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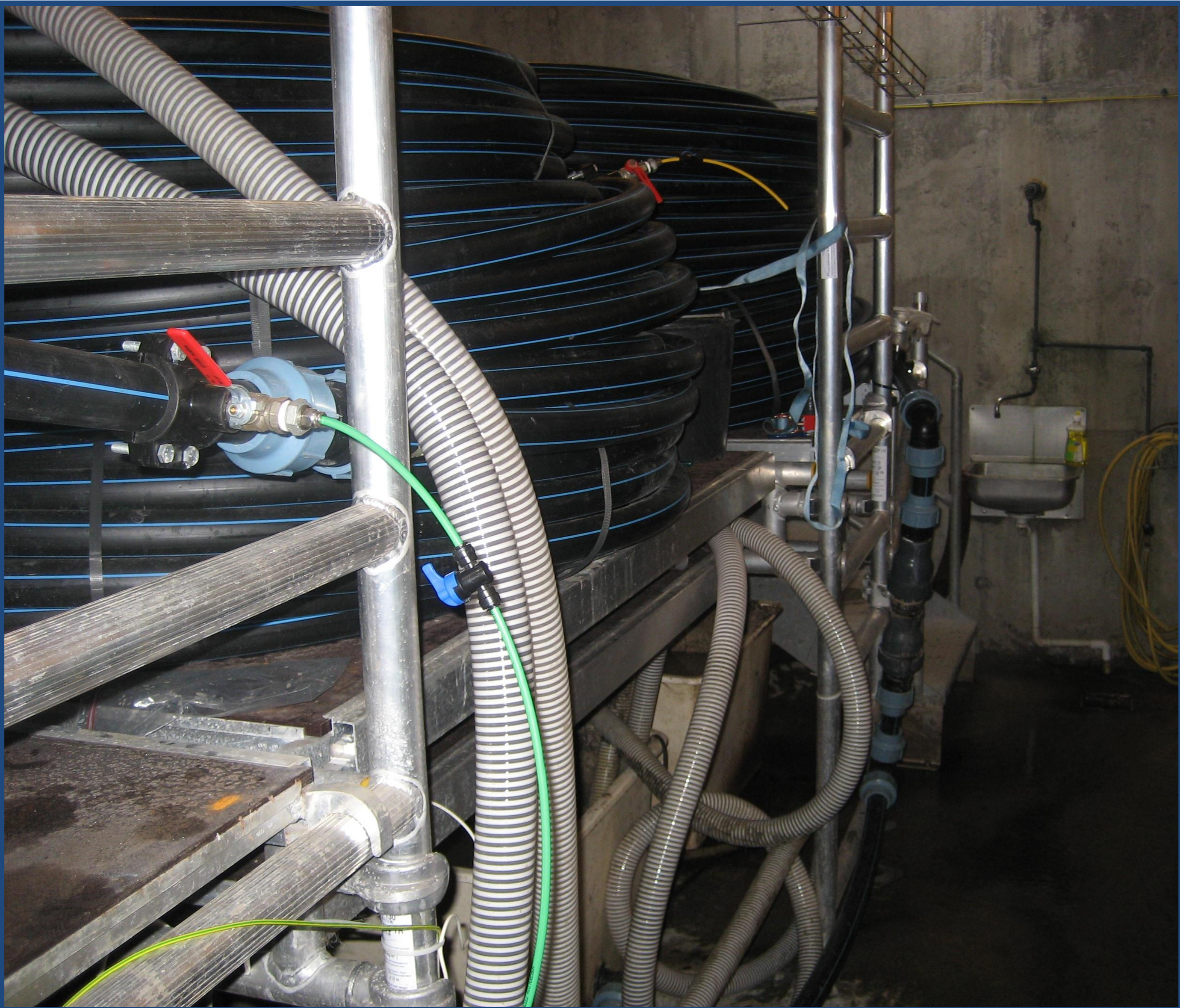
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H₂S-FORMATION UNDER VARYING FLOW CONDITIONS IN FORCE MAINS

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Sewer test facility in Frejlev, Denmark. Under the scaffold the two reservoirs can be seen. From here the waste water is pumped into the 1000 m PE force main (black). The grey hoses forms the loop back to the pump, which is located outside the picture to the bottom left.

