LIFE17 ENV/ES/000252

Deliverable D25
Handbook with results of Poland Seminar

Reporting Date
28/02/2023

LIFE NEXUS

Data Project

Project location:	Leon (Spain)
Project start date:	01/10/2018
Project end date:	31/12/2023
Total budget:	1,158,188 €
EU contribution:	677,720 €
(%) of eligible costs:	60%

Data Beneficiary

Name Beneficiary:	Szewalski Institute of Fluid-Flow Machinery of the Polish Academy of Sciences (IMP-PAN)
Contact person:	Janusz Steller, DSc
Postal address:	ul. Fiszera 14, 80-231 Gdansk, Poland
Telephone:	+48 58 5225 139
E-mail:	steller@imp.gda.pl
Project Website:	www.lifenexus.eu

IMP PAN Rep. 67/2023

Table of contents

1. Summary

This handbook comprises the printed proceedings of the International Symposium "Harvesting energy in municipal and industrial water cycles" which took place in Warsaw on October 27th, 2022 as a part of the annual HYDROFORUM event . The Symposium was organised within the framework of the Life NEXUS Project Action B4 "LIFE NEXUS boosting at European level and exploitation" (Sub-Action B4.1: Training seminars for pilot operators, maintenance workers and host facilities owners). Life NEXUS is a project co-funded by the European Commission under the LIFE Environment and Resource Efficiency Programme (contract LIFE17 ENV/ES/000252). The key project objectives are developing the European database of hydropower potential in the municipal water networks and promotion of utilising this potential by means of micro-hydropower technology. The promotion activities include building an innovative micro-hydro-power plant which would use hydropower potential at the entrance to Porma Drinking Water Treatment Plant in Spain, developing prefeasibility studies for a number identified potential sites where Porma approach could be replicated and conducting or attending a number of promotive/educational – meetings workshops/seminars/symposia/conferences.

The Symposium brought together over 50 representatives of various stakeholders. Out of 11 contributions delivered, seven contributions were directly related to the Life NEXUS project scope. Extended abstracts or full texts of all contributions were published in the original language (Polish or English) in HYDROFORUM 2022 Book of Abstracts, now available from the https://www.tew.pl/index.php/en/conferences-seminars website of the Polish Hydropower Association alongside with almost all pdf versions of the HYDROFORUM presentations. Please note the LN symbol which is used for all the Life NEXUS Symposium documents.

The present handbook comprises English version of all seven documents mentioned, including two contributions to Session I, four contributions to Session II and one contribution to Session III. The first contribution summarises the work on European inventory of hydropower potential in the municipal water networks. The web based database and the geomap are presented. This work was done mainly by the Lithuanian and Spanish teams. The second contribution summarises results of detailed analysis of hydropower potential in Lithuania including concepts of developing prospective energy harvesting sites and methodology applied to assess and rank their technical and economic attractiveness. Session II was planned as the Training Seminar as envisaged by the Life NEXUS Sub-Action B4.1 schedule. The Session started with an introductory lecture on some technical aspects of selecting hydraulic units, and especially PATs, for energy recovery installations. The next lecture delivered dealt with various examples of hydraulic energy recovery in Polish municipal and industrial water circuits. The lecture summarisation text as submitted by the authors has been supplemented by the Editor by extensive excerpts from the presentation, including authors notes. Particular attention is to be paid to very important practical conclusions addressed to the investors and developers of hydraulic energy recovery installations. The third lecture describes the pilot energy recovery installation at inlet to Porma Drinking Water Treatment Plant in Spain. Full text of the lecture is provided. The final contribution to the Training Session describes a PAT based energy recovery installation in Cracow Municipal Heating Utility. The last abstract of this handbook refers to an advanced research work - a CFD study on hydrodynamic phenomena taking place in a PAT flow system.

The Symposium Organisers expect that the present volume will appear useful for all those interested in development of energy harvesting technology from both municipal and industrial water circuits. Furthermore, the readers are invited to consider this handbook a guide to the presentations to be downloaded from the aforementioned TEW website.

Memorial statuette presented to Organisers
by the Commercial Chamber "Polish Waterworks" on the XXXth anniversary
of Polish Hydropower Association

2. Introduction

The idea of exploiting hydropower potential naturally available or artificially cumulated in some drinking water intake structures and delivery conduits is not new. It is enough to mention that the largest European hydropower installation using the drinking water scheme was erected as early as in 1950-ies. The use of water retention and flood protection dams as well as other multipurpose hydraulic structures for hydropower purposes has been considered obvious for even longer time, showing tradition dating back to the beginnings of previous century. Since mid of the previous century one can observe also high interest in recovery of energy lost in some industrial installations where abrupt lowering of liquid pressure is necessary due to technological reasons or the energy of liquid leaving the industrial installation is considered a by-product of the technological process, sometimes named "waste energy".

What has really changed in recent decades, it is the value attributed to such aspects of electricity generation technology as environmental impact, grid stability impact and supply safety. Efficient use of energy, including lost energy recovery, is probably the most environmentally friendly approach to the energy economy possible, contributing substantially to the energy supply safety as well. Due to this reason recent decades have seen rising interest in recovery of hydraulic energy lost also at the outlets of Waste Water Treatment Plants, storage tanks and some other water network spots of potentially lower capacity.

Despite rising electricity prices and the EU policy oriented on development of renewable and emission-free energy sources, developing micro- and mini- hydropower installations is always a matter of techno-economic compromise. The hydraulic energy recovery installations are generally expected to represent highly profitable projects with short pay-back time. The main reasons include very limited, if any, scope of civil engineering works and highly predictable, sometimes stable, hydraulic conditions. The main costs are related to the hydraulic unit, rearranging the piping at the site, mounting the necessary hydraulic, mechanical and electrical equipment, developing the control system, including the control software. A significant constraint remains quite often the space available for erection of the energy recovery installation.

Small hydropower installations are usually divided into small-, mini-, micro- and pico- categories. Due to practical reasons, power capacity is generally used as a criterion for this categorization. Most of energy recovery installations can be classified as micro- and mini- plants. However, it is technology applied which really means in case of any technical assessments.

Eventually, the technological choice depends in greater extent on the economic aspects. Therefore, in case of energy recovery plants with capacity above 100 kW, a classic unit taken "out of the shelf" may appear a reasonable option. In case of lower capacities, some simplified or specialized designs may be recommended, just to mention the well-known in-conduit designs – e.g. spherical and bulb ones- which are especially well suited for low head applications.

Another well justified compromise between the hydraulic unit price and performance can be also reached by using an impeller pump in turbine mode of operation (Pump As Turbine, PAT) instead of a classic hydraulic turbine. Some pump manufacturers noticed a chance of expanding their markets by offering their products for such application already a long time ago. The most consequent approach has been shown by KSB AG, leading pump manufacturer having tested comprehensively two series of centrifugal pump types in turbine mode of operation. Today, a potential KSB customer is offered a PAT type selected by the company specialist according to the wished installation operation point together with performance characteristics comprising head, power and efficiency curves as plotted vs the discharge. Although KSB centrifugal pump based PATs are most widely used and most extensively investigated by numerous internal and external researchers, there exists still substantial interest in products of other manufacturers, such as Sulzer and Caprari. Also some other pump manufacturers and research institutions continue their efforts to develop new series of PAT and micro-turbine types with modified flow system (usually pump casing with newly designed runner).

Due to lacking or difficult access to pump characteristics in turbine mode of operation, establishing relationship between best efficiency points in both regimes was a topic of numerous research activities already in the end of seventies. For almost two recent decades ever more projects have dealt also with methodology to determine the expected course of PAT performance curves. Unfortunately, the research results are often ambiguous and should be applied generally to pumps of similar design or at least similar specific speed. Nevertheless, they may appear highly helpful at the preliminary stage of prefeasibility studies. Some examples are presented in this handbook.

The well-known disadvantage of most pumps and modified pumps used as turbines is lack of internal regulation mechanism which results in steep efficiency characteristics and problems with matching the unit operation point to the available operation parameters. In case of centrifugal pumps the only reasonable regulation technique is a combination of flow throttling and bypassing. This requires using a system of regulation valves which price is often comparable or even higher than that of a PAT unit itself.

Another problem often encountered in energy recovery installations, especially those located at the end of water delivery conduits, is the waterhammer risk due to load rejection – an emergency transient state which can lead to swift unit runaway and discharge reduction. Various counter-measures - such as flywheels used to increase the rotating assembly inertia, advanced control valves and valve-stroking techniques are deployed to mitigate the hydraulic transient course. Emergency feeding of the monitoring and control system is of high significance and has to be carefully considered at the installation planning stage. In numerous cases detailed hydraulic transient analysis incorporating characteristics of all relevant flow system components is also required.

Modern technology offers a number of tools allowing not only to cope with installation safety challenges, but also with optimizing the electricity generation and consumption process – e.g. by means of the energy storage techniques. Planning the use of these opportunities is typically a task of the designer, but some essential assumptions have to be considered in detail even at the earlier stage of the project both from the technical and economical point of view.

As it can be seen even from the above brief overview, responsible planning of an energy recovery installation in a municipal or industrial water circuit may require coping with quite a number of detailed problems. Due to significance attributed by the European Commission and EU Member States to energy recovery and development of dispersed renewable energy sources some of these challenges are topics of the EU funded research and research & development projects.

Quantitative assessment of total usable hydropower potential in municipal water cycles in individual EU Member States has been attempted on numerous occasions. One of such attempts has been planned within the Life NEXUS project

Boosting sustainability of the urban water cycle:
energy harvest in water industry using micro-hydropower technology

The aims of the project include:

- identifying the hydropower potential associated with the dissipation of hydraulic energy in water supply networks and in industrial installations,
- promotion of the use of this potential by means of micro-hydropower technologies.

The project is being implemented within the framework of the European Union Life programme basing on the LIFE17 ENV/ES/000252 contract between the European Commission and a consortium consisting of the following members:

- CARTIF Foundation, Valladolid, Spain (consortium leader and project co-ordinator);
- Sociedad Mixta Aguas de León, S.L., Leon, Spain;
- Aquatec, Proyectos para el sector del agua s.a.u., Madrid, Spain;
- Vytautas Magnus University, Kaunas, Lithuania;
- Robert Szewalski Institute of Fluid-Flow Machinery of the Polish Academy of Sciences (IMP PAN), Gdansk, Poland.

The pivotal task of all project activities aimed at promotion of energy harvesting in the urban water cycles is development of a pilot installation at the Porma Drinking Water Treatment Plant in direct neighbourhood of the city of Leon (Spain). The electricity produced here is used for the internal purposes and therefore an energy storage facility has been planned in order to accumulate energy in the periods of generation excessing the demand and to feed the local grid in periods of increased demand. A significant number of replication prefeasibility studies have been prepared in Spain, Lithuania and Poland in order to promote developing similar installations throughout Europe.

A significant portion of project activities includes a series of workshops oriented on informing the prospective stakeholders about the existing opportunities and potential existing in their countries, available technologies and experience following from exploitation of the existing installations and the conducted prefeasibility studies. Providing a suitable platform for exchange of relevant information, opinions and expertise between

- designers and developers of hydraulic energy recovery installations,
- potential investors including municipal water supply and sewage network companies
- policy makers and relevant administrative institutions
- providers of relevant equipment, especially hydraulic machinery and armature
- relevant research and research & development entities

was the main goal of the Life NEXUS Symposium held in Warsaw on October 27th 2022. The symposium was organised as a part of the HYDROFORUM 2022 event, which allowed to bring together also numerous representatives of Polish hydropower sector. HYDROFORUM is the shortened naming of two- or three-day Polish Hydropower Conferences, which are organised annually by the Polish Hydropower Association together with the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences and the Polish Association for Small Hydropower Development. In 2022 we used the formula with HYDROFORUM event encompassing the Polish Hydropower Conference on the first and the Life NEXUS symposium on the second day, respectively. This was followed by a study tour to the Dębe hydropower plant located within 1 hour drive distance from Warsaw.

The debates of the Life NEXUS Project Symposium were opened by the introductory information delivered by the author of this text and the speech by Mr. Paweł Sikorski, an expert of the "Polish Waterworks" Chamber of Commerce [IGWP], who welcomed the delegates on behalf of the Chamber President, Mr. Krzysztof Dąbrowski, and his own. The speaker presented also the profile of IGWP activities and congratulated the Polish Hydropower Association its XXXth anniversary. On this occasion, he presented the TEW Board a statuette engraved with anniversary congratulations.

The subsequent sessions focused on the following topics

Session I:	Assessment of the hidden potential
Session II:	Technology – fundamentals and examples
Session III:	Research activities and innovative technologies

Session LN1 was opened by Dr Raquel M. Lopez, Life NEXUS project co-ordinator, who provided an extensive information about the project and the inventory of micro-hydroenergy recovery potential in the water industry. The crucial part of the work was conducted by CARTIF and the Lithuanian team headed by Professors P.Punys and A.Radzevicius who developed the web based map of existing and potential energy recovery sites. The Lithuanian colleagues delivered also on their extensive studies on installations replicating the pilot plant, as well as an assessment of the available potential. A special methodology of ranking the potential sites according to different techno-economic criteria has been presented.

Session LN2 has been planned as a training one. The session was opened by a 45 minutes lecture on some technical aspects of selecting hydraulic units, and especially PATs, for energy recovery installations. The material for the lecture was prepared by the IMP PAN team and the lecture itself was delivered by the author of this document.

