ENERGY SAVING IN WATERWAY NETWORKS – FROM PUMP TO HYDRAULIC MANAGEMENT

by

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1 INTRODUCTION

Pumping is extensively used in waterways, particularly in artificial canals. While Europe promotes energy-saving, the problematic is not straightforward in pumping management. Firstly, the actual efficiency of one pump is not easily estimated in situ. Indeed, pump manufacturers generally provide detailed information on pump efficiency at nominal rotation speed with the nominal characteristics of the motor, which includes the best efficiency point (BEP). However, no or little information are provided concerning off-design pump operation, which is usually the one faced in practice. Secondly, free surface elevation in navigation reaches may fluctuate significantly enough to change the operating point of the pump. Hence, a pump is no more chosen for one specific operating point but for several operating points. The choice of the more suitable pump is then not straightforward. Lastly, energy price fluctuates and energy-consumption may thus be more attractive depending on time. Temporary storing water in reach in-between pumping stations could help optimising pump operation along the day.

The study depicted in this paper is part of a European project entitled 'Greener Waterways Infrastructure' (GreenWIN). This project is one of those listed in the Interreg NWE programme with the ambition to promote key economic and social exchanges, as well as innovation, sustainability, and cohesion. The members of this project are mainly canal operators that aim at improving their infrastructure to reduce the CO_2 footprint of waterways. In this framework, improving pumping process constitutes a key-point. Liege University, a scientific partner of the project, is in charge of the development of a pump test bench, a numerical model for pump operation as well as a hydraulic model for waterway network modelling, as highlighted in Figure 1.

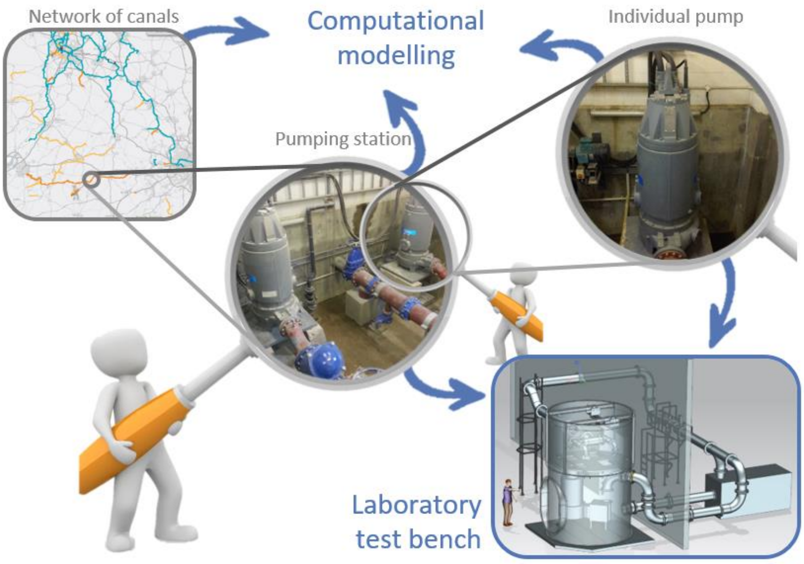

Figure 1: Project articulation emphasises the role of laboratory test bench, pumping station modelling and hydraulic network modelling to optimise energy consumption

2 METHODS

Three complementary avenues are considered through the GreenWin project to achieve more energy-efficient pumping in open-channel networks.

First, detailed characterisation of innovative pumping technologies efficiency for a wide range of realistic discharge and head conditions has been made possible through the design, implementation, and operation of a dedicated large-scale laboratory test-bench. This step helps assessing the effectiveness of enhancing energy-efficiency using ‘smarter pumps’.

Second, dynamic modelling of single-site pumping system, involving pumps and variable frequency drives (VFD), enables designing optimal control of individual pumping stations, i.e. ‘better use existing pumps’. Calibration and validation of this numerical model benefit from the datasets gained during the laboratory tests, while the computational model enables extrapolating results beyond the range of experimentally tested configurations.