Experimental Setup

The experiments were carried out in a sewer test facility at Aalborg University, Denmark. The test facility is supplied with fresh waste water from the town of Frejlev inhabiting approximately 2000 citizens. The test facility contains a 1000 m PE force main, diameter 50 mm, divided into 100 m sections each with an individual sample port. A schematic overview of the test setup can be seen in figure 2.

Prior to pumping the waste water into the force main and registering the flow the waste water had passed two separate settling reservoirs (each 100 L). In order to maintain a specific flow for ½-1 hour a loop was constructed, connecting one 100 m section back to the pump by flexible suction hoses. Fresh waste water could then be introduced into the system and cycled until a formation rate was obtained. The loop is illustrated by the four valves (green = open, red = closed) and green arrows in figure 2. The biofilm in the setup was established at a flow rate of 2.1 m³·hr⁻¹ (shear stress of 1 N·m⁻²).

Waste water samples were taken at the sampling port marked in figure 2 with a syringe and then injected into zinc-acetate immediately. The sulfide concentration was then measured spectrophotometric by the methylene blue method (Cline, 1969). Area specific sulfide formation rates were calculated by linear regression and related to pipe surface area.

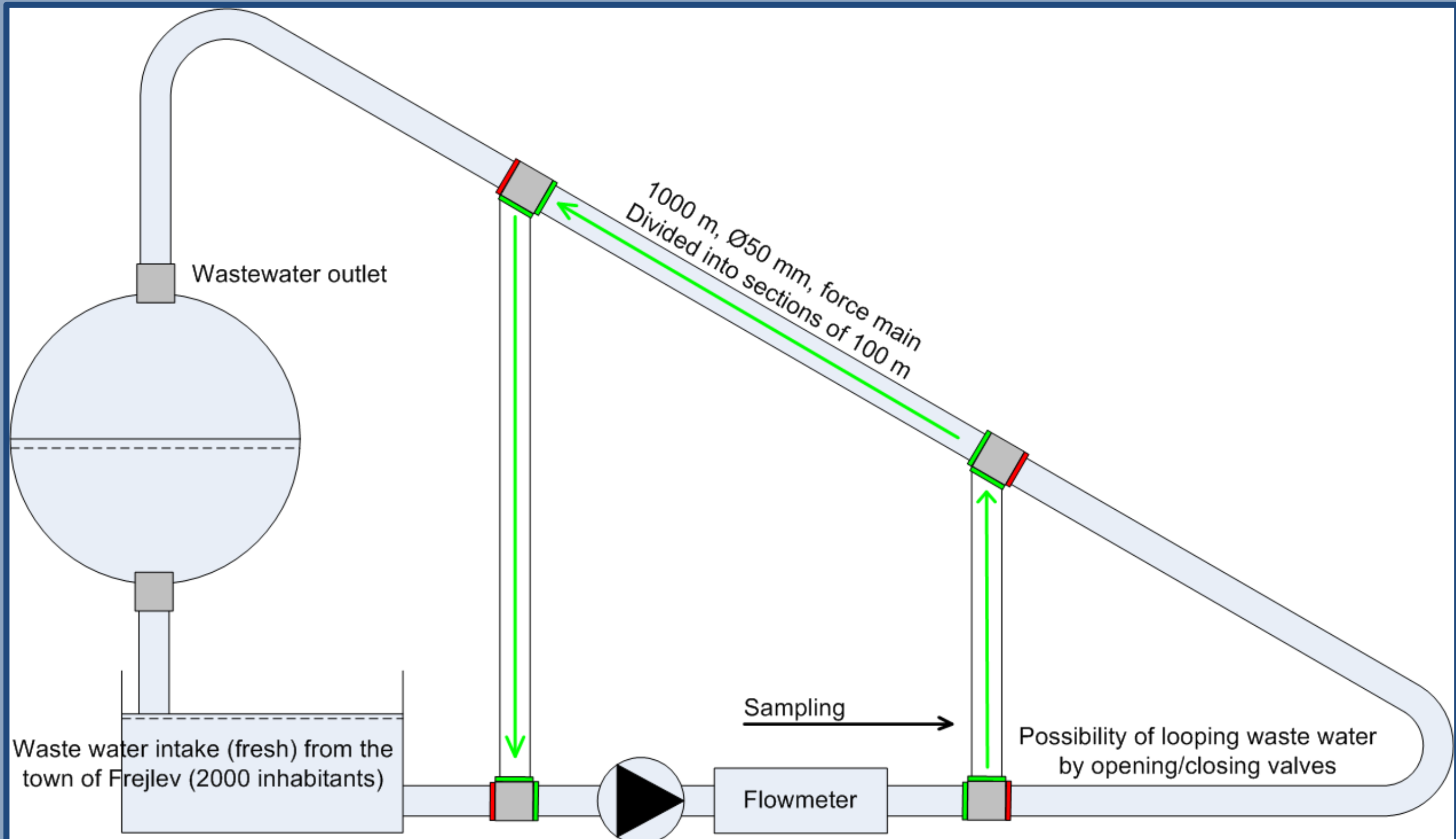


Fig 2: Schematic overview of the test setup

References

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Background