The introductory lecture was followed by 3 case study presentations:

LN2.2 M. Kaniecki, M. Lewandowski, A. Kamiński, S. Lewandowski:
Recovery of energy lost in technological processes of industrial enterprises.
Practical examples

LN2.3 J. Samaniego, L.A. Bujedo, R.M. López Fernández, V.I. Serna González, M. Mirete, J. Page:
Energy recovery in a DWTP using an innovative micro-hydropower system
based on the integration of a Pump as Turbine and an energy storage

LN2.4 M. Piękoś: Water turbine application in MPEC Cracow heating networks.

The final session dealt with various innovations in the field of small hydropower. Attention is to be brought to the work of a team from Wroclaw University of Technology who reported on their CFD study of centrifugal PATs.

The extended abstracts of all Life NEXUS Symposium contributions have been included in the HYDROFORUM Book of Abstracts which can be downloaded together with most of presentations from the following website of the Polish Hydropower Association (TEW):

https://www.tew.pl/index.php/en/conferences-seminars.

Due to promotional and training character of the Symposium, the contributors to sessions LN1 and LN2 were invited to submit texts with size exceeding the limit recommended for most authors of HYDROFORUM Proceedings.

The English version of all mentioned text contributions (extended abstracts and papers) has been included in this handbook. In case of paper LN2.2 the abstract was supplemented by excerpts from the respective presentation with the notes by the authors included. The Symposium Organisers expect that the present volume will appear useful for all those interested in development of energy harvesting technology from both municipal and industrial water circuits. Furthermore, the readers are invited to consider this handbook a guide to the presentations to be downloaded from the aforementioned TEW website.


Energia Odnawialna S.A.


PGE
Energia Odnawialna S.A.
www.energoprojekt.pl


Energia Odnawialna S.A.


Hotel
Restauracja

3. Potential

3.1. LIFE NEXUS: First European inventory of micro-hydroenergy recovery potential in the water industry

Introduction

Water and energy are two of the most important resources of the 21st century. In particular, cities are a framework where this water-energy nexus is becoming critical due to demographic movements, economic growth and global change pressures. The current con-text of water scarcity and need for low carbon intensity solutions is making it a challenge to continue to deliver core urban water services without increasing the impact on the environment. LIFE NEXUS Project pro-poses a breakthrough by considering urban water networks as a source of renewable energy. Despite the odds, to date limited analyses have been carried out to identify the energy recovery potential in the urban water cycle (UWC) [1-4].

Supply water is transported by pressured piping grids, while drain and sewage systems are usually gravity fed. Both types of grids may hold untapped energy deriving from abundant pressure (water head) or the kinetic energy (water flow). Usually, these points with excess of energy are located in:

1) Storage/service reservoirs (SRV) gravity fed or water treatment works in the raw water network located in upland areas and feed into Drinking Water Treatment Plants (DWTPs), either at catchment or distribution stages,
2) Wastewater systems, either upstream or down-stream of Waste Water Treatment Plants (WWTPs), collection or discharge stages,
3) Pressure reducing values (PRVs), are hydraulic devices that maintain pre-set pressure ranges and are installed to relieve the excess pressure and release it as waste heat,
4) Break pressure tanks (BPTs), whereby the pressure, kinetic and potential energy within the flow are dissipated to the atmosphere.

with in pipe generators, maintaining the same control on water flow and pressure whilst producing usable electricity ("green electricity"). It is important to mention that recovering energy at these locations will have no impact on the flow or pressure to downstream consumers. Furthermore, the pressure reduction is correlated to a decrease in the water leakages [5].

LIFE NEXUS Project is evaluating the technical / economic and environmental feasibility of the energy recovery in water networks by means of Small Hydropower Plants (SHP). Among the different available machines (traditional turbines or adapted machines), LIFE NEXUS demonstration will be focus on the innovative Pump as Turbine (PaT), a type of adapted ma-chine, that is becoming the technological solution for micro-hydraulic projects (≤ 100 kW) [6-8]. The main advantages of these machines are their immediate availability for installation and lower cost compared with conventional machines. A cutting-edge integration of a PaT machine together with battery storage is being carried out to enhance the possibilities of the energy management. This innovative system will be installed at the entrance of the Porma Drinking Water Treatment Plant (DWTP) located in Valdefresno, a small village nearby the city of Leon (Spain). Once they will be fully operating the energy generated will cover the total energy demand of the installation.

In parallel to the previous demonstration of the PaT technology, LIFE NEXUS has carried out the 1st European inventory of the energy recovery locations, including both new sites and existing hydropower plants. Although the catalogue was initially intended to harbor urban sites, finally it also has included industrial and irrigation locations, in order to boost energy harvest in other sectors. This abstract is focus on this LIFE NEXUS inventory and describes the min out-comes obtained so far within the Project.

Methodology

The information contained in the catalogue is georeferenced, mapped in layers according to their location and is accessible through a web platform. For data collection, a questionnaire based on an Excel platform was created, which contains 16 or 19 questions de-pending on the type of location. This questionnaire for data collection is available through the LIFE Project website in the Community Menu [9]. For the imple-mentation of the online survey, the LimeSurvey open source Tool was used.

The information has been published as a geo-referenced database [10]. The main characteristic of a GIS (Geographical Information System) is that it is possible to work with data located in space with reference to a geographic coordinate system, which allows us to generate georeferenced maps. Leaflet is used as the web map client. It is an open-source JavaScript library for mobile-friendly interactive maps. The main principles of Leaflet are the simplicity, performance and usability. It is well-documented and there are a wide variety of plugins that enables to extent the tool functionality. Leaflet is used to show the data con-tained in the json in a map.

Regarding the base map, in our case OpenStreetMap (OSM) and Mapbox will be used. OSM is created by a collaborative community for sharing free geographical data around the world in a free editable map of the world. This community add, verify and update the data using aerial images, GPS, maps and another free data so it is very complete. Map box is also an open source mapping platform for custom designed maps that contains data based in OSM. The visualization module is available through the Project website:

CARTIF and AQUATEC have been responsible for the contacts in Spain. Then, IMP PAN and ASU were in charge of Poland and Lithuania, respectively.

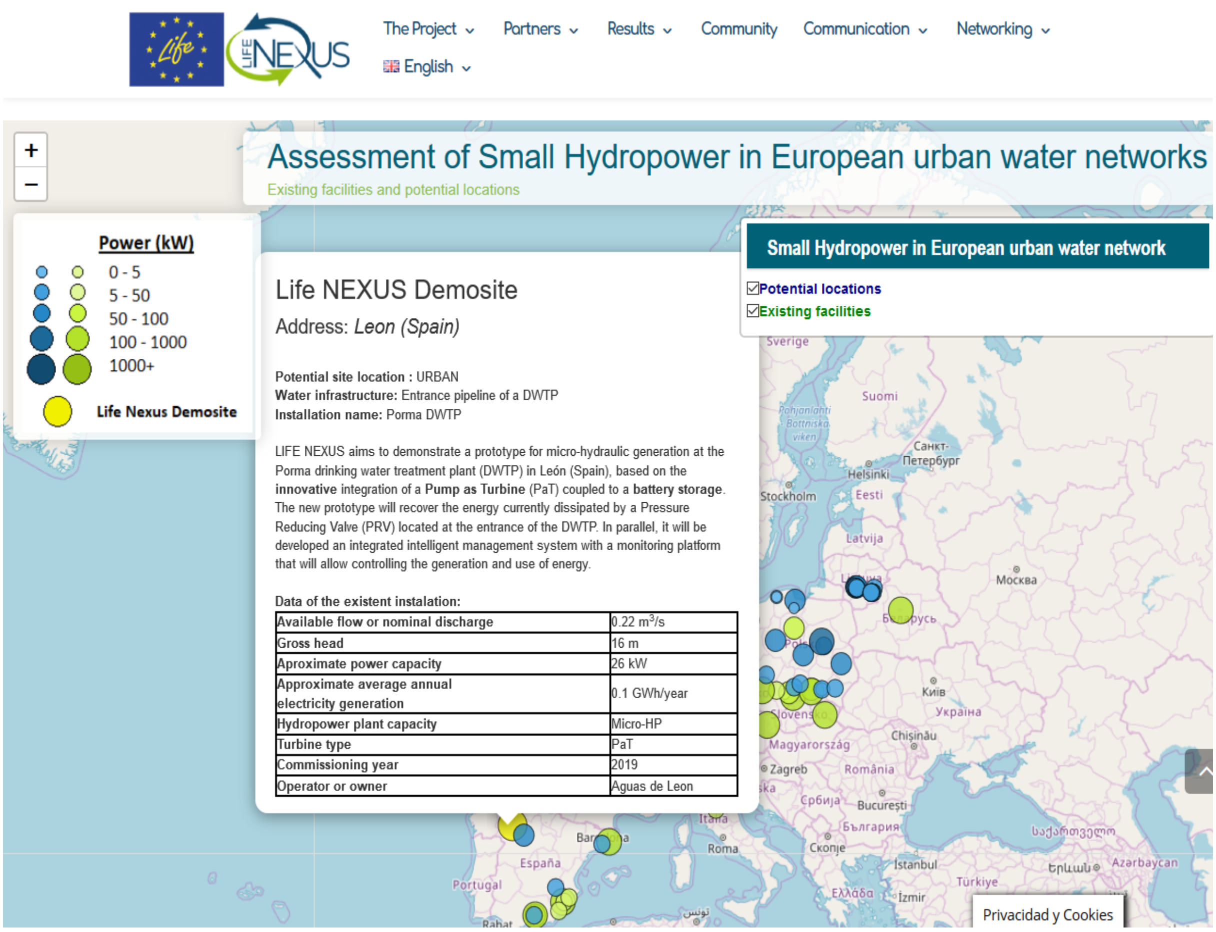


Fig.1. Visualisation of micro-hydro potential locations in urban water networks

Results

At this moment, the inventory contains 104 energy recovery locations (71 potential and 33 existing Hydropower plants) from 10 different European Countries: Spain, Lithuania, Poland, Austria, Belarus, Czech Republic, Germany, Italy, Slovakia and Switzerland.

Potential locations

LIFE NEXUS inventory has 71 potential locations, located in Lithuania (25), Poland (23) and Spain (23). The approximate power capacity derived from these locations, assuming a generation efficiency of 75%, is 2.97 MW. The theoretical annual electricity generation is 11.87 GWh/year assuming 4000 hours of operation per year.

Regarding the type of locations, 52 sites are located in the UWC, 18 are placed in irrigation channels and one is a “mixed” site for urban water supply and irrigation.

37 of the potential locations are located at a WWTP (downstream or upstream), 22 are SRVs located at the entrance pipeline of a DWTP. Finally, there are nine PRVs and three BPTs, all of them located at the en-trance to the distribution network.

Regarding the theoretical approximate power capacity (considering 75% of efficiency in the turbine), eight of them are Mini-hydraulic (≤ 1 MW), and the rest are Micro-hydraulic (≤ 100 kW).

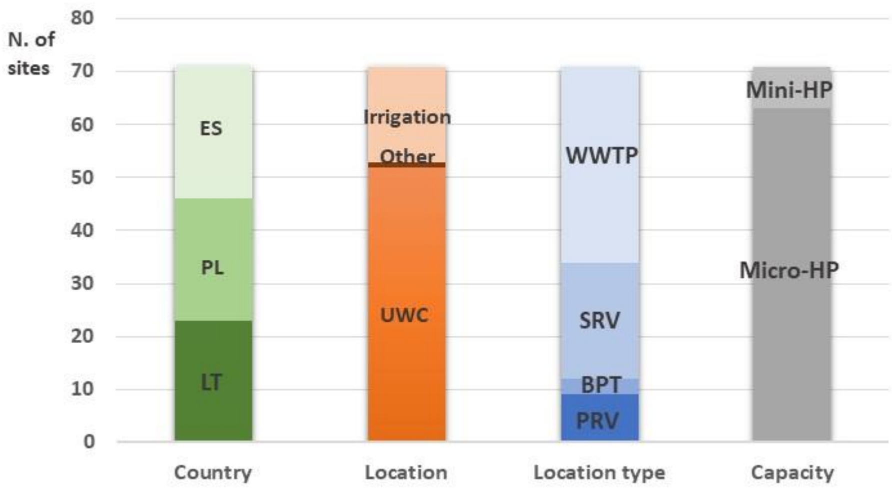


Fig.2. Characteristics of the potential energy recovery locations in the LIFE NEXUS inventory

Assessment of potential locations at country level

Lithuania: Due to the country’s topographic conditions – a purely lowland country, only sewage (wastewater) networks with free gravitational flow can be attractive for the harvesting water energy. Drinking water distribution systems are artificially pressurised and cannot be used for energy recovery. Only one site was spotted in the drinking water distribution network with a pressure-reducing valve. The urban water networks of the two largest country’s cities - the capital Vilnius and Kaunas were studied in depth along with a dozen smaller towns. So far, some 25 potential sites with their main characteristics were identified upstream or down-stream waste water treatment plants (WWTP). All of the power capacities are below 100 kW (eight of them below 10 kW) [11].

Poland: Potential sites are located in the sewage net-works and in WWTPs with free gravitational flows. Most of the power capacities are below 100 kW (five of them bellow 10 kW). However, there are two potential sites very promising with 201 kW and 525 kW located in a WWTPs and in a SRV respectively.

