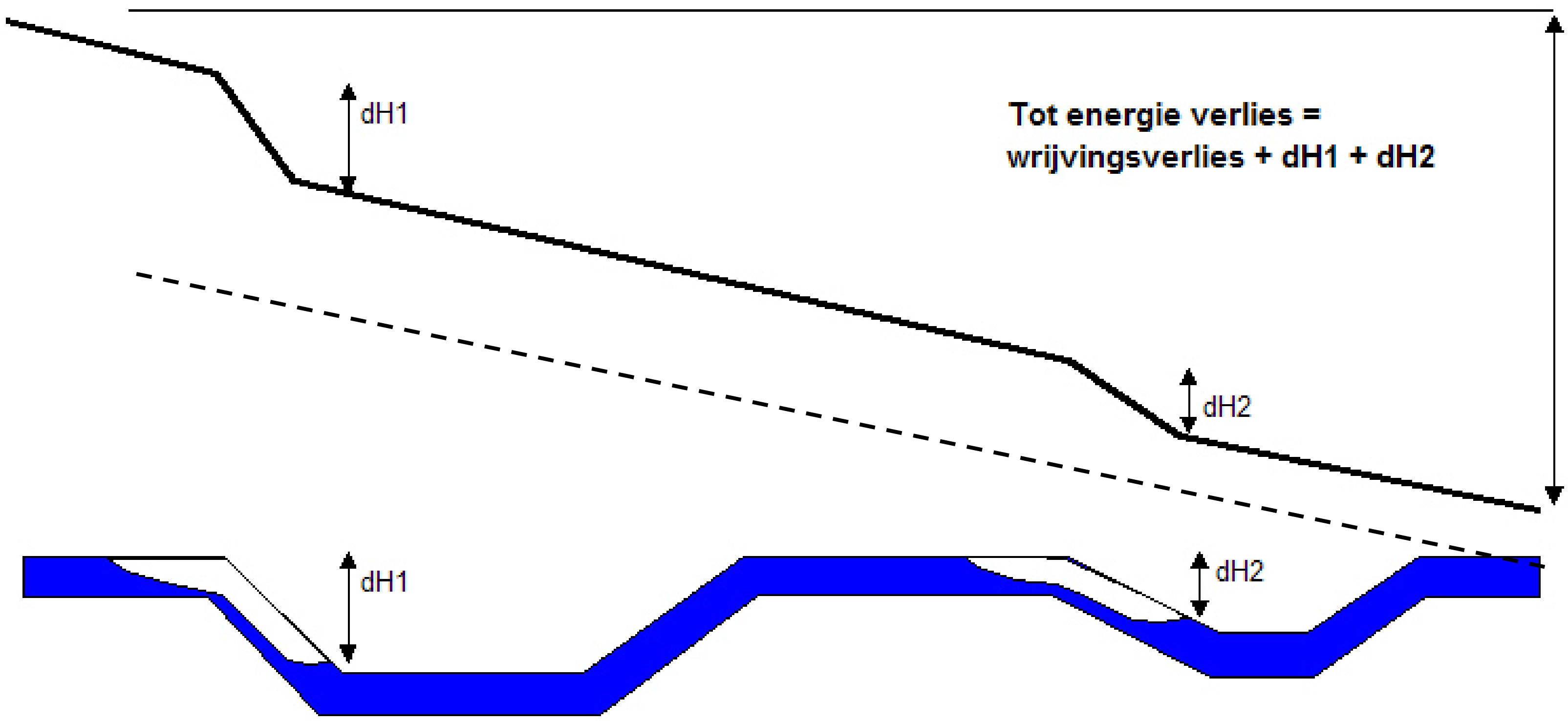
Detail: inverted siphon

Gas pocket head loss ≈ height of gas pocket

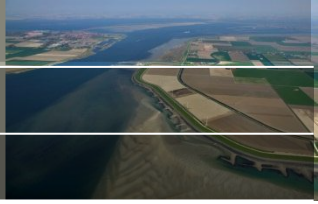
$$\text{Bernoulli}: z_1 + \cancel{\frac{p_1}{\rho g}} + \cancel{\frac{v_1^2}{2g}} = z_2 + \cancel{\frac{p_2}{\rho g}} + \cancel{\frac{v_2^2}{2g}} + \Delta H$$



Hydraulic gradient with gas pockets



R&D questions



What are the gas pocket transport modes?