Sulfide production in force mains is a known and well-studied subject, as it causes odor and corrosion problems. Sulfide problems are typically treated by either adding an oxidizing agent or precipitating the sulfide with metals (Hvitved-Jacobsen, 2002). In regard to waste water pumping strategy there is a focus on reducing energy consumption, which is done using VFD's (variable frequency converter) operation. Prior studies show a correlation between mean waste water velocity and sulfide formation rate (Holder and Hauser, 1987). A detailed knowledge of the influence on variations in flow conditions on sulfide formation is however lacking. Knowing how flow conditions influence sulfide formation it will be possible to design an optimized pumping strategy to minimize resource usage for sulfide abatement in terms of both energy and chemicals.

Theory

Sulfide is mainly formed inside the biofilm on the inner pipe surface by sulfate reducing bacteria (SRB). In order to reduce sulfate to sulfide, SRB needs sulfate and a carbon source (substrate). These are supplied from the bulk waste water. An illustration of these reactions are shown in figure 1. Prior studies show a relation between velocity and sulfide production (Holder and Hauser, 1987). When waste water velocity is increased the thickness of the diffusive boundary layer decrease and the size of the sulfate reducing zone increases as seen in figure 1. This will increase the sulfide formation rate.

The sulfide formation rate is assumed to have an upper limit as the forces required to decrease the thickness of the diffusive boundary layer increases. Furthermore sulfide is also produced when waste water is stagnant, however at a lower rate as sulfate and carbon must diffuse through the bulk waste water as well.