Spain: four of the sites identified are located at the entrance of urban water distribution networks, being three of them PRV devices, while the other is a BPT. Approximate power capacities are in the interval 36 – 74 kW. The rest of the locations in Spain are located in irrigation channels, being one of them a “mixed” site for urban water supply and irrigation. Most of these locations are secondary storage reservoirs (SRVs) and show very different capacities: 11 sites bellow 10 kW and four sites with capacities above 150 kW.

Replication studies in potential locations

Thirty-five locations out of the total 71 have been selected for the so-called “replications studies”, where the technical-economic viability of new mini-hydraulic projects is being assessed, considering the regulatory and policy context of each country.

In Lithuania, the viability of SHP energy recovery was performed at eight potential locations: three WWTPs, four wastewater collectors (upstream of WWTPs), and one site in the drinking water network. The latter represents a separate case.

Existing installations

The 33 existing hydropower plants are located in nine different European countries: Belarus (1), Slovakia (1), Germany (1), Italy (1), Switzerland (3), Austria (4), Czech Republic (6), Poland (6) and Spain (10). The total installed power output of these installations is 14.82 MW and the annual electricity generation is 73.8 GWh/year.

Thirty of the installations are placed in the UWC and the other three are located in several industries: metallurgy, power plant and oil refinery.

Regarding the location in the UWC; one turbine is located in the cooling system of a metallurgical industry and other one is located in a desalination plant. Then, seven turbines are located at the entrance of a DWTP, nine are in the downstream of a WWTP and finally 15 are at the entrance of a drinking water distribution network.

Regarding the type of turbine, there are two others (cross-flow or pressure exchanger), four Kaplan, eight Pelton, nine Francis and ten PaTs.

Finally, regarding the hydropower plant capacity, there are three SHPs (1-10 MW), 17 mini-hydraulic plants (100 kW – 1 MW) and 13 micro-hydraulic plants (≤ 100 kW).

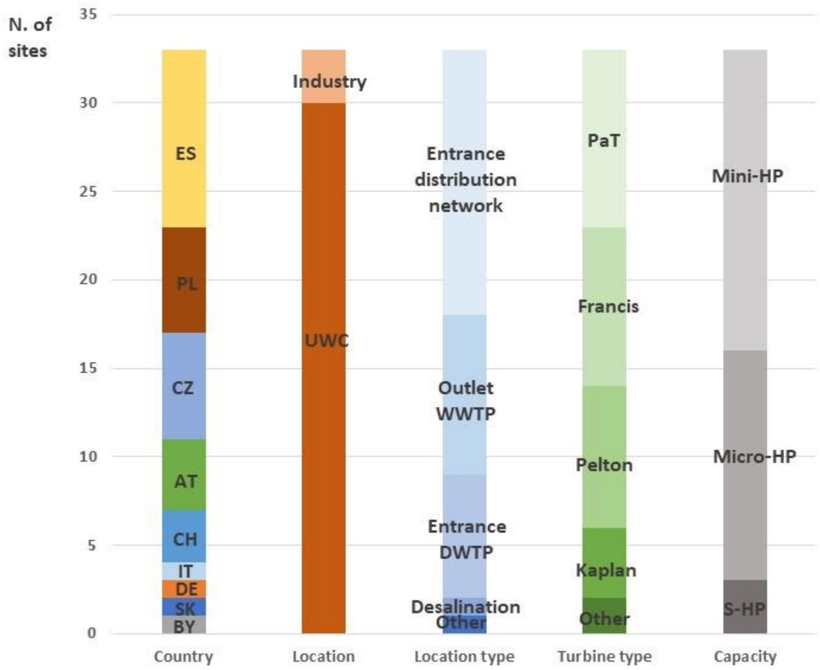


Fig.3. Characteristics of the existing installations included in the LIFE NEXUS inventory

Assessment of existing installations at country level:

Lithuania: No existing hydropower plants operating in water and waste water infrastructure have been identified so far in this country. The same is for other Baltic countries.

Poland: six hydraulic energy recovery installations are currently under operation in Poland. Four of them operate in the UWC and the other two are located downstream the WWTPs of the PKN Orlen Oil Refinery (130 kW Francis turbine) and the Skawina Hydropower Plant (1.4 MW Kaplan turbine)

Spain: A number of ten hydraulic energy recovery installations are operating in the country and all of them operating in the UWC. Nine of the facilities are micro-hydropower installations (power capacity in the range of 11-90 kW), involving seven PaT machines, one Francis turbine and one cross flow turbine. Finally, there is an energy recovery device (Pelton turbine) in a desalination plant with a power capacity of 514 kW.

Replication studies in existing installations:

One hydropower plant out of the total 33 has been selected for the so-called "replications studies". It is rehabilitation of a decommissioned energy recovery installation in the PKN Orlen Oil Refinery in Poland. Several alternatives for the substitution of the Francis turbine by other turbines located in different locations of the plant are being studied.

(1) Micro-hydropower plants are an appropriate solution to recover the untapped energy existing in water networks, and thus, they can support the clean energy transition in the European water industry.

(2) LIFE NEXUS inventory has mapped 71 potential locations along Poland, Lithuania and Spain, which all together lead to an approximate "sleeping" potential of 2.97 MW. The energy generated can be used on site, as for the case of the LIFE NEXUS demosite, where the energy harvest by means of the PaT will cover the total demand of the installation.

(3) Most of the potential locations included in the inventory have a capacity below 100 kW (micro-hydropower) and are located mainly in WWTPs (downstream or upstream) or in SRVs located at the entrance pipeline of DWTPs.

(4) LIFE NEXUS inventory has mapped 33 existing Hydropower plants along Europe, with a total installed power output of 14.82 MW. Most of the installations are located in the UWC, mainly at the entrance of a DWTP, at the entrance of a distribution network, or downstream of a WWTP. PaTs are the most installed machines in this energy recovery plants, followed by Francis and Pelton turbines. Regarding the capacity, almost have of them are mini-hydropower plants and the other half are micro-hydropower plants.

Acknowledgments

LIFE NEXUS Project has received funding from the LIFE financial instrument of the European Commission LIFE17 ENV/ES/000252.

References

1. ESHA, Mhylab et al.: *Energy recovery in existing infrastructures with small hydropower plants*. Multipurpose Schemes – Overview and Examples. FP6, SHAPES, 2010.
2. Choulot, A., Denis, V., Punys. P.: *Integration of Small Hydro Turbines into Existing Water Infrastructures. Hydropower – Practice and Application*. Rijeka. InTech, 2012. pp. 239-276.
3. Bousquet, C., Samora, I., Manso, P., Rossi, L., Heller, P., Schleiss, A.J.: *Assessment of hydropower potential in wastewater systems and application to Switzerland.* Renewable Energy 113, 2017, pp. 64-73.
4. Gallagher, J., Harris, I.M., Packwood, A.J., McNabola, A., Williams, A.P.: *A strategic assessment of micro-hydropower in the UK and Irish water industry: Identifying technical and economic constraints.* Renewable Energy 81, 2015, pp. 808-815.

5. Almandoz, J., Cabrera, E., Arregui, F., Cobacho, R.: *Assessment through Water Distribution Network Simulation*. J. Water Resour. Plan. Manag. 131, 2015, 458–466.
6. Williams A: *Pumps as Turbines – A User´s Guide.* ITDG Publishing, London, 2nd ed., 2003.
7. Steller, J., Adamkowski, A., Stankiewicz, Z., Lojek, A., Rduch, J. & Zarzycki, M.: *Pumps as Turbines for Hydraulic Energy Recovery and Small Hydropower Purposes in Poland*. Proceedings of the International Conference HIDROENERGIA, p. 10, Bled, Slovenia, June 12-13, 2008.
8. De Marchis, M., Milici, B., Volpe, R., Messineo, A.: *Energy Saving in Water Distribution Network through Pump as Turbine Generators: Economic and Environmental Analysis*. Energies 9, 2016, p.877.
9. LIFE NEXUS project: LIFE NEXUS Community. 2022. https://www.lifenexus.eu/en/community/
10. LIFE NEXUS project: *European inventory of micro-hydroenergy recovery potential in water industry*. 2022. https://www.lifenexus.eu/en/results/eu-inventory/
11. Punys, P., Jurevičius, L. *Assessment of Hydropower Potential in Wastewater Systems and Application in a Lowland Country, Lithuania*. Energies 15(14), 2022, p.1.

Authors

Raquel López Fernández. PhD in Chemistry. In 2005 she became full-time staff in the Environment Division of CARTIF Technology Centre and leaded the research line related to water and wastewater treatment. In 2015 she moved to the Energy Division in CARTIF and since then, her work is related to water-energy Projects and Smart Cities initiatives. Currently she is the Coordinator of the LIFE NEXUS project.

Víctor Iván Serna González. MSc in Telecommunications Engineering. He has been working in the Environment Division of CARTIF Technology Centre from 2007 as Project Manager and R&D engineer participating in several National and European R&D projects related to the use of ICT technologies and data analysis applied to energy efficiency management, in particular in ICT solutions for energy efficiency, renewable energy systems integration in buildings and Smart Grids and development of tools for energy planning.

Luis Angel Bujedo is an industrial engineer and MEng. He has been working over 25 years in the efficient use of energy in CARTIF. Participates in several energy platforms PTE-EE, Task 38, and has experience in energy facilities, as well as energy management in industrial and residential buildings. He has given conferences and training on solar cooling energy efficiency in buildings. Has the capacity to provide training of trainers on energy efficiency in buildings.

Jesús Samaniego received the Electrical Engineer´s Degree in 2002, and the MEng in the Automatic Control and Systems program in 2004, both from the University of Valladolid. He has worked as R&D engineer and Project Manager in the Energy Division of CARTIF since 2002, where he has participated in several National and European R&D projects in the fields of energy efficiency, renewable energies simulation and integration in buildings and in the electrical grid, demand response programs and power quality energy. He is an author of several publications about energy efficiency and renewable energies.

Janusz Steller, DSc in mechanical engineering, graduated in 1977 from the Faculty of Mathematics, Physics and Chemistry of the University of Gdańsk specializing in theoretical physics. Since then, an employee of the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences (IMP PAN). In 2019 awarded with a DSc degree by the Wroclaw University of Technology. Now senior specialist in the Centre for Hydrodynamics of the IMP PAN. President of the Polish Hydropower Association. Main professional interests include cavitation and cavitation erosion, methodology of hydraulic machinery design and exploitation, as well as that of the performance and diagnostic tests under field and laboratory conditions, general problems of hydropower development.

Petras Punys, PhD in Hydraulic Engineering. Since 2002 a full Professor at Water Resources Engineering Institute at Lithuanian University of Agriculture (currently Vytautas Magnus). He has written a large number of papers on hydrology, hydropower, river basin management as well as text books or chapters of books. Since 1993 he has been the chairman of the Lithuanian Hydropower Association, now he is the honorary chairman. Participated in a number of EU and locally funded projects on small hydropower, water management issues.

Algirdas Radzevičius. PhD in Hydraulic Engineering. Since 2012 he is Director of Hydraulic Engineering Institute of Aleksandras Stulginskis University (currently Vytautas Magnus University). The main research area – alternative energy, wastewater treatment technologies, physical modelling of hydraulic processes. Leaded 2 EU and 12 national research projects, published more than 40 articles, 2 manuals, 9 course books.

Mariano Mirete. Expert in design, execution and commissioning of pumping installations, solar pumping, photovoltaic solar installations for self-consumption and turbine installations in drinking water networks. Energy audits and bill optimization in AQUATEC

3.2. Assessment of Hydropower Potential in Wastewater Systems in a Lowland Country, Lithuania

Introduction

The untapped potential of small, mini, and micro hydropower (MHP) systems in engineered water conduits of urban areas has largely remained unexplored. This alternative energy source is receiving more attention from regulators in several countries [1-4]. While other European countries have widely invested in this technology, Lithuania and other Baltic countries are still behind in their potential development rate.

Assessment of wastewater resources for hydropower generation is a crucial task. Knowing the amount of wastewater and its flow rate and distribution over time is essential. Flow rate frequency analysis must be per-formed to construct the flow duration curve (FDC), which is a key element for estimating hydropower energy. A big issue is accounting for wastewater flow in the collection network, i.e., upstream of the wastewater treatment plant (WWTP). A methodology is needed to construct the FDC for ungauged sites [4].

Lowland or low-lying areas of a country represent challenges for installing hydro turbines in urban water networks compared with regions with a steep topography surrounded by mountains. The accuracy and completeness of the hydraulic data are crucial, espe-cially when evaluating low- and ultralow-head sites.

The specific objectives of this study were as follows: (1) To review the available best practices of energy recovery in wastewater systems and identify method-ology based on local conditions; (2) To search for the potential sites for the installation of hydro turbines and to evaluate wastewater resources for harnessing hydropower; (3) To review and propose tools to facilitate preliminary and/or feasibility analysis of hydro schemes and to review turbines and their installation layouts in wastewater systems; (4) To show best practice in performing multicriteria analysis for the selection of optimal sites.

Materials and Methodology

The study area was the urban water network with po-tential micro-hydro sites to be deployed in Lithuania. Due to the country's topographic conditions, mostly sewage (wastewater) networks with a free gravitational flow are attractive for harvesting water energy. More than 20 potential sites for installing hydropower tur-bines were identified [5]. Most of them were located in the sewage network, while only one site was spotted in the drinking water distribution network with a pressure-reducing valve.

This study examined the opportunities for MHP energy recovery at three WWTPs, four wastewater collectors (upstream of WWTPs), and one site in the drinking water network. The layouts of water network systems, their engineering drawings, and spatial information (GIS data) from water companies were analysed [6]. In contrast, the assessment of the head did not present any difficulty.