- Dimensionless variables

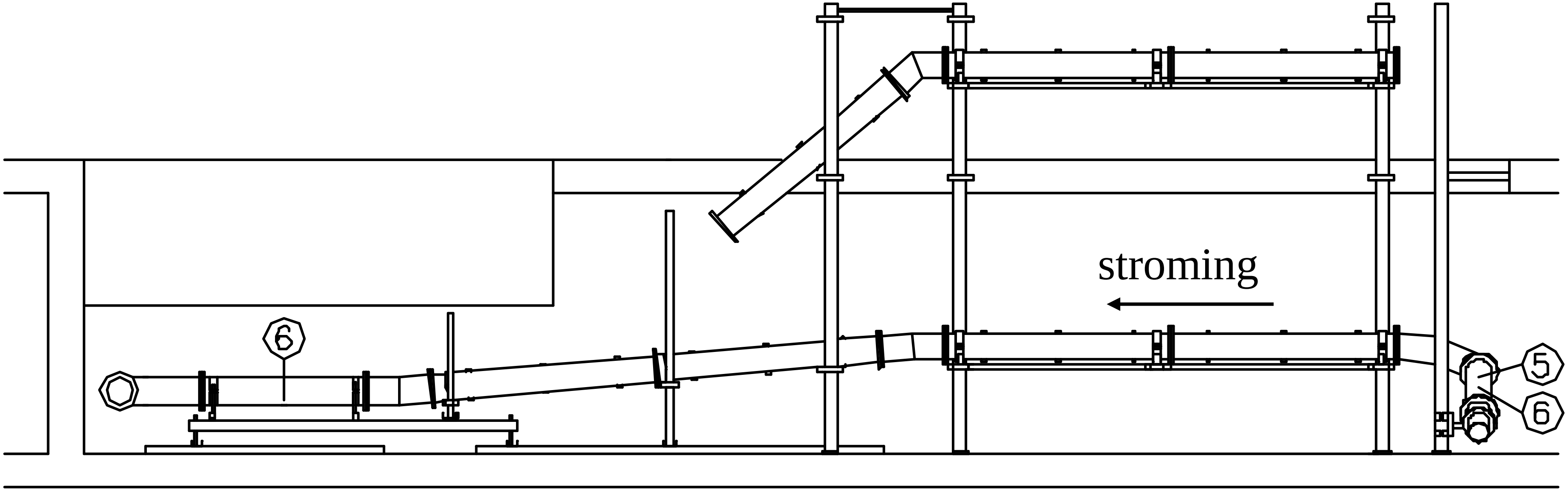
What is maximum gas pocket length and head loss?

- Water discharge
- Pipe angle
- Air discharge

What is influence on gas discharge of

- Length of downward slope
- Water quality
- Pipe diameter

Experimental research – test set-up side view



Experimental facility at treatment plant

- In operation from April 2008 – April 2009

Hydraulic jumps in large scale facility

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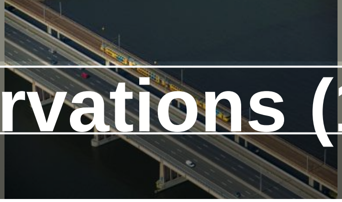
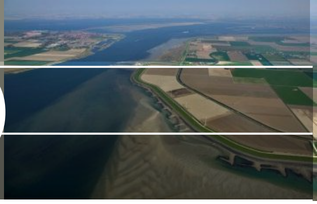
Visual observations in 150 mm pipe

Experiment in D=150 mm, slope 10 degrees
velocity 0,25 – 1,0 m/s

Visual observations in large scale facility

See also

www.youtube.com/capwat

Conclusions from visual observations (1)

Gas transport mechanism

- **hydraulic jump downstream of gas pocket**
- **turbulence extracts gas bubbles from the pocket**
- **drag force > buoyant force ➔ gas bubble transported**
- **drag force < buoyant force ➔ gas bubble rises**

- $$Drag = 0.5\rho \cdot C_D \cdot A_b \cdot \left(v_w - v_b\right)^2 = 0.5\rho \cdot C_D \cdot \pi R_b^2 \cdot \left(v_w - v_b\right)^2 \sim R_b^2$$
- $$Buoyancy = \left(\rho_l - \rho_g\right) \cdot g \cdot V_b = \left(\rho_l - \rho_g\right) \cdot g \cdot \frac{4}{3}\pi R_b^3 \sim R_b^3$$