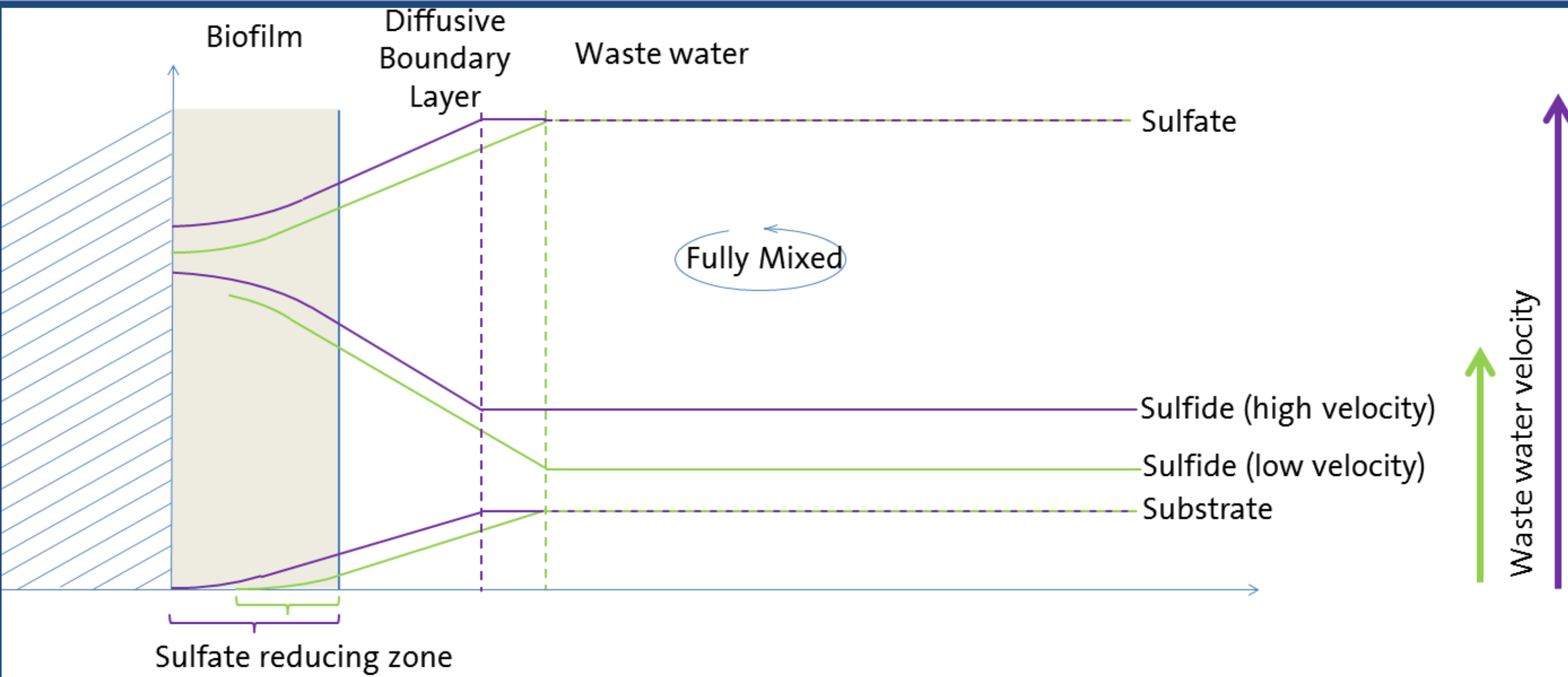


Fig 1: Illustration of the diffusive boundary layer and it's influence on concentration profiles in the waste water and biofilm of force mains.

Results

As seen in figure 3 the sulfide formation rate depends on the shear stress (τ) as expected. The rate at no flow (r_0) was estimated to 0.13 gS·m⁻²·hr and increasing with the shear stress. At higher shear stresses the rate levels out at a max rate of (r_{max}) of 0.38 gS/m²/hr. A Michaelis-Menten like equation was fit to the data yielding the following expression, with an R-squared value of 0.59:

$$r_{sulfide} = r_0 + \frac{r_{max} \cdot \tau}{K_M + \tau} = 0.13 + \frac{0.25 \cdot \tau}{0.018 + \tau}$$

The nonlinear trend indicates that it is possible to control sulfide formation based on flow variations. At shear stresses > 0.4 N·m⁻² the transport time can be reduced significantly without increasing the sulfide formation rate, thus decreasing the total formed amount of sulfide. The low K_M -value indicates that the maximum formation rate is reached fast and this is possible to benefit from even at low shear stresses.

With the knowledge of how flow variations influence sulfide formation it is possible to find an optimal duty point that takes both energy consumption and sulfide formation into account. This will help decrease the overall resource cost of sulfide abatement.

