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DEVELOPMENT AND EXPERIMENTAL TESTING OF A HYDRAULIC STAND WITH PUMPS INTENDED FOR A CENTRAL HEATING SYSTEM

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1. Introduction

Contemporary engineering education increasingly relies on integrating theoretical knowledge with practical activities; laboratory stands play a key role in the experimental verification of models, the visualization of phenomena, and the development of relevant professional skills [1-3]. I In the fields of thermotechnics and hydraulics, experimental teaching plays a crucial role as it enables students to connect theoretical foundations with practical experience and real technical systems. For example, when testing pumps, measurements of flow rate, head, and power are conducted, allowing the determination of characteristic curves and comparison with nominal data. In the analysis of hydraulic systems, the pressure drop in pipelines and fittings is observed as a function of geometrical and hydraulic parameters. Regarding thermotechnical systems, the analysis is based on measuring temperature differences between the supply and return lines, as well as the flow rate in the system, which makes it possible to calculate the actual heat output, identify losses, and evaluate the energy efficiency of the heating system. In this way, students gain a comprehensive understanding of the functioning and optimization potential of complex energy systems [4], [5].

It is well known that there is a gap between theory and application. Laboratory work ensures a deeper understanding of abstract concepts and their application in real-life scenarios; this enhances the development of critical thinking in students [2], [6]. Although virtual and distant labs have certain benefits, such as wider accessibility and more flexibility, the educational experience of physical interaction with equipment is more memorable and effective [5], [7], [8].

Contemporary research has indicated the significance of open projects and active learning in a laboratory setting. For instance, a 2022 analysis in the field of chemical engineering has shown that project-based learning (PBL) focused on design can enrich students' experience and deepen their understanding [9].

A systematic review of PBL learning in engineering (2024) has demonstrated that PBL improves technical skills and soft skills while contributing to interdisciplinarity [10].

In addition, virtual learning has also been taken to the next level. A 2023 study has shown that immersive virtual learning activities (VLAs) rely on visual and haptic feedback to improve the understanding of complex mechanical concepts and increase knowledge retention [1]. Also, the adoption of VR simulations in education shows that virtual laboratories can effectively replace physical ones, especially in terms of accessibility and student engagement [11], [12].

Laboratory transformation through digital technologies and active learning has also been confirmed on the interdisciplinary level. A 2023 study reports positive reactions among physics teachers in Germany, Finland, and Croatia when it comes to the combinations of digital tools (smartphones, simulations) and laboratory work in developing digital competence in students [13]. Active learning practice in higher education improves conceptual thinking, motivation, and interpersonal skills [14].

In the context of contemporary education, the concept of Education 5.0 incorporates a holistic and humanistic approach, ethical awareness, international cooperation, and technology to support student-oriented learning [15]. This framework highlights the importance of technology, inclusivity, creativity, and ethical considerations – all components that can be effectively implemented through laboratory stands and immersive tools such as VR and digital twins.

The development and implementation of a laboratory stand with pumps for central heating systems is not only a technical instrument, but also a powerful pedagogical tool. It can be used to explore pump properties, determine operating points, draw pipeline curves, test valves, regulate flow through a bypass, and apply a frequency drive; this allows the direct application of theoretical knowledge in industrially relevant scenarios [9, 11, 15].

This paper aims to demonstrate the process of developing a hydraulic stand with pumps used in central heating systems and experimental testing. The emphasis is placed on the educational role of such a stand and preparing students for future professional challenges.

2. Laboratory Stand Description

The Fig. 1 presents the schematic overview of the laboratory stand.

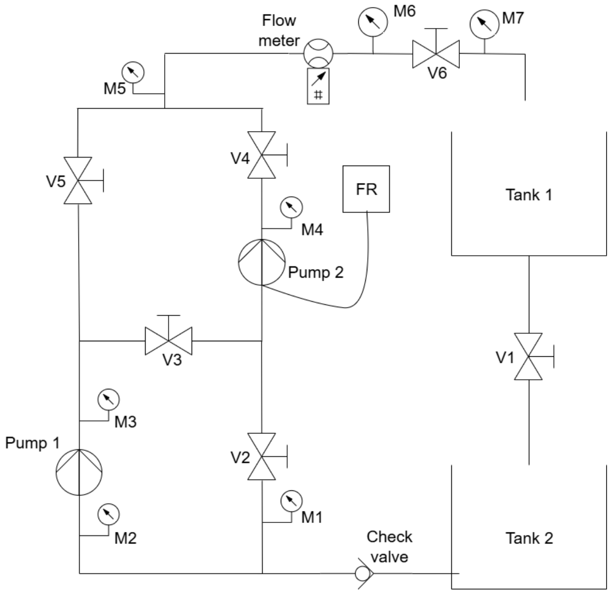

Fig. 1. Schematic overview of the laboratory stand

The most crucial components of the stand are shown in Fig. 2. Together, they enable a detailed exploration of how the pumps and the valves operate and how to regulate flow in central-heating systems.