Both mechanisms occur simultaneously

- **small bubbles flow downward**
- **large bubbles flow upward**

Net air-water discharge ratio is ~ 0.001 only

Dimensionless parameters

Head loss is related to height of air pocket

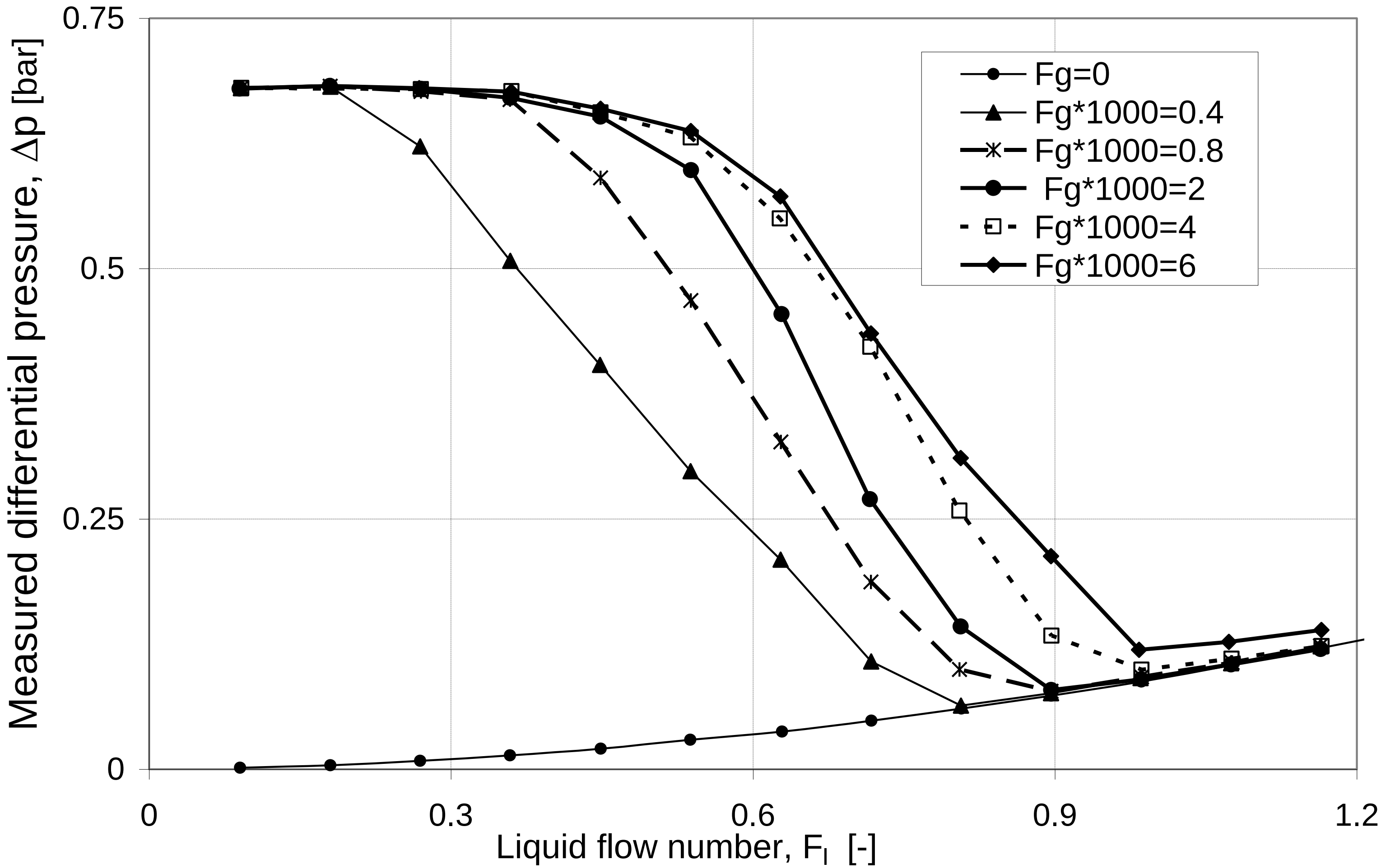
- Elevation difference of downward sloping reach L*sinθ