The last step consists in assessing the benefits resulting from temporary water storage in the reaches in-between pumping stations. This couples the optimisation of interconnected pumping stations and requires hydraulic modelling to simulate the dynamic water level variations along the reaches. Different levels of complexity are considered for hydraulic modelling and optimisation. The hydraulic modelling of open-channel networks coupled to the VFD-pump computational model constitutes one key innovation of the research project.

3 RESULTS

3.1 Experimental Pump Test Bench

The novel laboratory test bench is represented in

Figure *2*.a), and is described in detail by Hardy et al. (2021), together with the procedure followed to collect experimental data. It involves a 4.5 m high tank with a storage capacity of 30 m^3, which can accommodate pumps up to 300 kW of power, 0.3 m^3/s discharge and 2 tonnes weight. This test bench for pumps includes a variable speed drive and a complete automatic acquisition system, which enables to characterise the pumping process for nominal and off-design operation as illustrated in

Figure *2*.b).

a) b)

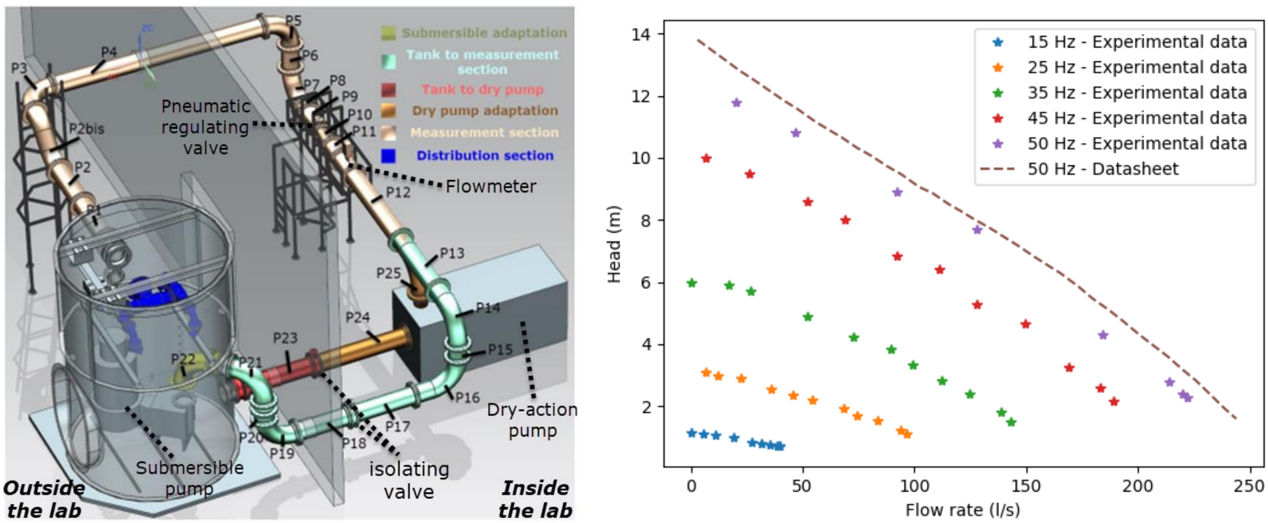

Figure 2: a) Pump test bench CAO; b) Experimental pump curves and comparison to datasheet nominal curve

3.2 Pump Computational Modelling

A numerical model for pump operation, including an asynchronous motor model [Fitzgerald et al., 2003] and also mechanical and hydraulic aspects, has been developed in the framework of the project. It can be calibrated based on a test performed in the test bench. The pump Amarex KRT D 250-400/206UG-S was used as a study case. As seen in Figure 3.a), fairly accurate predictions of pump performance have been obtained for a broad range of operation conditions. The value of this combined experimental and numerical characterisation of the pumps is to provide to the pump operator a full characterisation of the pump performance, well beyond the nominal conditions which are usually reported by the manufacturer. In this instance, an overall efficiency map combining motor efficiency and pump efficiency is shown on Figure 3.b). A software is currently under development allowing pump users to obtain the operating values of their pump for different configurations. The hydraulic efficiency can be taken into account in the overall efficiency by supplying an equivalent head losses coefficient to the whole piping (discharge and suction).

a) b)