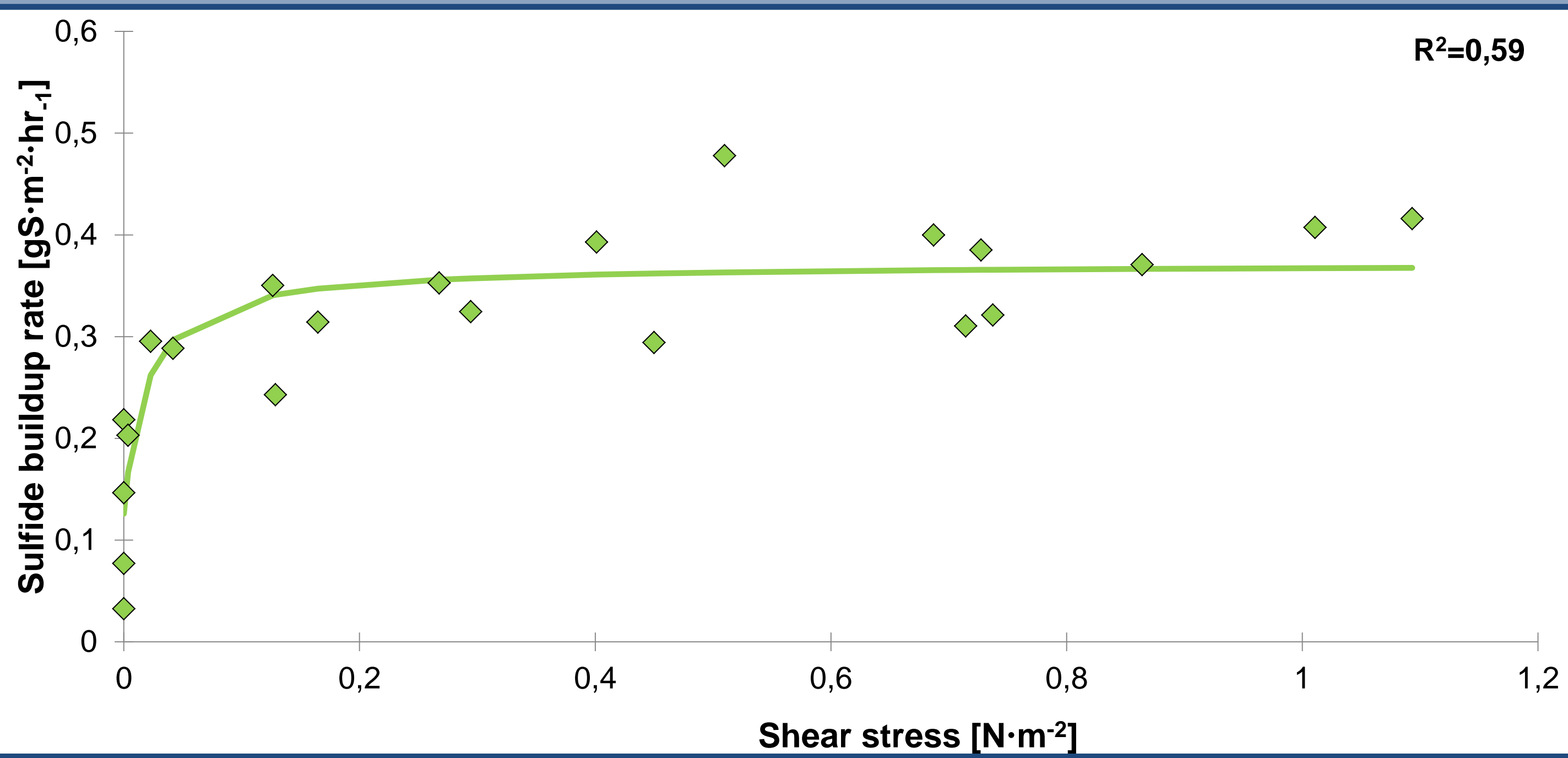


Fig 3: Sulfide formation rate related to shear stress

Conclusion

- A correlation between shear stress and sulfide formation rate was found in the shape of a growth curve
- A half-saturation constant of 0.018 N·m⁻² indicates that a constant sulfide formation rate is reached already at low shear stresses
- This knowledge opens up the possibility to design pumping strategies to reduce overall costs in sulfide abatement