Sewage volume data were obtained in various temporal formats from WWTPs and water utility companies. Additionally, measurements of wastewater-level fluctuations at the outlets of WWTPs and key structures of the collection network (upstream of the WWTP) were conducted to reveal the pattern of wastewater flow. Spot measurements (from 1 to 3 months) using data loggers at a 30 min intervals were also performed. The recordings obtained were trans-formed into volumetric discharge values.

The following tools were tested: (1) RETScreen Expert, (2) In-Conduit Hydropower Project Screening Tool, and (3) Business Case Assessment Tool. RETScreen Expert was identified as the most comprehensive tool for assessing the feasibility of eight potential sites.

The multicriteria analysis of siting potential micro-hydro facilities in urban water networks was carried out using the software HYPSE. Collected field data and data generated by RETScreen Expert software were used as the input for a two-dimensional impact matrix, including alternatives or scenarios (e.g., projects or actions) and their criteria according to which the other options must be evaluated.

Results

The analysis of the mean annual wastewater flow at the outlets of the 56 collected WWTPs operating in the country showed that it correlates quite well with the population equivalent (PE) and wastewater collection (service) network area (A, km2). The proposed methodology allowed for establishing a flow duration curve for an ungauged site using only three parameters.

A selection field for classical turbines is relatively narrow in a flat terrain where elevations and flows are relatively low. This can be explained by the low flow rates and small size of turbine units, which increases the unit price of turbines (EUR/kW) compared to the larger capacity of hydro turbines. Only reaction-type turbines can be used at low-head schemes, e.g., propeller, Kaplan, seldom crossflow, and Francis. The development of compact and modular turbines is a recent trend in turbine technology, e.g., a generator unit using a propeller turbine in an axial flow design. A submersible turbine and a generator are combined in one unit; therefore, the need to use a powerhouse is eliminated, and installation costs are reduced. Turbine costs com-prise approximately half of the conventional hydropower project development costs. To offset this drawback of conventional turbines, low-cost generators, e.g., pumps as turbines (PaTs), have been suggested. In contrast to an axial propeller (or Kaplan) turbine, PaT units are much more sensitive to clogging issues when operating in effluents charged with suspended particles.

RETScreen software, a conventional hydropower project tool, requires a great deal of engineering preparation before it can be used to assess hydropower schemes in municipal water distribution systems. Its technical level is much higher than other available screening tools; it can be easily adapted to complete feasibility studies and preliminary design of in-conduit hydro schemes.

No studies have been performed in Lithuania on the impact of wastewater quality on the operation of hydraulic machines and their clogging. Available data from water companies show that the average concentrations of TSS in raw effluent can reach 500 mg/L. After treatment, they decrease at least 25-fold, down to 20 mg. Large solids, rags, and other fibrous materials from wastewater can be severe for operating turbines if not monitored. This harsh environment can be considered when installing turbines in such locations.

In total, 17 criteria were used for the multi-criteria analysis (Table). Twelve criteria were to be maximised, while five were to be minimised. Their grouping was as follows: (1) technical-related (TEC; layout, turbine type, design flow, gross head, etc.), (2) economic-related (ECO; investment costs, electricity generated, simple payback, etc.), and (3) environmental-related (ENV; GHG reduction and use of electricity).

The following conclusions were drawn up: (1) While the potential of energy recovery from wastewater systems using micro-hydro plants (MHPs) is an appropriate solution to improve the energy efficiency of the municipal water sector, it has seen no exploitation due to a number of technical and non-technical issues in low-lying countries. Non-technical problems include a lack of awareness about the scale of the existing resources available in water networks; (2) The potential in low-land areas in terms of power capacity resulting from mostly low-head sites cannot be compared to that of elevated topography. In addition, for flat terrain, the selection field for turbines is relatively narrow; moreover, the low flow rates and small size of turbine units increase the unit price of turbines; (3) A methodology was developed to quantify the potential and identify conduit hydropower sites in a lowland country's wastewater systems, including resource assessment, suitable tools to make a preliminary assessment of potential sites, and choice of turbines and their operating parameters in a harsh environment. The lack of in-depth studies on wastewater quality's impact on hydro turbines, particularly the risk of clogging them in sew-age networks upstream of WWTPs, can be a severe problem; (4) A conventional multi-criteria analysis can help select the most appropriate site for constructing MHPs in urban water areas to achieve energy recovery. There are plenty of multi-criteria tools available on the market for solving any real-world issue. However, at least preliminary site assessments and design procedures must be accessible beforehand for this analysis.

#	Criterion	Unit of Measure	Direction	Weight (%)	Group and Weight		K1	K2	K3	V1	V2	V3	A1	A2
1.	Layout	Score: [1, 2]	Max	5.88	TEC	58.81	1	1	2	2	2	2	2	2
2.	Turbine type	Score: [1, 3]	Max	5.88	TEC		2	2	3	3	3	2	2	2
3.	Design flow	m^3/s	Max	5.88	TEC		0.36	0.14	1.00	1.80	1.80	0.17	0.17	0.17
4.	Gross head	m	Max	5.88	TEC		35	27	4	2	2.9	53	15.5	10
5.	Substation	Score: [0, 1]	Max	5.88	TEC		0	0	0	1	1	0	1	1
6.	Transmission line	km	Min	5.88	TEC		0.05	0.05	0.1	0.05	0.05	0.05	0	0.4
7.	Power capacity	kW	Max	5.88	TEC		98	29	28	20	34	73	20	13
8.	Capacity factor	%	Max	5.88	TEC		43	40	76	65	64	73	39	38
9.	Tailwater effect	%	Min	5.89	TEC		0	0	25	0	20	0	0	25
10.	FDC type	Parameter	Max	5.89	TEC		0.47	0.42	0.56	0.6	0.6	0.57	0.62	0.62
11.	Total initial costs	k€	Min	5.88	Econ	29.42	101.1	61.7	76.3	50.8	80.9	47.3	18.7	14.0
12.	Electricity generated	MWh	Max	5.88	Econ		367	102	185	111	189	331	69	43
13.	Simple payback	yr	Min	5.89	Econ		4.3	15.5	5.5	7.3	5.8	1.6	4.4	6.7
14.	O&M costs	k€	Min	5.88	Econ		13.5	6.2	4.6	4.2	4.9	3.8	2.6	2.6
15.	Electricity revenue	k€	Max	5.89	Econ		36.7	10.2	18.5	11.1	18.9	33.1	6.9	4.3
16.	GHG reduction	tCO_2/MWh	Max	5.88	ENV	11.77	99	28	50	30	51	89	19	12
17.	Use of electricity	Score [1, 2]	Max	5.89	ENV		1	1	1	2	2	1	2	2
Total (%)				100		100								

References

1. Choulot, A., Denis, V., Punys, P. Integration of Small Hydro Turbines into Existing Water Infrastructures. In Hydropower—Practice and Application; InTech: Rijeka, Croatia, 2012.
2. Beltran, H., Vidal, R., Basiero, L., Santos, J.M., Basiero, J.A., Belenguer, E. Micro hydro installation analysis in a wastewater treatment plant. Renew. Energy Power Qual. J. 2014, 12, 15–20.
3. Gallagher, J., Harris, I.M., Packwood, A.J., McNabola, A., Williams, A.P. A strategic assessment of micro-hydropower in the UK and Irish water industry: Identifying technical and economic constraints. Renew. Energy 2015, 81, 808–815.
4. Bousquet, C., Samora, I., Manso, P., Rossi, L., Heller, P., Schleiss, A.J. Assessment of hydropower potential in wastewater systems and application to Switzerland. Renew. Energy 2017, 113, 64–73,
5. Lopez-Fernandez, R.M., Gonzalez, V.I.S., Punys, P., Radzevičius, A., Steller, J., Jagielska, A. Web-based Atlas of Micro-hydro Inventory in Urban Water Networks. In Proceedings of the Hydroforum 2019: 9th Polish Hydropower Conference, Gdansk, Poland, 9–10 October 2019.
6. Punys P, Jurevičius L. Assessment of Hydropower Potential in Wastewater Systems and Application in a Lowland Country, Lithuania. Energies. 2022; 15(14):5173.

Authors

Petras Punys, PhD in Hydraulic Engineering. Since 2002, he is a Full Professor at the Department of Water Engineering of Vytautas Magnus University. He has written many papers on hydrology, hydropower, river basin management, and textbooks or chapters of books. Since 1993 he has been the chairman of the Lithuanian Hydropower Association. Participated in a number of EU and locally funded projects on small hydropower, water management issues.

Algirdas Radzevičius. PhD in Hydraulic Engineering, actually Professor at the Department of Water Engineering of Vytautas Magnus University. Since 2012 he has been the Director of Hydraulic Engineering Institute at Vytautas Magnus University. The main research area – alternative energy, wastewater treatment technologies, physical modelling of hydraulic processes. Leaded 2 EU and 12 national research projects, published more than 40 articles, 2 manuals, 9 coursebooks.

4. Recovery of energy dissipated in the municipal and industrial water cycles – selected technological aspects

Introduction

According to data from the Polish Central Statistical Office, the national consumption of electricity for water supply and waste management amounted in 2020 to approximately 3100 GWh, which accounted for nearly 2 % of total electricity consumption in Poland [1]. However, it is believed that in many developed countries the wastewater treatment sector alone consumes 3 to 5 % of national electricity consumption [2, 3]. Therefore, for a long time, the prospect of energy balancing the water and sewage sector by using the energy potential hidden in the technological line has been extremely attractive

It is worth noting that in addition to energy recovered from the technological cycle, some water and sewage plants use independent RES sources, e.g. solar panel farms or hydroelectric power plants, located outside the water supply network. Ultimately, a number of such plants and their individual installations – such as water treatment plants (DWTP) or wastewater treatment plants (WWTP) – are able not only to cover their own needs, but also to be a source of energy necessary for the needs of others - especially municipal. The rational management of electricity produced for own needs is facilitated by equipping such installations with energy storages, as foreseen in the pilot installation of the Life NEXUS project in Porma [4].

The best possibilities of using hydraulic energy are usually created by water intakes and pressure reduction chambers at the inlet to water treatment plants, pressure reservoirs or inlets to individual fragments of the municipal network. This is particularly important in mountainous and sub-mountainous areas. A good example is the Mühlau hydroelectric power plant, operated since the beginning of the 50s by the IKB Municipal Works in Innsbruck. The power plant is located 450 m below the water intake for the city and the surrounding area. It is equipped with 2 hydraulic units with Pelton turbines of 6 MW total capacity and annual production of 34 GWh [5]. On a large scale, the hydropower potential of municipal water supply network is used in Quito - the capital of Ecuador. The annual production of electricity of the local company EPMAPS hydropower plants amounts to over 200 GWh [6]. There are only a few installations in Poland that use the hydropower potential of drinking water and have a power in the range of 100 to 400 kW, e.g. [7]. The vast majority of these are installations. not exceeding several dozen kilowatts

In the case of wastewater treatment plants (WWTP), the most important source of useful energy today is methane obtained as a result of fermentation of communal sludge [2]. In some cases, however, energy associated with the discharge of purified water from water treatment plants can make a significant contribution to meeting one's own electricity demand [3, 8]. Typical places of hydraulic energy recovery in the water and sewage cycle are shown after [9] in Fig. 1.

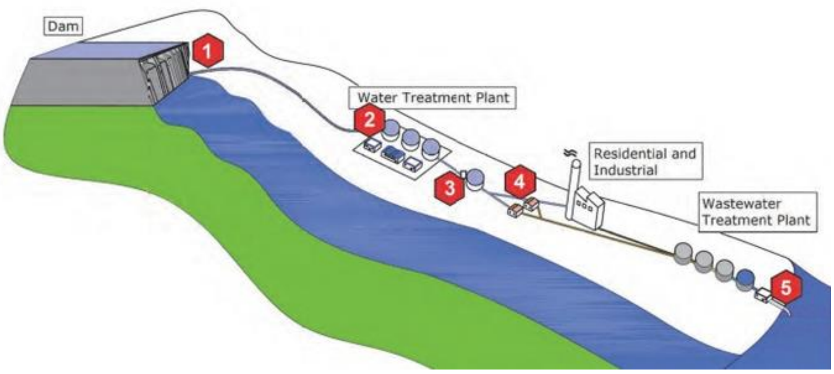


Fig.1 Typical sites of hydraulic energy recovery in the municipal water and sewage circuit. 1 – water intake; 2 – DWTP, 3 – water reservoirs, 4 – consumers; 5 – discharge from the wastewater treatment plant [8]

Available technologies of hydraulic energy recovery

For techno-economic reasons, the most desirable approach is the use of hydraulic energy available at water intakes and in pressure reduction chambers upstream water treatment plants or storage reservoirs. It is here where the highest heads and raw powers may be expected. When the raw power exceeds about 50 kW, and the head – 60 and 20 m respectively, Pelton and Francis turbines can be taken into consideration. With power and head values at the lower end of this range and even below it, turgo turbines and cross-flow (Banki-Michell) ones are economically viable, while for power values below 100 kW and heads in the range of 10 to 100 m, also single-stage pumps in turbine motion (PaT) can be recommended. With heads of several dozen meters and high discharge variability, hydraulic units with diagonal turbines developed by the Swiss company MhyLab can be a solution. The typical range of applications of some classical water turbines and PaTs is shown in [10] in Fig. 2. More up-to-date information can be found, among others in the review by A.Cholout, V.Denis and P.Punys [11].

