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# Title: Advanced Analysis of Pressure Data in a Vacuum Sewer System for Operational Assessment and Utilisation

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**Abstract:** The building and operation of blackwater vacuum system is complex, requiring precise monitoring and control to address challenges such as pressure fluctuations, leak detection, and maintenance. Current pilot systems lack comprehensive frameworks and data-driven analysis, leaving operational improvements widely unexplored. This study seeks to fill this gap by developing methodologies to understand system behaviours better, optimise performance, and provide actionable recommendations for implementation, contributing to more sustainable wastewater management.

**Keywords**: vacuum sewer systems; pressure data analysis; ROSS

## INTRODUCTION

The vacuum blackwater sewer system at Jenfelder Au in Hamburg is a part of the circular economy concept HAMBURG WATER Cycle® (HWC), integrating energy recovery from municipal blackwater and external co-substrates (fats) into wastewater management [5][6]. Traditional systems face challenges such as high costs, extensive water use, and limited adaptability to demographic changes [1][3]. These hurdles are addressed by the resource orientated sanitation system (ROSS) Jenfelder Au. Primary goals of this research were to enhance the understanding of blackwater vacuum systems, investigate unusual system behaviours, and identify opportunities for operational improvements.

## BACKGROUND

The vacuum system Jenfelder Au exclusively transports blackwater of approx. 2,000 inhabitants and its sewers expand from a central vacuum station to over 3,700 m in three branches. In this research the pressure and operational behaviour of the first branch (1,555 m with a separation in branch 1.1 and 1.2) was analysed. The system design includes height jumps for efficient flow management, maintaining a theoretical maximum pressure loss of about 52 kPa (cf. Figure 1). The main branch is connected to vacuum toilets (cf. Figure 2) which operate with a low water consumption (1.5 l per flush). They are flushed with mechanical valves operating up to 70 $kPa_{abs}$. This indicates a working pressure of 40 – 48 $kPa_{abs}$ at the vacuum station.

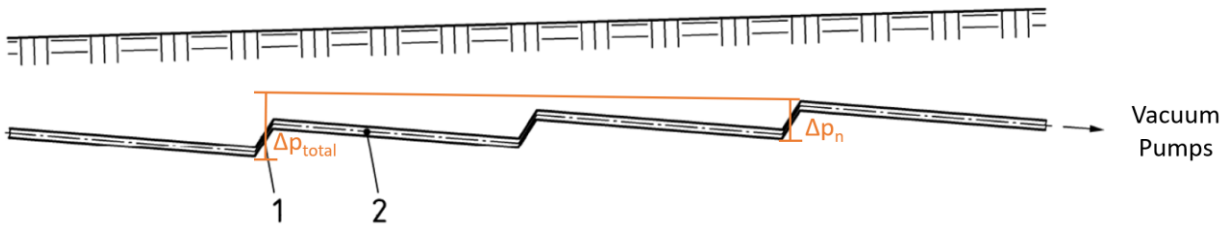


**Figure 1** Pattern example of a vacuum system (not to scale) with a pressure loss of $\Delta p_n$ over one height jump and $\Delta p_{total}$ as the pressure loss over all height jumps with consideration of frictions and hights of pipe laying [cf. DIN EN 16932-3 2022-12]. – Legend: 1: ascending section; 2: descending section.

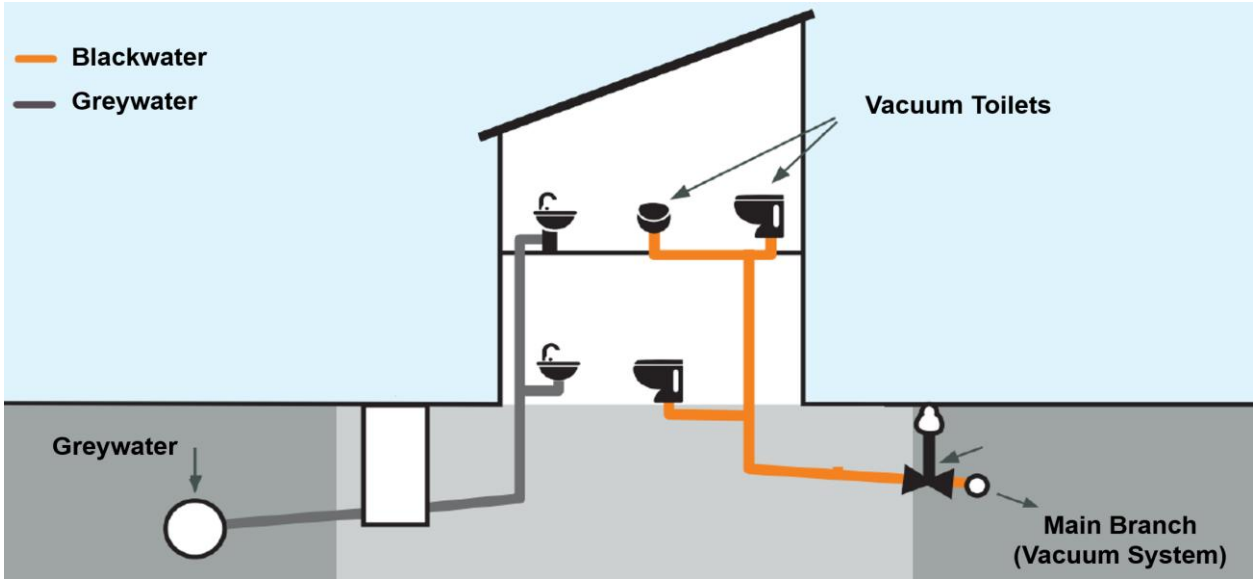


**Figure 2** Vacuum toilets are connected to the main branch [cf. 4]

## METHODOLOGY

To capture critical system metrics, data from pressure sensors and operational systems like the vacuum and blackwater pumps was collected in programmable logic controllers (PLCs) and a supervisory control and data acquisition system (SCADA). An algorithm was programmed to cluster reoccurring system dynamics, distinguishing between normal and disruptive operations (e.g., leaks caused by open toilet valves) in a database. With the clusters, control strategies were established to enhance system availability. Furthermore, algorithm possibilities were to improve predictive maintenance.