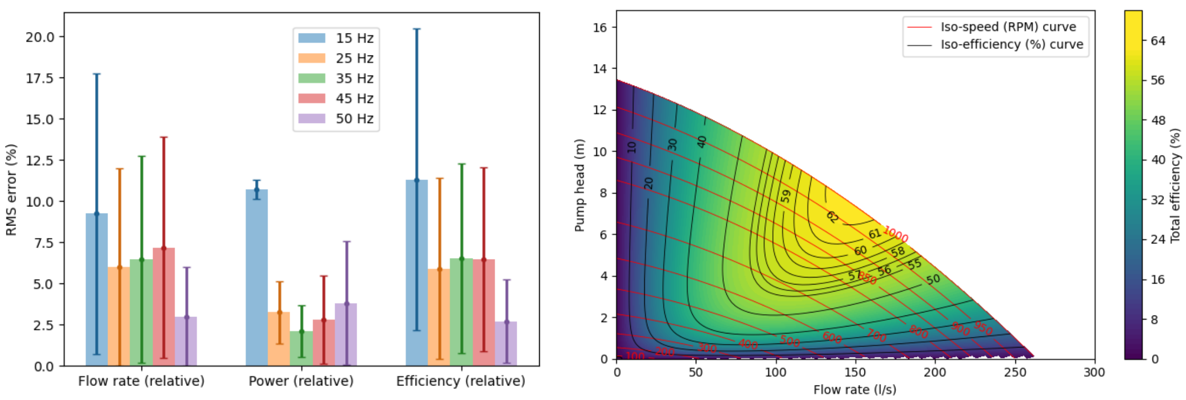

Figure 3: a) Distribution of the RMS relative error and standard deviation for flow rate, power consumption and total efficiency between numerical model and experimental results; b) Mapping of the overall efficiency of the pump for varied flow-rates, heads and rotation speed.

3.3 Waterways Network

The hydraulic numerical model of waterway network is currently under development. Yet, a first analysis of measurements has been performed considering the Kennet & Avon system as a study case using the detailed pump modelling described in the last section. The main water volume exchanges during the year 2017 are summed and described in Figure 4. This Sankey diagram shows a volume of pumped water more than twice the volume of lock exchanges.

Furthermore, the analysis of the pumping stations in Figure 5 shows that pumps exhibit around 45 % in efficiency in situ. The general nominal efficiency of pump locates between 60 % and 80 %. The difference between observed and expected efficiency may be explained by operation at higher flow rate than the nominal one. Indeed, the main preoccupation of canal operators is usually to get a high enough flow rate. As a result, pumps are oversized and consequently do not work at their nominal point and lose efficiency. As represented in Figure 3.b), the nominal efficiency can be extended to off-design operating point by adjusting the pump rotation speed. There is still a small decrease in efficiency (a few percent) when decreasing the rotation speed because of electrical motor efficiency, but this is negligible compare to the loss in efficiency of the pump when it doesn't operate at nominal point. Consequently, a 10 % increase of performance may reasonably be achieved for each station if the system operation is optimised.