Water velocity is related to drag – buoyancy ratio

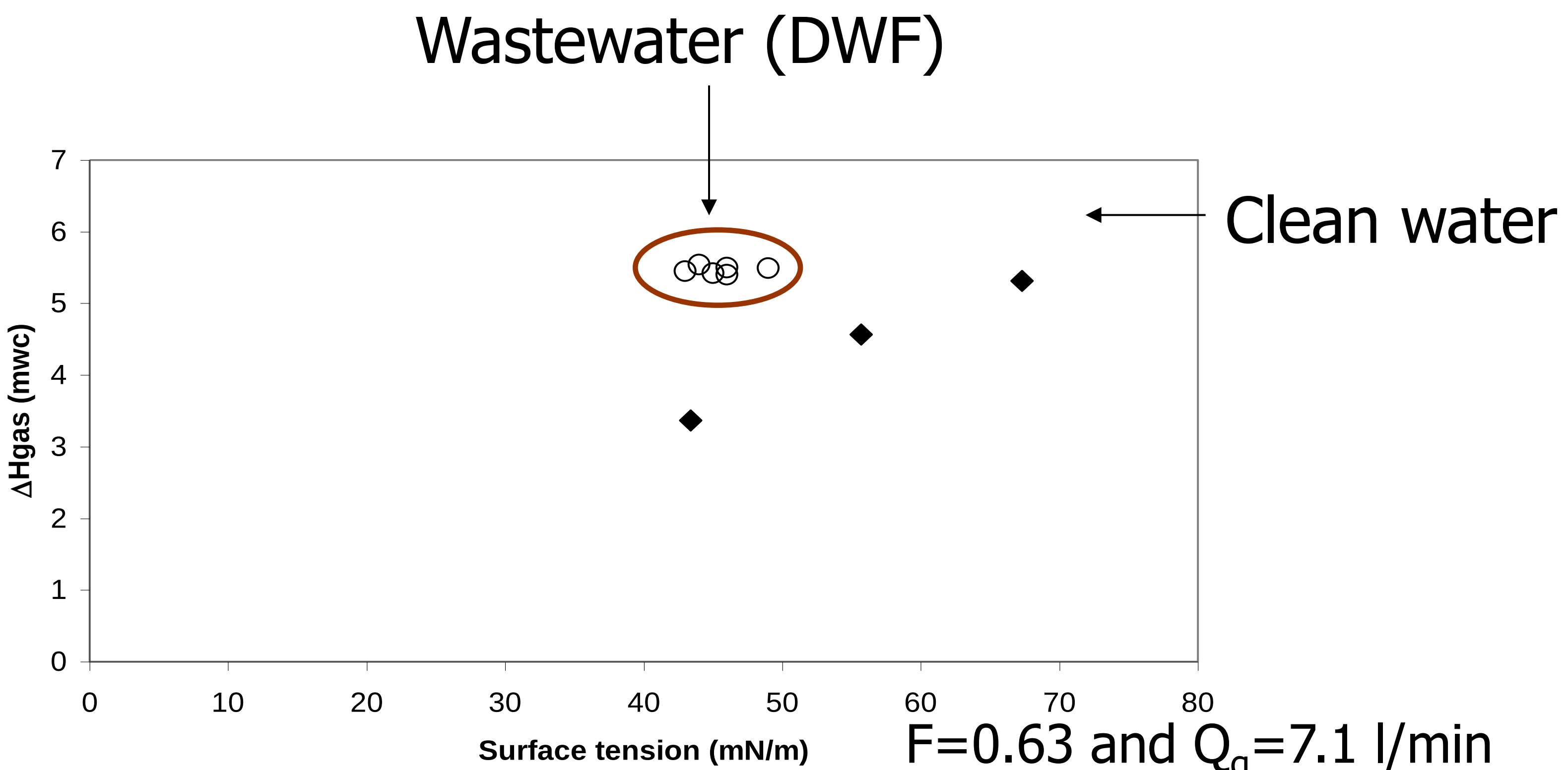
$$C_d \rho v^2 R_b^2 \sim \rho g R_b^3 \sin\theta$$