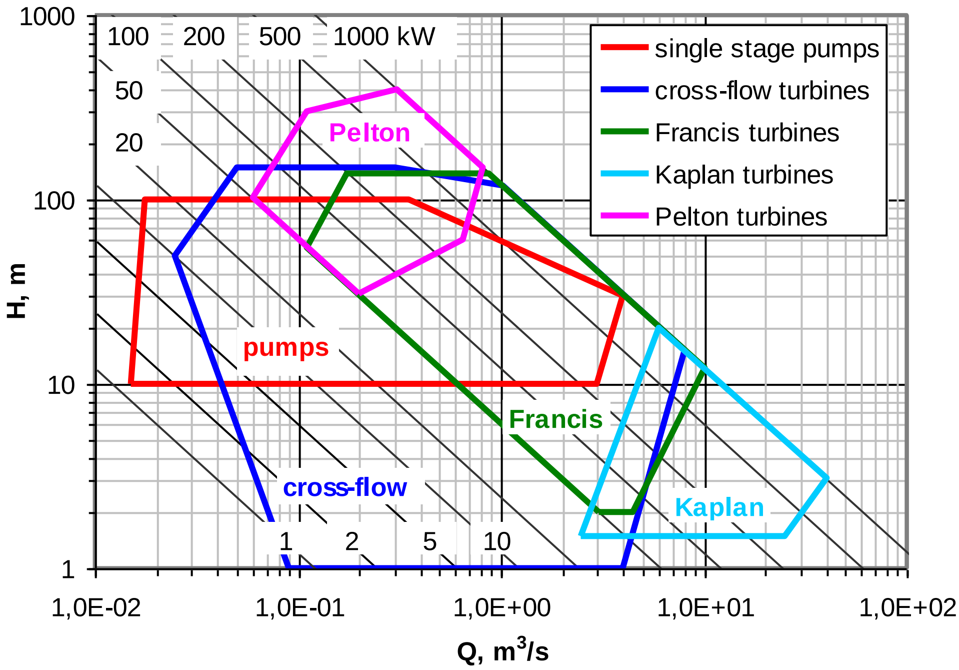


Fig.2 Application range of some classic turbines and pumps in turbine motion used in microhydropower and energy recovery installations, according to [10]

Over the last few decades, there has been a clear increase in interest in hydraulic energy recovery in low-head locations, which definitely dominate in the case of water discharges from wastewater treatment plants. High-speed Francis turbines are still used here [8], but in many cases tubular turbines in various configurations are a good solution (Fig. 3, 4), and at the lowest heads – also some gravity and hydrokinetic units [12, 13]. The last ones are particularly well suited for open channel applications.

Particularly noteworthy are hydraulic units installed inside the pipelines ("in-conduit"), which include primarily compact tubular units with a "wet" synchronous or asynchronous generator. In the first case, rotors with permanent magnets (e.g. neodymium) are often used. Typically, these are units with adjustable rotational speed and a turbine equipped with fixed guide vanes and runner blades (Fig. 5)

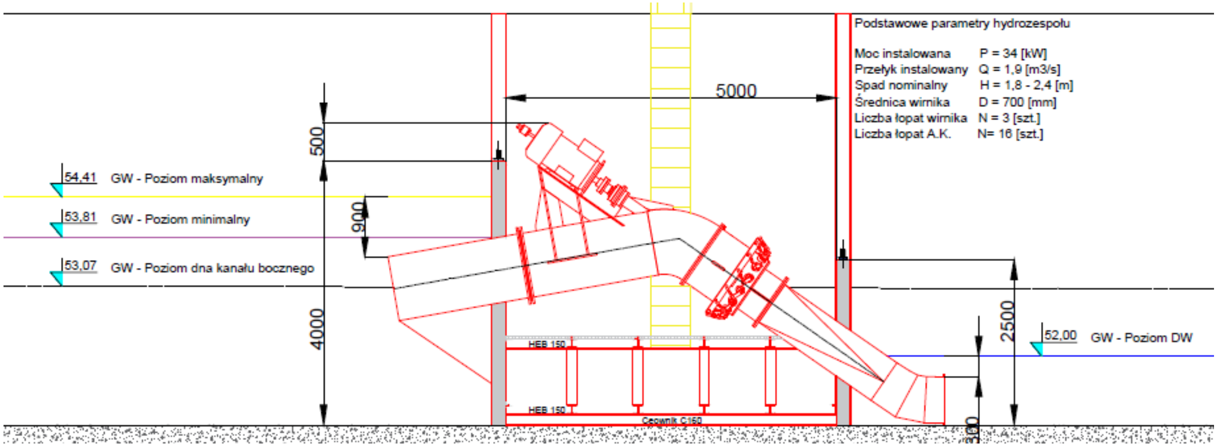


Fig.3 Hydraulic with an elbow tubular turbine proposed for energy recovery in the outflow channel of one of the Polish wastewater treatment plants (courtesy of TG DNALOP Sp. z o.o.)

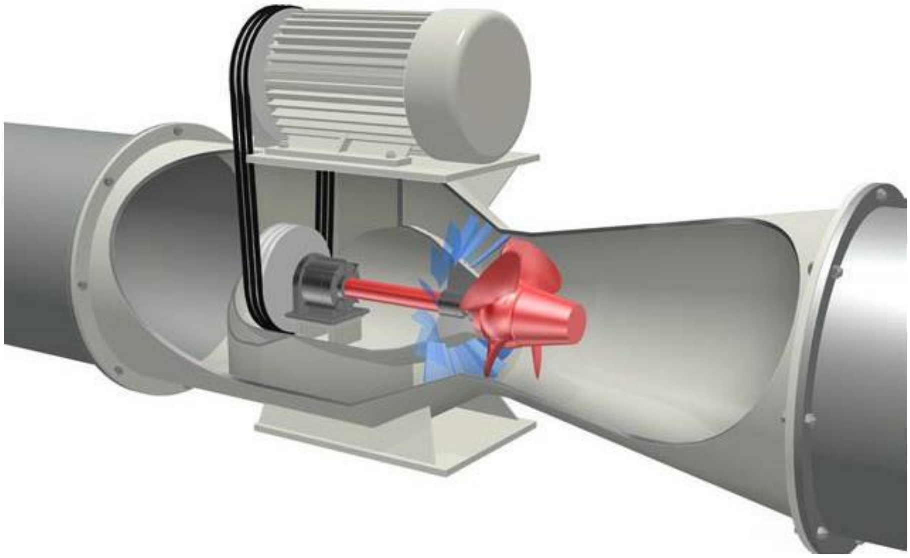


Fig.4 Hydroelectric unit with tubular microturbine manufactured by Fuji [12]

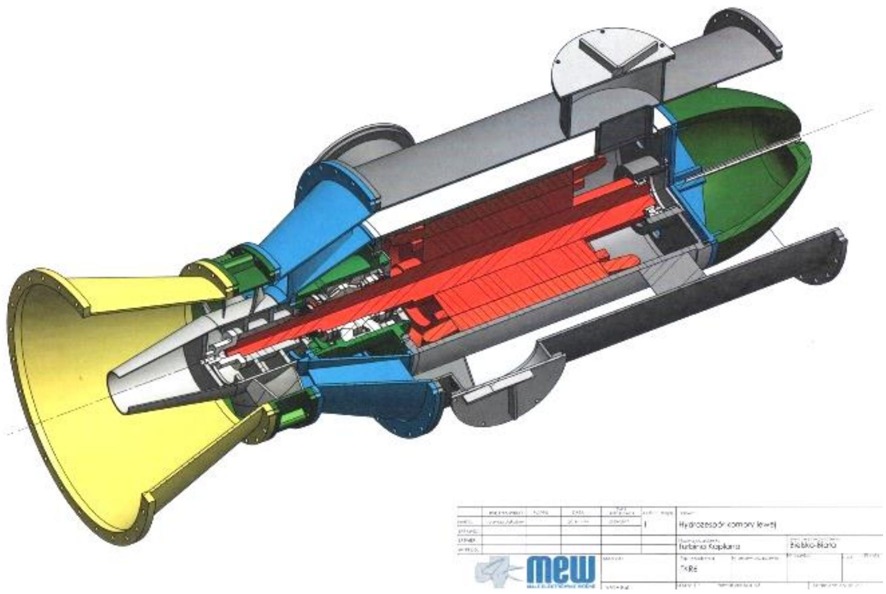


Fig.5 Tubular compact microhydro unit with a wet generator manufactured by MEW Sc in cooperation with the KOMEL Institute (with manufacturer's consent)

Another interesting "in-conduit" solution are hydraulic units with turbines equipped with vertical Gorlov runners, manufactured by the American company Lucid Energy under the trade name Lucid Pipe Power System [12÷14]. According to the manufacturer's information, the turbines use pressure differences between 0.7 and 3.5 m H2O, therefore they are installed in series in packages consisting of up to 3 modules (Fig. 6).

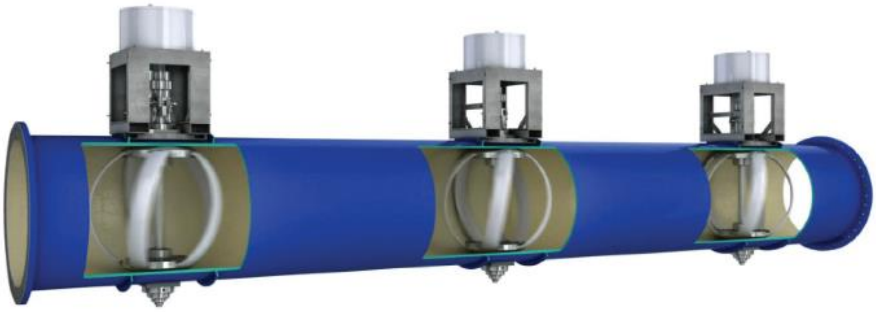


Fig.6 Lucid Pipe Power System energy recovery unit [14]

The basic condition to be met by any energy recovery installation in a municipal or industrial hydraulic circuit is to ensure reliability and the ability to maintain the existing or previously assumed parameters of liquid flow in the place where energy recovery is planned. If in this place the liquid flows through a pipeline with a dissipation device (e.g. a pressure reduction valve), the recovery should be carried out on a parallel (bypass) pipeline – so as to ensure quick redirection of flow to the section with the previously used or backup dissipation device in case of an emergency (Fig. 7)

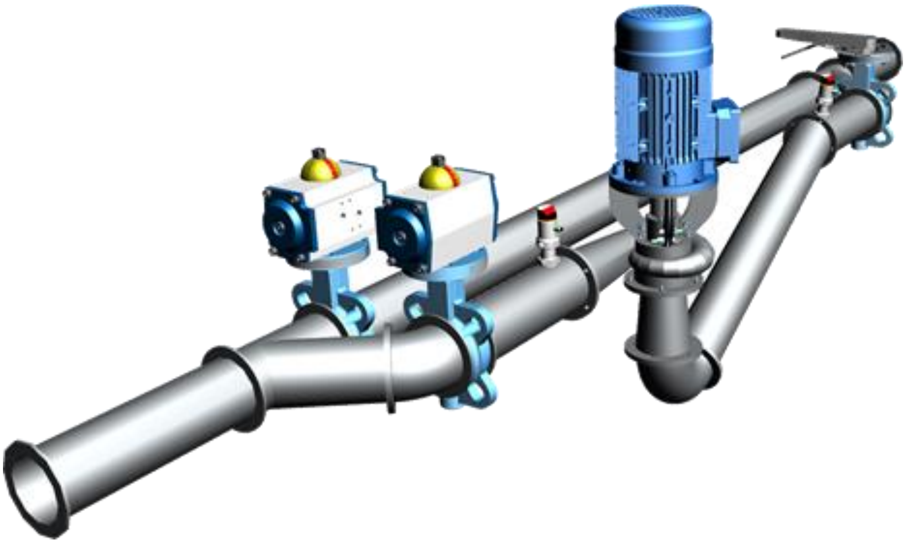


Fig.7 Typical configuration of the hydraulic energy recovery system with a small Francis turbine at the control valve bypass [8]

If the existing or planned parameters of fluid flow (pressure and flow rate) are variable over time, it may be necessary to equip the installation with an appropriate control system. Appropriate safeguards and regulatory measures should be maintained also in case of open flow channels.

Pumps in turbine mode of operation

The possibility of using pumps in turbine mode of operation in micro-hydroelectric power plants, and especially in energy recovery installations in industrial technological lines and municipal water circuits, became the subject of intensive research and development works in the 70s. Representatives of KSB AG showed particularly great commitment. Their numerous reports on this subject can be found in the proceedings of the Pump Congresses held until the 90s Karlsruhe, e.g. [10, 15÷17]. At the turn of the 70's and 80's, other pump manufacturers joined the trend of this work, and above all numerous scientific and research and development centres. In Poland, such work was carried out until the 90s primarily by the teams of Prof. M. Zarzycki (Silesian University of Technology) and K. Steller (Institute of Fluid-Flow Machinery of the Polish Academy of Sciences in Gdańsk) [18 ÷24].

In the West European countries, this interest was based on the increase in prices of traditional energy carriers, mainly conditioned by the situation in the Middle East. In some countries of the Eastern Block, which still preferred development of the energy-intensive sectors of the economy, difficulties have arisen in balancing the power in the national power system and providing it with proper operating parameters. The problems concerned especially the peripheral areas of the electrical grid.