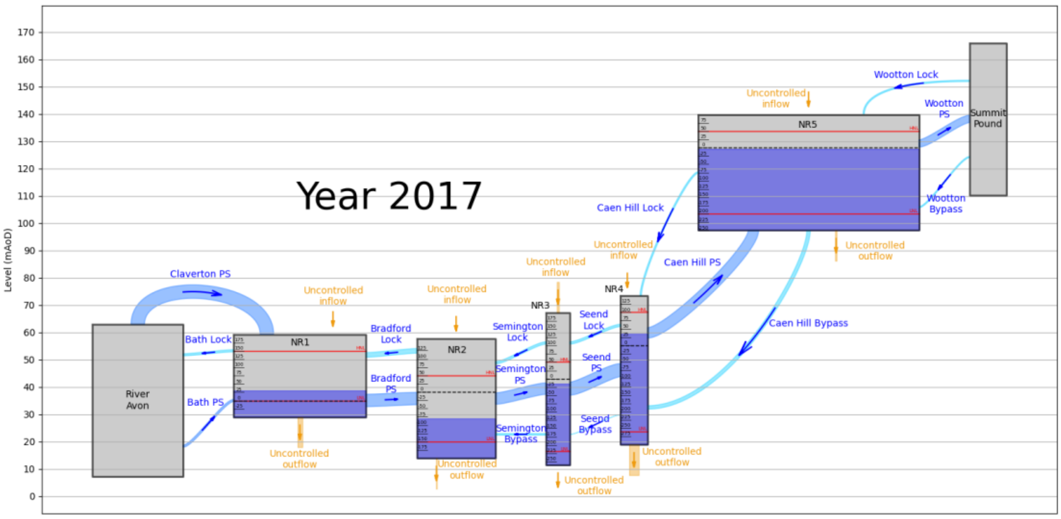

Figure 4: Kennet & Avon canal – Main water exchanges in 2017 (PS: Pumping station; NR: Navigation Reach). The thickness of arrow exchange is directly proportional to the amount of water transferred from one reach to another. Light blue stands for lock exchanges, dark blue for PS exchanges and yellow for water losses (obtained by a mass balance of the reach considering a mean water level constant along the reach) due to evaporation, infiltration and other uncontrolled flows.

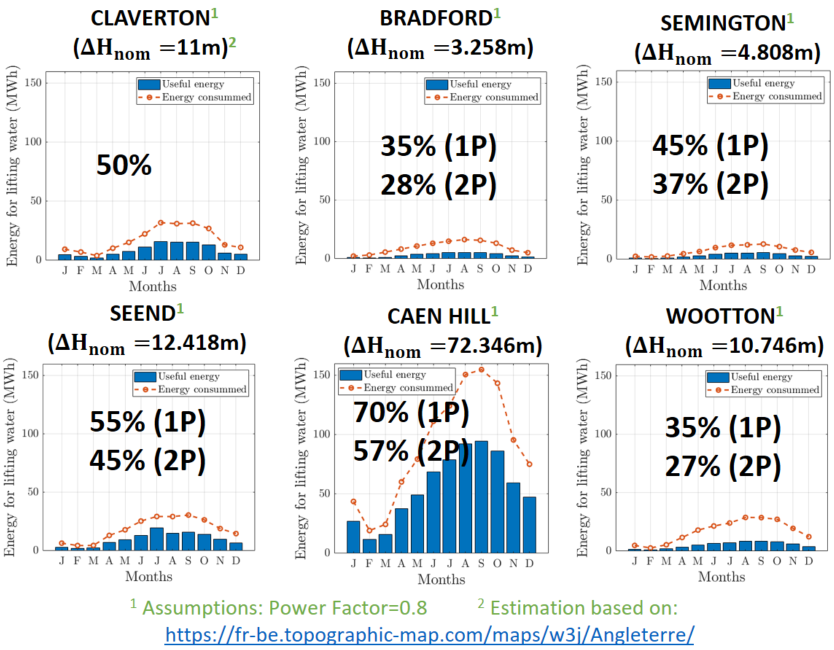

Figure 5: Mean monthly energy consumption of pumping stations in Kennet & Avon from 2010 to 2019. Performance are indicated for each pumping station for both one-pump operation (1P) and two-pump operation (2P).

4 CONCLUSION

The hybrid methodology applied in the framework of the GreenWin project combines laboratory experiments and numerical modelling to gain a better understanding of opportunities for energy-savings in the pumping systems used to operate open-channel navigation networks. It has proven its potential to reduce the energy consumption in waterways through a better pump management. The plus-value of further modelling will be to suggest concrete actions to be applied in the field to get closer of best efficiency-scenarios.

5 ACKNOWLEDGMENTS

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6 REFERENCES

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SUMMARY

Worldwide, navigation is made possible in artificial waterways thanks to the support of a considerable number of high capacity pumps. In waterways without natural water supply, pumping is required to maintain the water level within a range suitable for navigation, compensating for water transferred by locks operation and other losses (leakages, infiltration, evaporation). Across Europe, pumping in waterways represents 25-33 % of annual electricity use by WMOs (Waterway-Management-Organisation). However, in terms of energy-efficiency, many of the pumps used in waterways do not operate optimally. Main reasons for this include pump oversizing and the absence of variable speed drive. In this communication, we present an international, interdisciplinary and intersectoral research project based on a novel, large experimental pump test bench, a computational model of the pumping process and a numerical model of waterways exchange. The goal of this hybrid research project is to improve waterways pump management and then to provide energy saving.