$$F = v \Big/ \sqrt{gD}$$

Air pocket head loss measurements



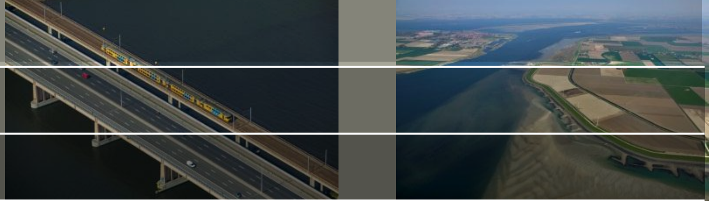
Results – Wastewater



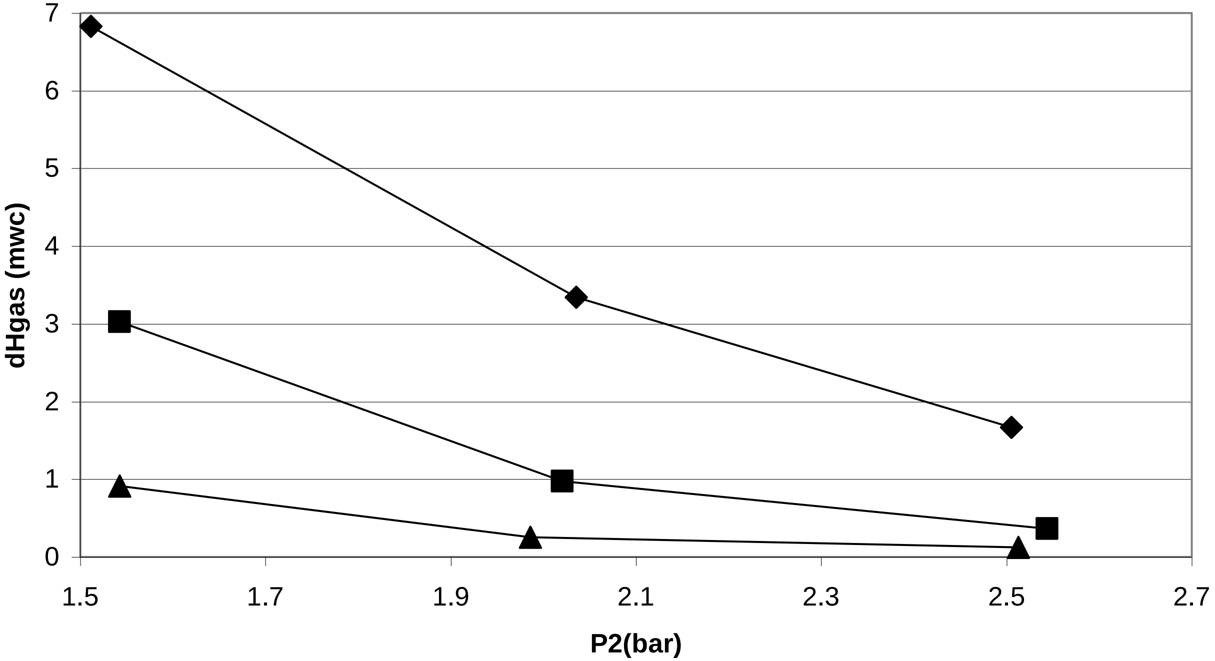
F=0.63 and Q_g=7.1 l/min

Gas pocket resistance is equal

Results – Increased pressure



Low gas flow (0.71 l/min)