One of the reactions to the above-mentioned challenges was a return to the development of small hydropower. A significant obstacle on this route appeared low availability of electromechanical equipment, determined primarily by the limited – and in Eastern Europe often liquidated – production potential of small capacity water turbines. In this state of affairs, the use of pumps available "off the shelf" in turbine mode of operation turned out to be a fully justified solution.

This statement remains valid even today, when much more easily accessible water turbines with a capacity of several tens of kilowatts can still hardly compete economically with pumps in turbine motion. Modern PaT machines have also achieved a significant increase in efficiency. Particularly interesting results are obtained by replacing the original pump impeller with a turbine impeller and possibly making additional changes in the flow system (Fig. 8). In the 80's and 90's reconnaissance works in this direction were carried out at the IMP PAN. Currently, intensive research and development works on the PaT series, built on the basis of centrifugal pump housings equipped with Francis impellers, are carried out by a consortium consisting of HydroVacuum SA company located in Grudziądz and Wrocław University of Science and Technology (the team of Dr P.Szulc).

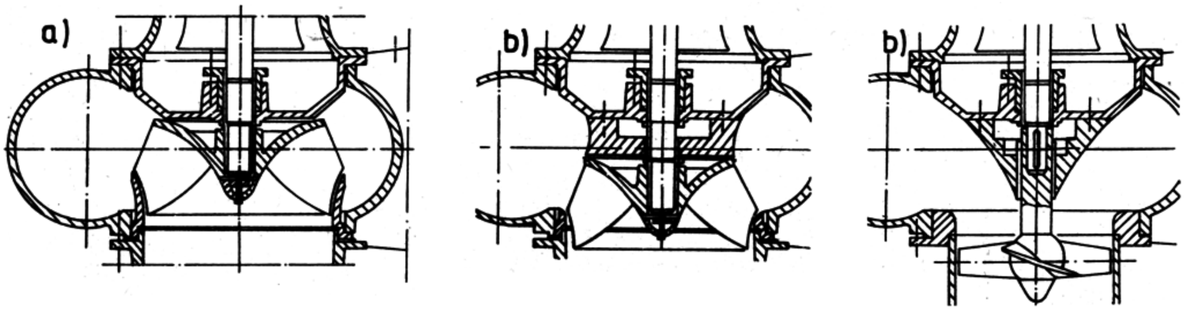


Fig.8 Cross-section through the 400 UM 250 mixed-flow pump and proposals for modification of its flow system as considered in the IMP PAN in the 80s [18]

The comprehensive flow characteristics of each hydraulic turbomachine are usually plotted in the (Q, n) or (Q_{HD}, n_{HD}) plane where Q and n denote the discharge and rotational speed, respectively, and the subscripts H and D - reduction to the unit head and the impeller reference diameter (Fig. 9). The H>0 (H<0) note indicates operation at the differential pressure at the pump inlet and outlet consistent (inconsistent) with the design assumptions. From the practical point of view, the pumping and turbine operation in areas (a) and (c) are of interest.

The four-quadrant performance characteristics of the rotodynamic machine plotted in such a plane clearly indicate that at each speed the optimum working area in the turbine motion is shifted towards higher values of Q and H relative to the optimum operating point in pumping mode of operation (Fig. 10). According to E.Schmiedl [16], the following relationships between parameters in pump (p) and turbine (t) regime should be expected:

$$Q_t/Q_p = 1.5 \div 2.4 \quad \text{and} \quad H_t/H_p = 1.7 \div 3.7.$$

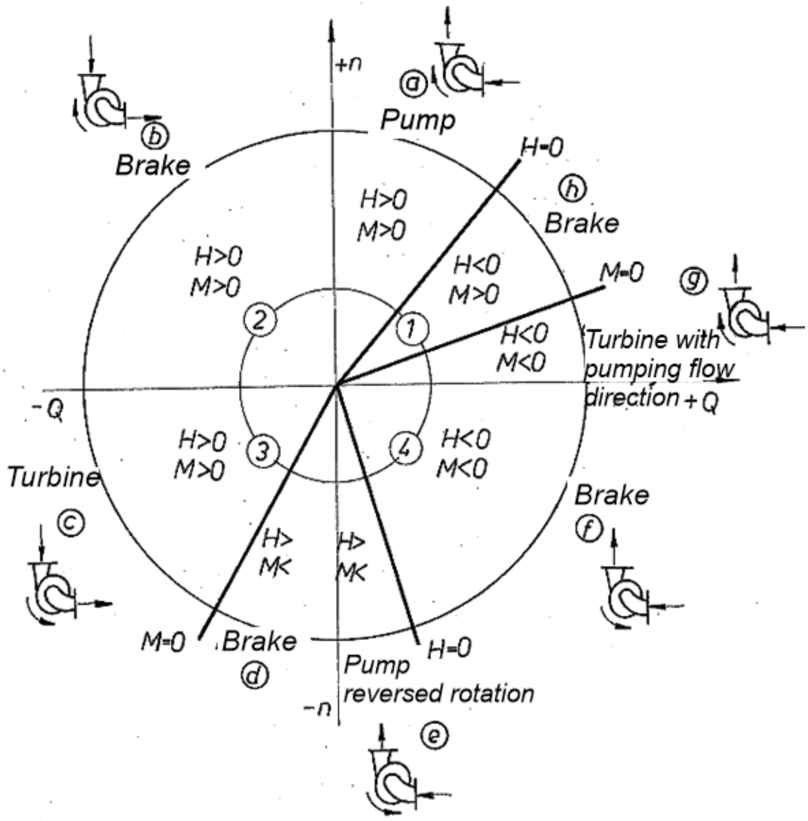


Fig. 9 Operation areas of a hydraulic rotodynamic machine in the (Q, n) plane [20]

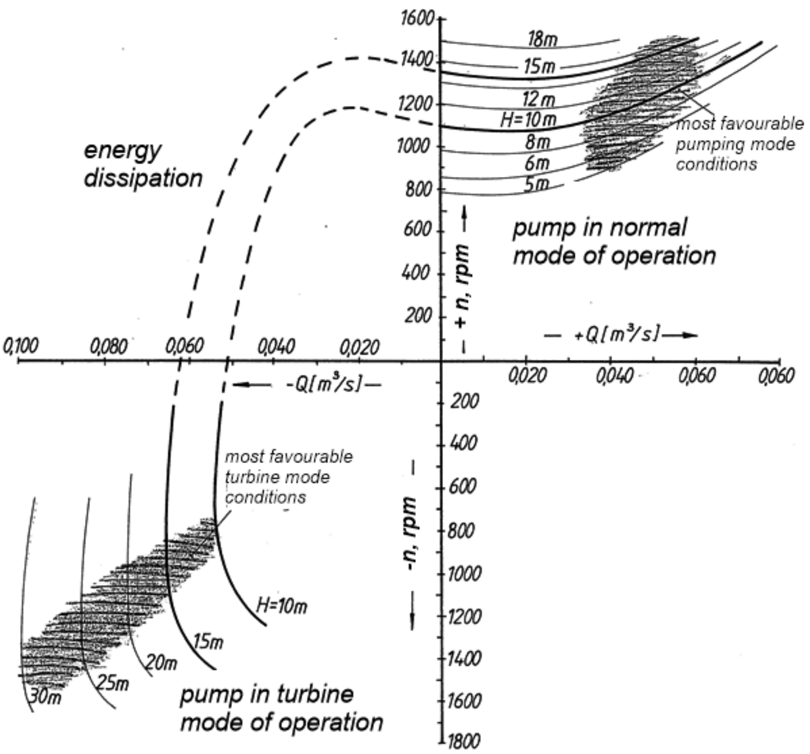


Fig.10 Four-quadrant characteristics of a 150 PJM 250 centrifugal pump of Leszno Pump Manufacturers [21]

These relationships are of fundamental importance when selecting a pump for turbine operation basing on its characteristics in pump motion. Unfortunately, they depend significantly on the pump design features of the pump and therefore show a very large differentiation [20]. A relatively new overview of recommended relationships can be found in the work of M. Pérez-Sánchez et al. [25].

Pressure reduction nodes in the water supply network often operate with variable discharge and for this reason the regulatory properties of PaT are extremely important. Unfortunately, in the case of centrifugal pumps (Fig. 11), the possibilities of speed control are very limited. It should also be noted that, as in the case of Francis turbines, an increase in rotational speed at fixed head leads to a decrease in the discharge. According to the analyses carried out by the authors of this text, in many cases a more advantageous solution than speed control may be shown by the use of control valves in serial or parallel configuration (Fig. 12)

The situation is different in case of pumps with higher specific speed – i.e. mixed-flow (Fig. 13), diagonal, and even more so – propeller. Due to the operating range limited to low heads, their use in energy recovery systems concerns mainly water outlets into open reservoirs.

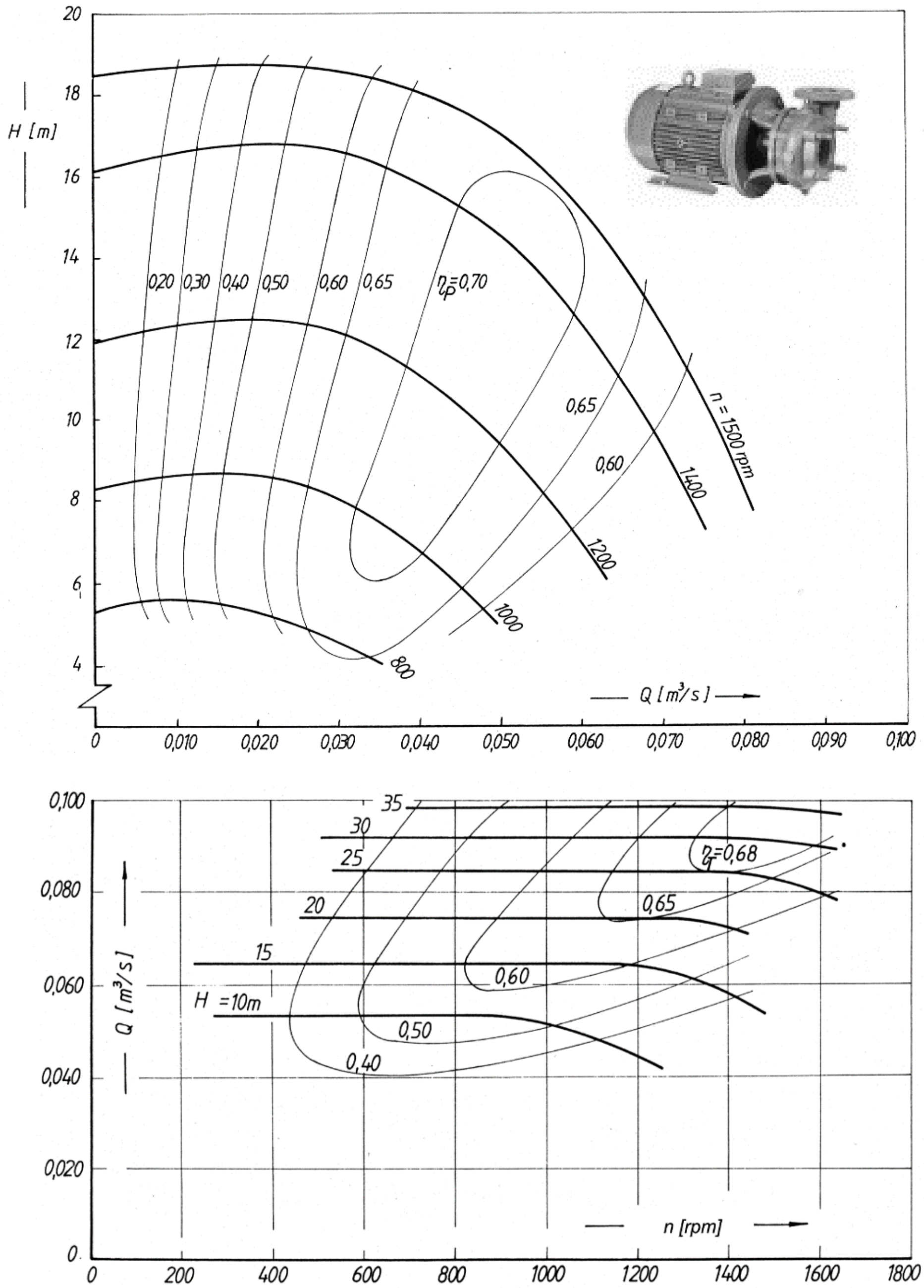


Fig.11 Efficiency hill diagrams of the 150 PJM 250 (Leszno Pump Manufacturers) centrifugal pump in the pump (a) and turbine (b) modes of operation [21]

Fig.12 Schematic diagrams of throttling regulation of a hydraulic energy recovery unit