Fig. 2. The laboratory stand

Two centrifugal pumps (Grundfos UPS 32/40 180) are the core components. In practice, they are used as circulation pumps for floor heating. One pump is connected to the electricity grid via a flow regulator. This allows a precise regulation of flow and thus the working pressure. In addition, it enables the investigation of system efficiency when the flow is regulated via the valve, bypass, or frequency drive.

The pipeline was made of water pipes certified for a maximum working pressure of 15 bars. This provides safety and reliability during experiments. The valves direct fluid so that the pumps can be connected in a series or in parallel, depending on the type of experiment to be conducted. The pumps push water from the tank through the pipeline. At the end of the system, just before the return to the tank, there is a valve that can be easily removed with two holders, and it can be replaced with a valve of a different kind. This allows students to explore the properties of different valve types.

Manometers are distributed along the entire system at several locations. Hence, it is possible to monitor pressure values precisely in different parts of the stand. A digital flowmeter is installed in the last branch of the pipeline. Flow can also be estimated by measuring volume in the upper tank. It is equipped with a level gauge with scaled divisions. This enables comparisons between the measures obtained for flow.

This stand configuration allows students and researchers to use practical training and experimental tests to deepen their understanding of the complex hydraulics processes, draw pump and valve characteristics, determine the working points of the system, and analyze the efficiency of regulating flow with a valve, bypass, or frequency drive.

In the next section of the paper, we shall present the results obtained for this particular stand in order to illustrate its functionality and potential for educational and research purposes.

2.1 Experiments

A laboratory stand developed at the Department of Energy and Processing Engineering, Faculty of Engineering, University of Kragujevac, can be used to conduct different experiments in the field of water hydraulics and fluid mechanics. The laboratory can be used for the following experiments:

- Measuring flow and pressure to determine the reference points for drawing the curves for the pipelines and the curves for the pumps;
- Evaluating the pump efficiency (measuring electrical power and hydraulic power with different loads;
- Testing the system with different performance shares among two pumps connected in a series and/or in parallel;
- Testing the flow regulation in the system with different regulation systems (e.g., bypass, valves, a frequency drive);
- Comparing flow measuring with a direct or indirect method;
- Determining the properties of different types of valves.

2.1.1 Pump characteristics curve

One of the most basic and common experiments is drawing pump characteristics. The parameters of both pumps can be measured. To minimize the impact of measurement errors, it is recommended to draw the properties of Pump 1, as the manometers are installed immediately before and after the pump, thereby reducing the likelihood of errors due to local pressure losses at the measurement locations. The experiment procedure starts with starting the pump. The valves are positioned not to disturb fluid flow. The valves 2, 3, and 4 are closed, so the fluid runs through the pump branch 1, valve 5, and enters the outlet branch that contains the turbine flow gauge.

Flow is evaluated with the already mentioned digital gauge device or by measuring the volume of the fluid that fills the tank after some time. The manometer installed in the suction and discharge pump pipeline detects the pressure. The values change depending on system resistance.

The first measurement, which represents the first point on the pump curve diagram, is most commonly obtained by reading pressure values and determining their differences. This also includes the reading of the flow value from the digital gauge instrument. The next measurement is conducted by increasing local resistances in the system, recording pressures at the pump inlet and outlet, and recording flow.

Each difference in pressures before and after the pump (pump load) has a corresponding flow value in the pipeline. By plotting these values on the ordinate and abscissa of the Cartesian coordinate system, students can connect the dots and obtain the pump system curve. After a series of consecutive measurements, we have obtained the values presented in Table 1.

Table 1. The results of the pump measuring 1

Case no.	**Pressure in the pipeline** [bar]	**Pressure in the suction pipeline** [bar]	**Fluid flow** [m^3/h]
1	0.43	0.025	0.01
2	0.39	0.025	0.2
3	0.34	0.02	0.58
4	0.32	0.02	0.93
5	0.27	0.015	1.21
6	0.21	0.01	1.64
7	0.16	0.0075	2.36
8	0.1	0.005	2.8

The Fig. 4 shows the pump curve obtained by performing measurements for eight different valve 6 positions.