## RESULTS

The analysis revealed important operational characteristics and insights into system behaviour. While transmission delays between pressure sensors and the PLC were negligible for data analysis, they must be considered when pinpointing leak locations. Pressure variability, under both normal and fault conditions, was characterised to develop baseline patterns. These patterns help in the identification and localisation of leaks, which are a significant source of inefficiency. They also enhanced the operational system behaviour, as theoretical maximum pressure losses over all hight jumps were rarely and shortly shown in peaks. The main pressure distribution kept close to the pressure distribution at the vacuum station (cf. Figure 3). This observation was supported by the analysis result of a significantly higher operational air-to-water ratio (AWR) compared to theoretical calculations. More air has to be pumped out of the system resulting in higher system dynamics and therefore lower pressure losses but also a higher energy consumption.

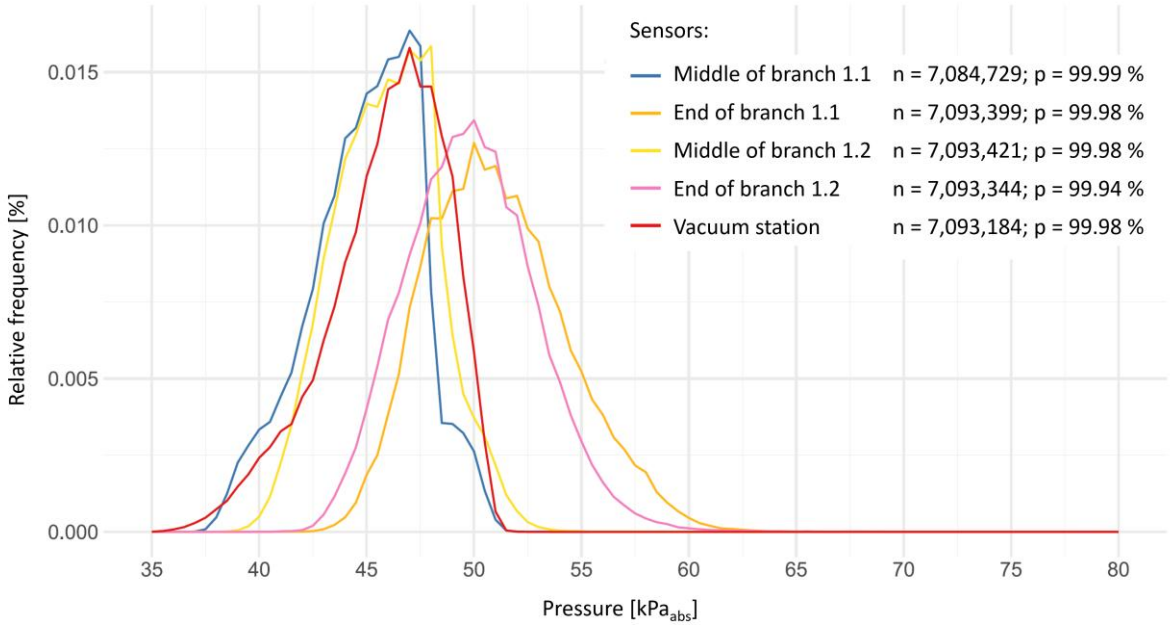


**Figure 3** Pressure distribution of n samples with a significance p at different locations in branch 1

Furthermore, data-driven recommendations for sensor placement and configuration were provided to improve monitoring and maintenance capabilities. These insights provide guidance on setting and controlling operating figures like pumping frequencies and operating pressures to minimise operational downtime. Additionally, maintenance strategies were refined by identifying critical system components that require prioritised attention.
Overall, the findings demonstrated the potential for using data analyses for significantly improving the system's operational transparency, increasing its reliability through algorithm integration, and optimising its performance.

## DISCUSSION

The pressure and operational analysis highlights the potential and challenges associated with vacuum sewer systems. Adaptive control helps in maintaining system stability and, with a visualisation of pressure trends, operators can respond to anomalies promptly. However, challenges such as data integration and countering incrustation with predictive maintenance remained. Furthermore, the need for robust bus-protocols and further comparing data analyses to address these challenges was underscored.

Implications extend beyond the immediate operational improvements. The methodologies developed can serve as a blueprint for implementing similar systems in other urban and rural settings, thereby contributing to broader goals of sustainability and resilience in water management. Also emphasised is the importance of predictive maintenance, which reduces response times and prevents costly failures.

## CONCLUSIONS AND FUTURE WORK

The findings underscore the transformative potential of advanced instrumentation, control, and automation in wastewater management. The pressure data analysis provides valuable insights into

system's behaviour, and with an integration of automated controls operational efficiency will be enhanced. The methodologies and findings offer a pathway for scaling vacuum sewer systems in diverse settings.

Future work will focus on addressing the identified challenges, particularly in data integration and predictive maintenance analyses. Furthermore, comparisons with other case studies are intended to enhance the development of guidelines. By building on the foundation established in this study, the water sector can move closer to achieving sustainable and efficient resource management on a global scale.

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