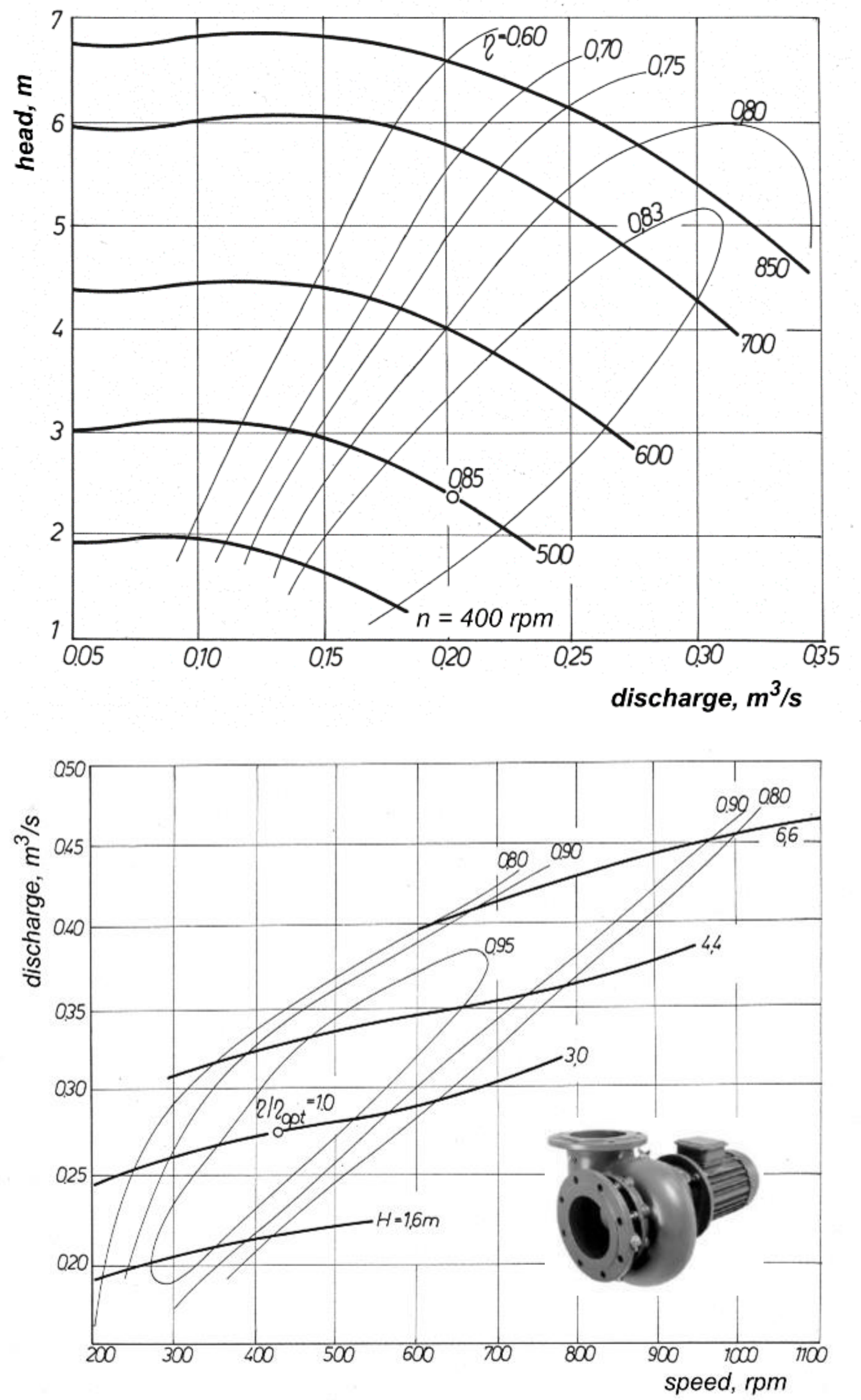


Fig.13 Efficiency hill diagrams of the 400 UM 250 (Leszno Pump Manufacturers) five-blade mixed-flow pump in pump (a) and turbine (b) modes of operation [18]

Selection of a pump for turbine operation

General approach

The selection of a machine for energy recovery in a hydraulic system always begins with the identifying the available hydropower potential and the installation conditions at the planned place of energy recovery. As in the case of preliminary studies of all hydroelectric power plants, the basis is a flow duration curve determined on the basis of measurements lasting a sufficiently long time – preferably not less than one year. An example of such a curve is shown in Fig. 14.

The selection of a recuperation machine is not possible without information about the useful head, which should be expected at different flows (Fig. 15). In the case of pressure reduction chambers, e.g. located upstream of the water treatment plant or at the inlet to the storage reservoirs, the conditions at the water intake, hydraulic losses and pressure requirements below the energy recovery point are essential. Where recovery occurs at the discharge of water into an open reservoir, the water level in that reservoir may be crucial. Sometimes the same remark refers also to flow-dependent hydraulic losses in the section upstream the water outlet.

In fact, the situation may be quite complex – inlet conditions can change, hydraulic losses can reach tens of meters, pressure at the outflow may depend on a number of additional factors. The authors are familiar with the situation in which, with the same flow, the useful head on the reducing valve varies from a few to several dozen meters. Diagrams of head fluctuations or pressure and flow rate can help to understand these peculiarities (Fig. 16), as well as calculations of head losses in the pipelines.

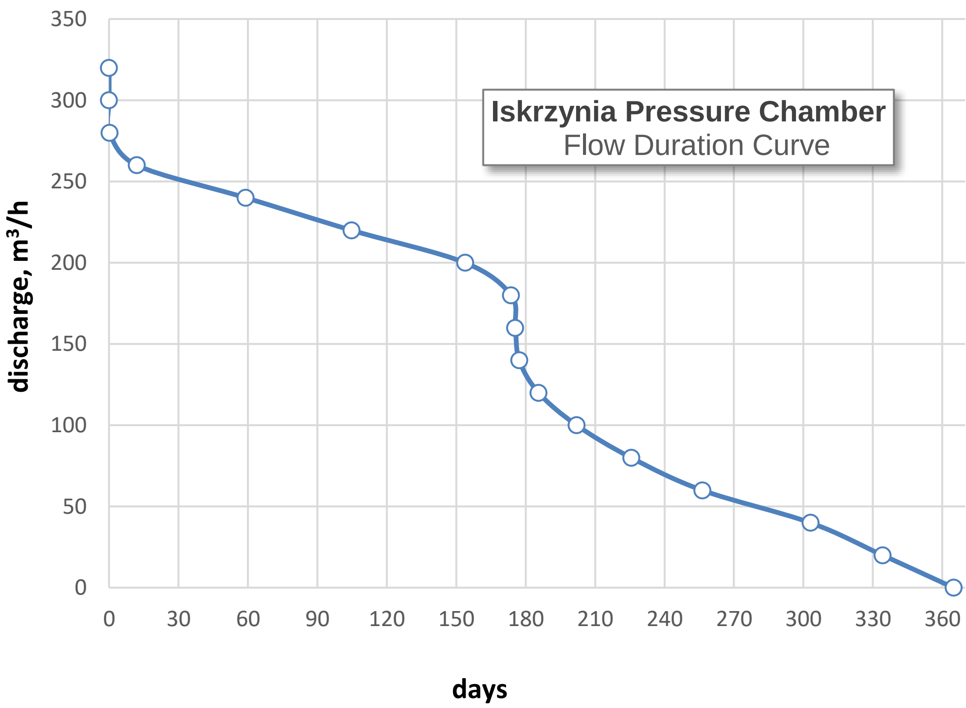


Fig.14 Flow duration curve of the MPGK Krosno pressure reduction chamber in Iskrzynia (basing on the data of 2022)

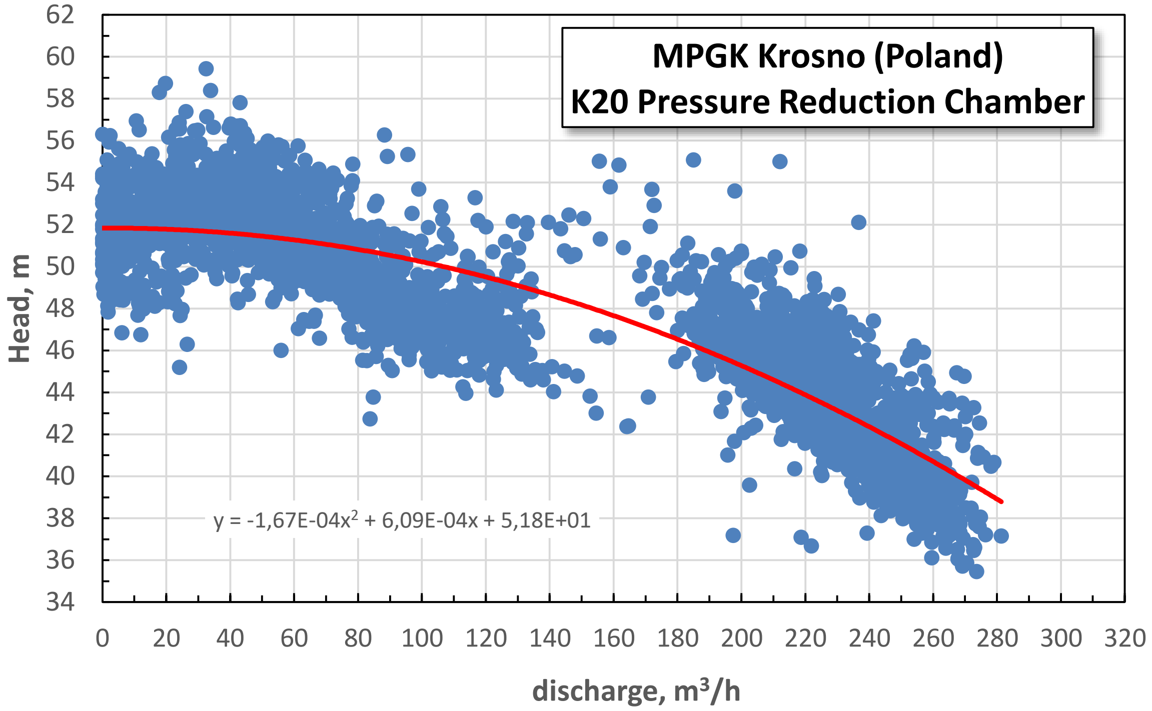
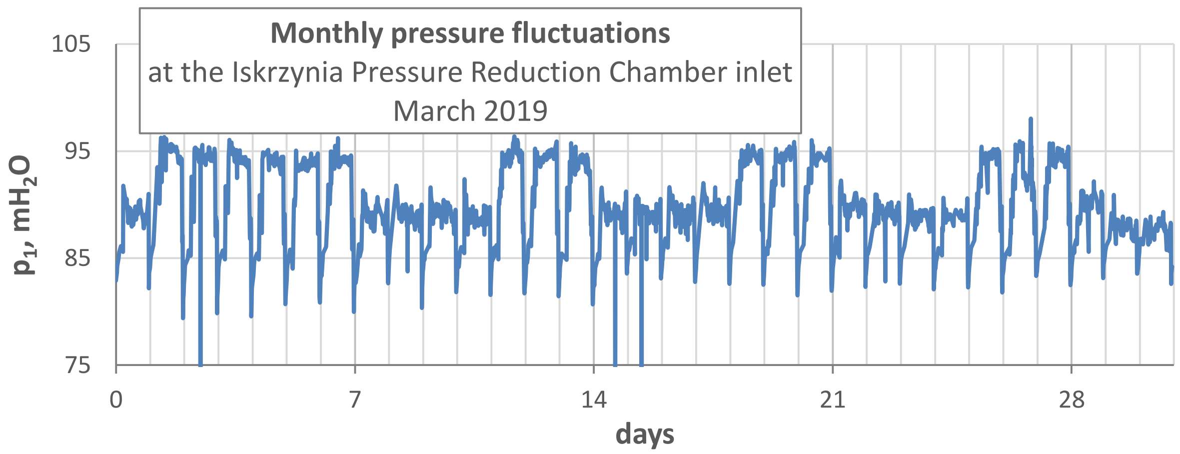


Fig..15 Operation points of the pressure reduction valve in the chamber as above



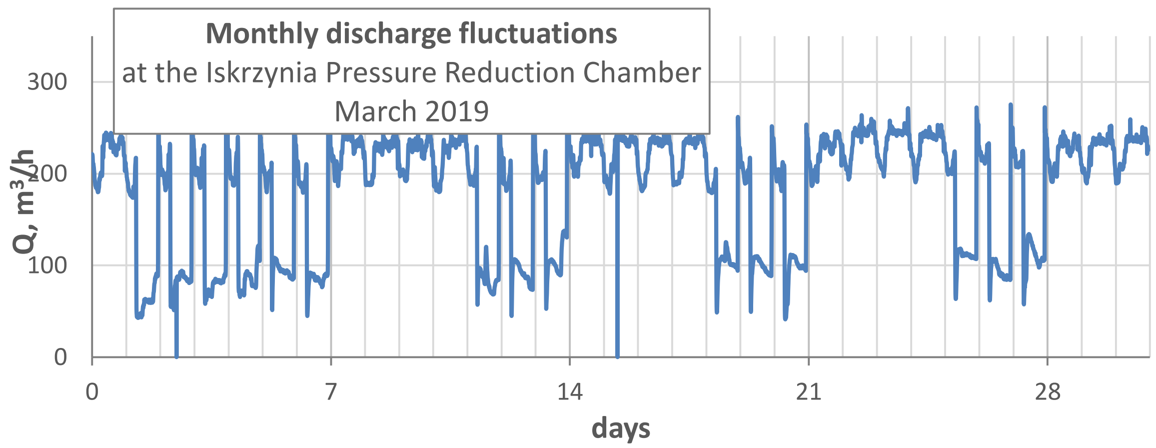


Fig.16 Inlet pressure and discharge fluctuations in the MPGK Krosno pressure reduction chamber in Iskrzynia (March 2019)

The information above is usually the basis for the indication of the design operating point of the energy recovery machine (PaT). In the simplest approach, the median discharge following from the flow duration curve can be taken as the design flow rate, and the value resulting from the course of the Q-H graph trend line (Fig. 15) as the design head. The design operating point chosen in this way is usually close to optimum one and can be the starting point for advanced optimization, which already requires creation of an appropriate goal function that takes into account the characteristics of the recuperation machine and the adopted hydraulic unit control method. These issues will not be considered further.