RESUME

Dans le monde entier, la navigation est rendue possible dans les voies navigables artificielles grâce à l'appui d'un nombre considérable de pompes de grande capacité. Dans les voies navigables dépourvues d'alimentation naturelle en eau, le pompage est nécessaire pour maintenir le niveau d'eau dans une fourchette adaptée à la navigation, en compensant l'eau transférée par le fonctionnement des écluses et les autres pertes (fuites, infiltration, évaporation). En Europe, le pompage dans les voies navigables représente 25 à 33% de la consommation annuelle d'électricité des WMO (Waterway-Management-Organisation). Cependant, en termes d'efficacité énergétique, de nombreuses pompes utilisées dans les voies navigables ne fonctionnent pas de manière optimale. Les principales raisons en sont le surdimensionnement des pompes et l'absence d'entraînement à vitesse variable. Dans cette communication, nous présentons un projet de recherche international, interdisciplinaire et intersectoriel basé sur un nouveau banc d'essai expérimental de grande taille pour les pompes, un modèle informatique du processus de pompage et un modèle numérique des échanges dans les voies navigables. L'objectif de ce projet de recherche hybride est d'améliorer la gestion des pompes des voies navigables, puis de permettre des économies d'énergie.

ZUSAMMENFASSUNG

Weltweit wird die Schifffahrt auf künstlichen Wasserstraßen durch eine große Anzahl von Hochleistungspumpen ermöglicht. In Wasserstraßen ohne natürliche Wasserversorgung ist das Pumpen erforderlich, um den Wasserstand in einem für die Schifffahrt geeigneten Bereich zu halten und das durch den Schleusenbetrieb übertragene Wasser sowie andere Verluste (Leckagen, Versickerung, Verdunstung) auszugleichen. In ganz Europa entfallen 25-33 % des jährlichen Stromverbrauchs der Wasserstraßenverwaltungen auf das Pumpen von Wasserstraßen. Was die Energieeffizienz betrifft, so arbeiten viele der in Wasserstraßen eingesetzten Pumpen jedoch nicht optimal. Hauptgründe hierfür sind die Überdimensionierung der Pumpen und das Fehlen eines drehzahlvariablen Antriebs. In dieser Mitteilung stellen wir ein internationales, interdisziplinäres und sektorübergreifendes Forschungsprojekt vor, das auf einem neuartigen, großen experimentellen Pumpenprüfstand, einem Berechnungsmodell des Pumpvorgangs und einem numerischen Modell des Wasserstraßenaustauschs basiert. Ziel dieses hybriden Forschungsprojekts ist es, das Management von Wasserstraßenpumpen zu verbessern und anschließend Energieeinsparungen zu erzielen.

RESUMEN

En todo el mundo, la navegación es posible en las vías navegables artificiales gracias al apoyo de un número considerable de bombas de gran capacidad. En las vías navegables sin suministro natural de agua, el bombeo es necesario para mantener el nivel del agua dentro de un rango adecuado para la navegación, compensando el agua transferida por el funcionamiento de las esclusas y otras pérdidas (fugas, infiltración, evaporación). En toda Europa, el bombeo en las vías navegables representa entre el 25 y el 33% del consumo anual de electricidad de las OMA (Organizaciones de Gestión de Vías Navegables). Sin embargo, en términos de eficiencia energética, muchas de las bombas utilizadas en las vías navegables no funcionan de forma óptima. Las principales razones de ello son el sobredimensionamiento de las bombas y la ausencia de accionamientos de velocidad variable. En esta comunicación, presentamos un proyecto de investigación internacional, interdisciplinar e intersectorial, basado en un novedoso banco de pruebas experimental de bombas de gran tamaño, un modelo computacional del proceso de bombeo y un modelo numérico de intercambio de vías navegables. El objetivo de este proyecto de investigación híbrido es mejorar la gestión de las bombas de las vías navegables y, a continuación, proporcionar un ahorro de energía.