F

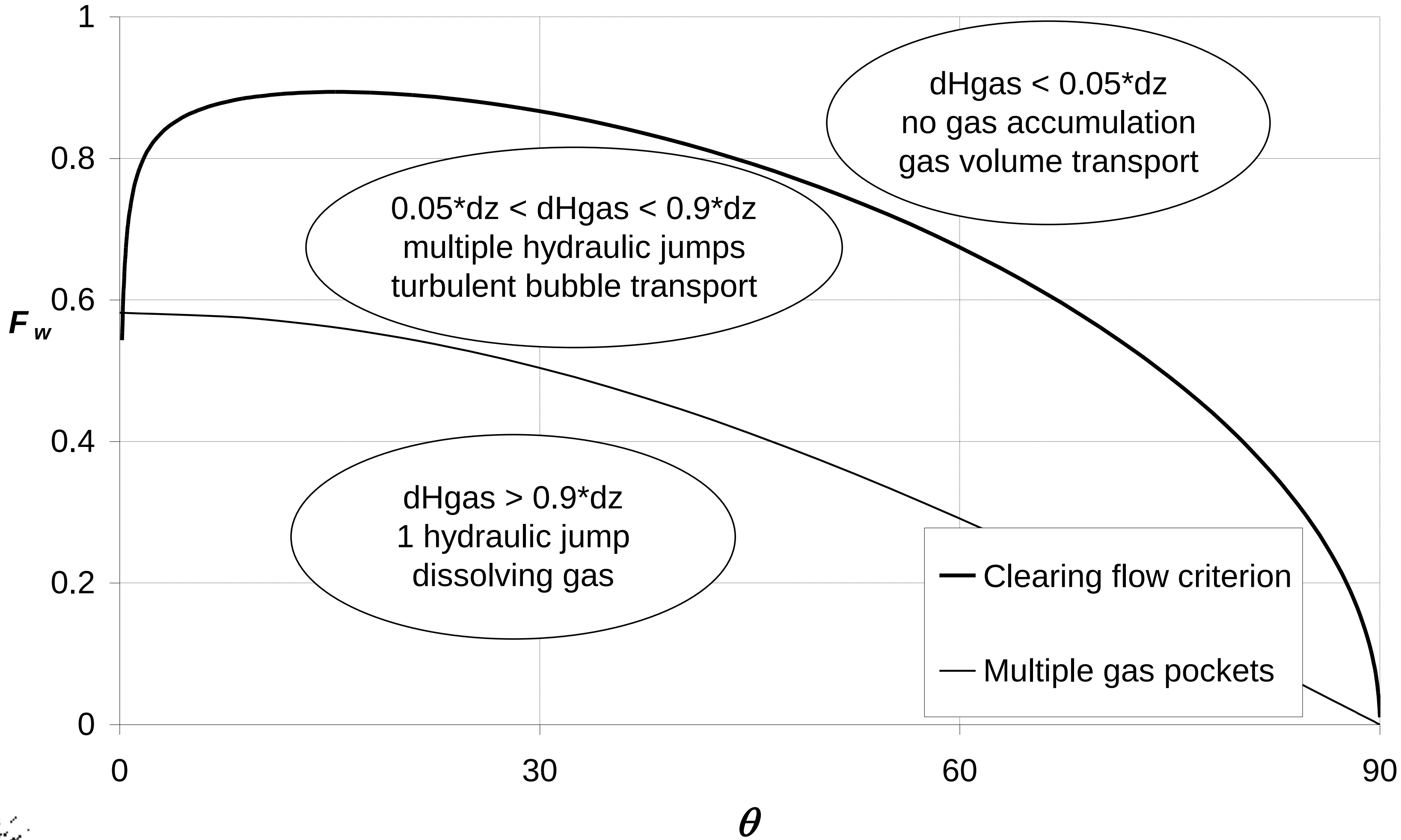
0.27

0.45

0.63

Increasing pressure reduces gas pocket

Gas transport mechanisms



Solutions to maintain design capacity

Pump pit

- Deflection plate reduces air entrainment with factor 1000

Pumping station

- Most air valves on pumps can be closed without adverse effects
- Evaluate appropriate switch-off level and switch-off procedure

Pipeline

- Downward sloping reach
  - > the steeper, the better
  - > Maximum air transport capacity in vertical pipe
- If air admission in pumping station is minimised, additional measures in pipeline not necessary

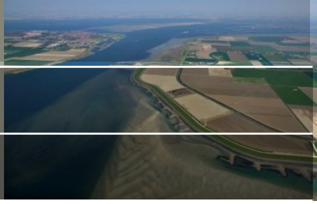
CAPWAT main project results

- New design guidelines available on the hydraulic design and operation of pressurised wastewater mains
- PhD report Lubbers, 2007
  - Focus on lab experiments
- PhD report Pothof, 2011
  - Air transport model and
  - validation experiments in long downward sloping pipe with clean water and wastewater
- Many scientific questions still unanswered (MSc/Phd project?)
  - How does turbulent mixing drive the air flow?
  - Is velocity of rising air pockets correctly predicted by model?
  - When does surface entrainment start to enhance the air transport in closed conduits?

Exercise (old exam)

See hard copy

Answer to Exercise



Part 1, no air in system

a. $\Delta H = H_{stat} + C^* Q^2 = 5 + 80^*Q^2$, Q in m^3/s
   a. C is derived from Darcy-Weisbach: $C = \lambda^*L / (2^*g^*D^*A^2)$
b. See graph
c. Duty point is Q = 1400 m^3/h at 17 m

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Answers part 2, with air

Part 2, with air

a. Water and pump inertia cause level drop in pump pit after stop
b. 1.68 m * Area (0.2 m^2) * 6 cycles/hr = 2 m^3/hr;
c. F_g = Q/(A*sqrt(g*D)) = 0.0008
d. Rescale gaspocket head loss data using
   a. L*sin11 = 7.6 m
   b. Translate Flow number to discharge in m3/h. F_w = 0.6 → Q = 1500 m^3/h. See result in graph
e. New duty point at Q = 1200 m^3/h at H = 20 m

Answer 1b) and 2d)