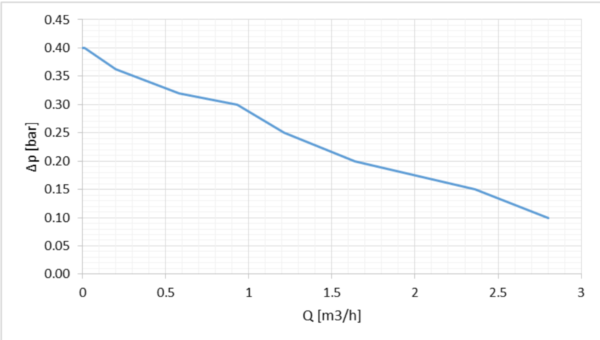

Fig. 4. The pump curve obtained based on performing measurements at the laboratory stand

As can be seen from the image, the curve is relatively flat. The shape of the curve stems from the fact that the pump is a component of the heating system. In such systems, the curves are flat since the pumps used are centrifugal (*i.e.*, pressure changes gradually with flow). Such a shape ensures the stable system operation because changes in the resistance of the installation do not cause large oscillations in pressure and flow, which further contribute to quieter operation and better regulation.

3. Conclusions

The developed laboratory stand with the pumps for central heating systems can be a key tool in students' education. Such teaching methods enable the direct use of theoretical knowledge. Students can gain clear insight into how pumps work, valve properties, flow regulation, and system efficiency. This can contribute significantly to a deeper understanding of complex hydraulic processes and the development of practical professional skills.

The paper demonstrates the results obtained for some experiments. Due to length limitations, the paper does not include the results obtained for regulating flow via a drive frequency, comparing flow with a direct or indirect method, and the evaluations for different types of valves. In addition to standard experiments, the stand is flexible enough to enable, with certain modifications, other experiments. It is, hence, a valuable resource for research work. This approach to practical learning strengthens critical thinking, motivation, and independent problem-solving. Hence, theory and practice in modern engineering education are successfully blended.

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References

[1] R. Padilla Perez and Ö. Keleş, "Immersive Virtual Reality Environments for Embodied Learning of Engineering Students," *arXiv preprint*, Mar. 2025.

[2] K. Boettcher *et al.*, "Developing a real-world scenario to foster learning and working 4.0 – on using a digital twin of a jet pump experiment in process engineering laboratory education," *European Journal of Engineering Education*, vol. 48, no. 5, pp. 949–971, 2022.

[3] Ö. Keleş *et al.*, "Experiential Learning of Engineering Concepts in Immersive Virtual Learning Environments (VLEs)," *Journal of STEM Education: Innovations and Research*, vol. 24, no. 2, 2023.

[4] D. May *et al.*, "Rapid transition of traditionally hands-on labs to online instruction in engineering courses," *European Journal of Engineering Education*, vol. 48, no. 5, pp. 842–860, 2022.

[5] D. Basu and V. K. Lohani, "Learning and engagement with an online laboratory for environmental monitoring education," *European Journal of Engineering Education*, vol. 48, no. 5, pp. 861–879, 2023.

[6] S. Terkowsky *et al.*, "Digital transformation in physics lab courses: a tri-national survey," *arXiv preprint*, May 2023.

[7] S. Rogers, "Experiential and authentic learning in a Living Lab: the role of a campus-based Living Lab as a teaching and learning environment," *Journal of Learning Development in Higher Education*, no. 28, 2023.

[8] K. Frady, "Use of virtual labs to support demand-oriented engineering pedagogy…: a systematic review," *European Journal of Engineering Education*, 2022.

[9] "Constructivist-based experiential learning: A case study… distillation laboratory," *Education for Chemical Engineers*, vol. 41, 2022.

[10] "Project-Based Learning (PBL) as an Experiential Pedagogical Methodology in Engineering Education: A Review of the Literature," *Education Sciences (MDPI)*, 2024.

[11] "Immersive Learning: A Systematic Literature Review… Virtual Reality," *MDPI*, 2023.

[12] "A review on cultivating effective learning: synthesizing educational theories and virtual reality…" *PeerJ Computer Science*, 2023.

[13] S. Zacharias Lahme *et al.*, "Physics lab courses under digital transformation…," *arXiv preprint*, May 2023

[14] "Active learning"—Meta-analysis summary, *Wikipedia*, 2025.

[15] "Student 5.0: immersive learning in next-gen Automation… Industry 5.0 era," *Frontiers in Education*, 2025.