PaT selection basing on the turbine mode operation characteristics

The rising interest in the use of pumps in turbine motion for the needs of microhydropower and recovery of hydraulic energy in industrial installations and municipal water and sewage networks has encouraged some impeller pump manufacturers to test performance of the entire series of PAT types. In addition to the already mentioned KSB AG, one should also mention such European companies as Sulzer (Switzerland) and Caprari (Italy), and in Poland – the HydroVacuum SA company located in Grudziądz. The result of their work are nomograms or collective diagrams of characteristics of PaT type series in the (Q-H) plane (Fig. 17). These diagrams may be available for one (synchronous) rotational speed, but deriving characteristics for other speeds requires only the use of

discharge: $:\varphi = \frac{Q}{nD^3},$ and (1)

head: $\psi = \frac{Q}{nD^3}$ factor. (2)

The collective characteristics should be considered approximate ones. They can only be used to preselect the type of PaT from a specific family. Therefore, for the purpose of final selection, it is always necessary to contact the manufacturer's representative, who should be able to provide the operational characteristics of the finally selected machine. This contact is recommended also at an earlier stage.

An example of the above-mentioned operational characteristic PaT designed to operate at a constant rotational speed is shown in Fig. 18. This characteristic consists of a flow and energy part. In the Q-H plane the following curves are shown vs discharge:

head at overspeed (M = 0; n = var);

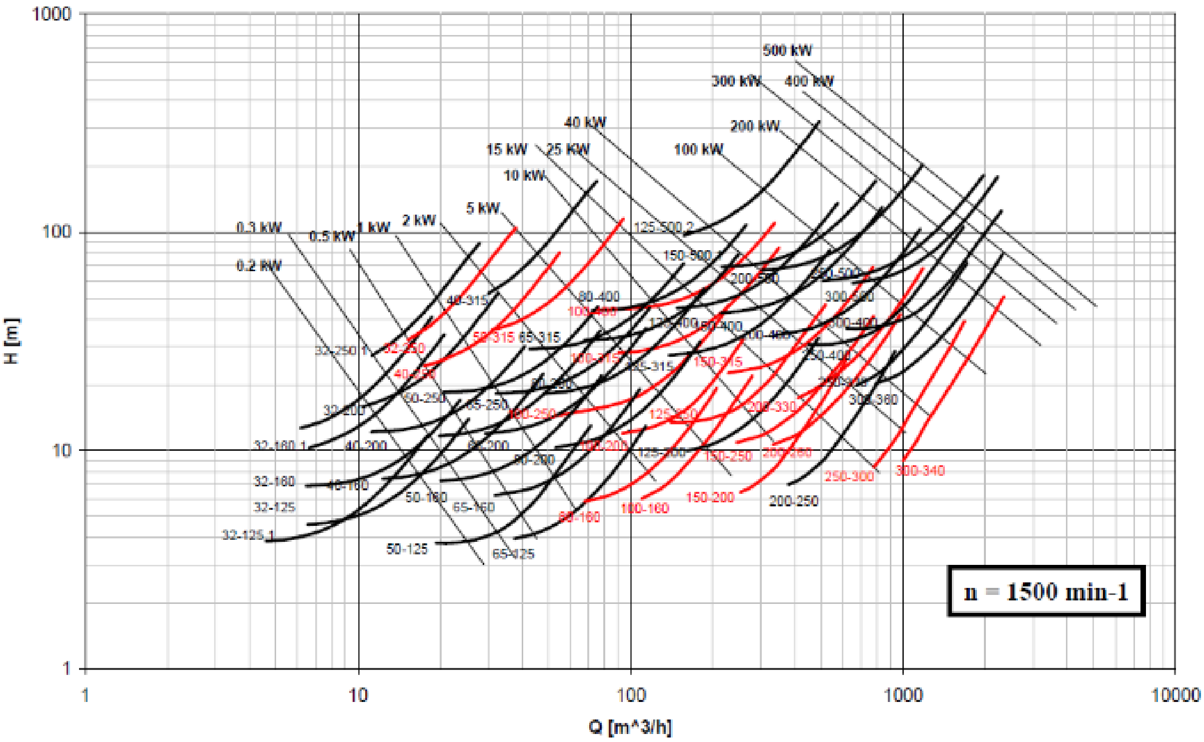
head during the standstill (M = var; n = 0);

head during normal operation (M = var; n = const),

with M denoting the torque at the shaft.

In the energy part, the curves of efficiency and power at the shaft have been plotted. All charts show also the design operating point. These characteristics, together with the characteristics of the motor in generator mode, can be already directly used to forecast electricity production.

ETA Turbinenraster für 1500 min-1



Omega Turbinenraster für A-Rad bei 1500 min-1

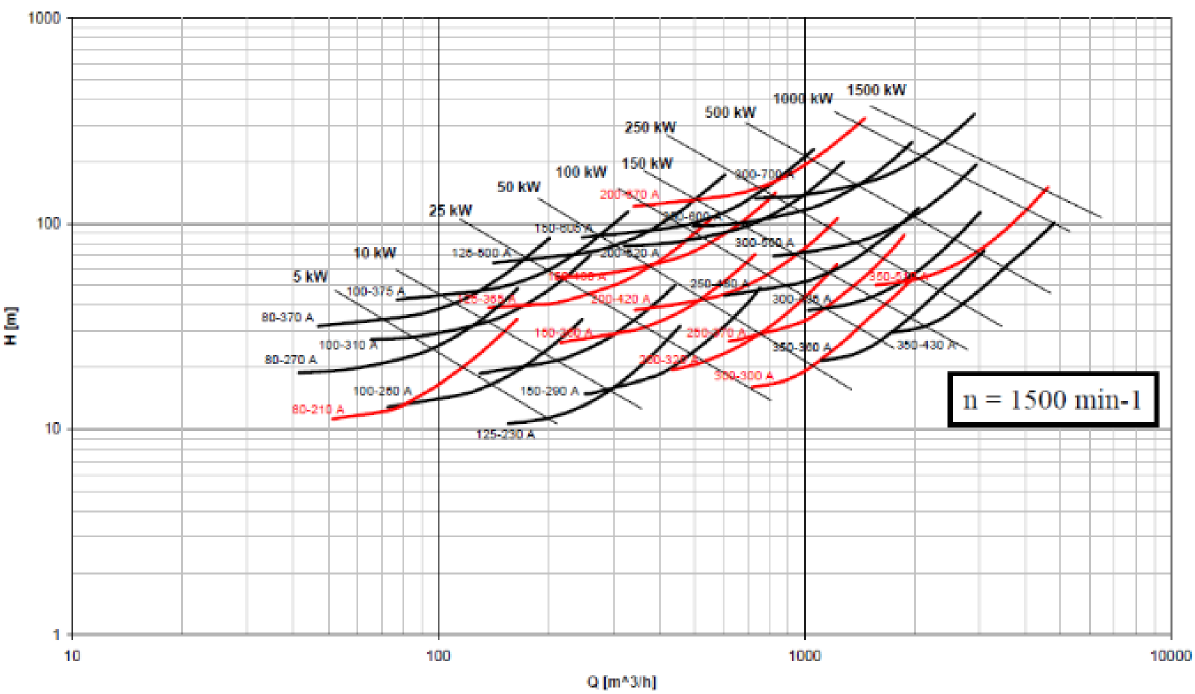


Fig.17 Collective characteristics of PaTs based on KSB centrifugal pumps of the Etanorm and Omega series

Baureihe-Größe / Tipo Type-Size / Serie Modèle / Tipo Omega 350-430A Turbine	Nenndrehzahl / Velocità di rotazione nom. Nom. speed / Nominaal toerental Vitesse nom. / Revolutiones nom. 1020 1/min	Laufrad-Ø / Ø Girante Impeller diameter / Ø Waaier Diamètre de roue / Ø Rodete 440 mm	KSB
Projekt / Progetto Project / Projekt Projet / Proyecto PaT 3000 m3/hr	Angebots-Nr. / Offerta-No. Project No. / Offertenr. No. de l'offre / Offerta-No. 4003485840	Pos.-Nr. / Pos.Nr. Item No. / Positienr. No. de pos. / Pos.-Nr. 100	KSB Aktiengesellschaft Postfach 200743 06008 Halle (Saale) Turmstraße 92 06110 Halle (Saale)

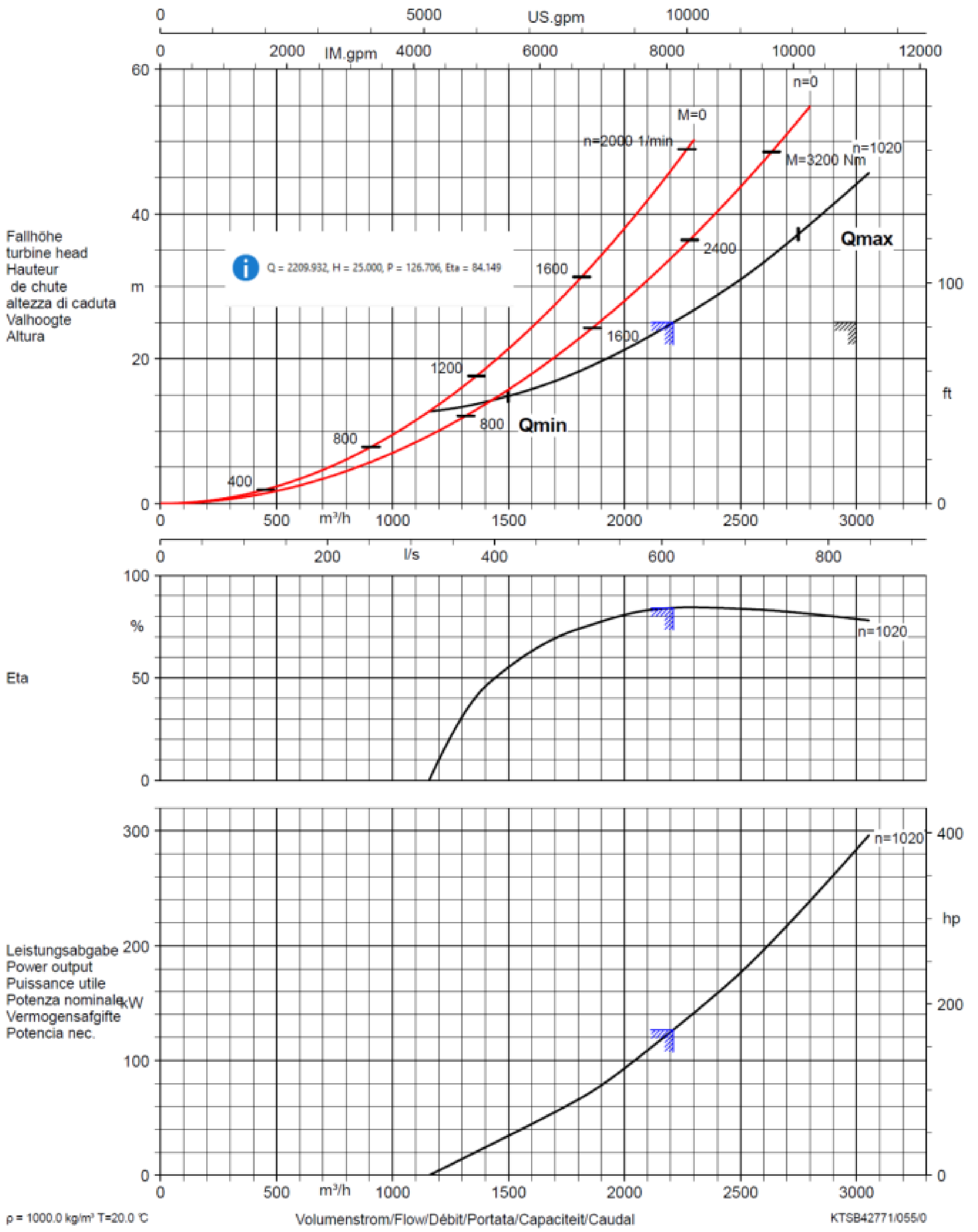


Fig.18 Characteristics of an Omega 350-430A PaT with a 440 mm impeller/runner and operating at a rotational speed n = 1020 rpm

PaT selection basing on their characteristics in the pumping regime

Access to the flow and performance characteristics of the entire series of pumps in turbine operation is possible with machines supplied by few manufacturers, and even then it is often quite limited. Therefore there exists quite substantial interest in the relationship between the characteristics of pumps in both operation modes and in the procedures for selecting a pump for turbine operation based on the characteristics in the pumping mode. A typical procedure consists of the following steps:

a) determination of the optimum operating point of the sought machine in pumping mode basing on the parameters of the design operating point in turbine mode and approximate formulas;
b) selection of the pump from the nomogram and characteristics in pumping mode basing on (a) (Fig. 19);
c) determination of characteristics in turbine operation basing on the approximate formulas;
d) assumption of the energy recovery installation regulation technique and analysis of its operational characteristics.

Of course, it is crucial to know the relationship between the performance parameters at the optimum operating point in both modes of operation. In general, there is a consensus that simple formulas containing only constant coefficients, and sometimes efficiency in pump motion, should be used for machines with flow system of the similar shape. More universal formulas require consideration of differences in the geometry of the flow system. This condition is most easily met by using the specific speed parameter (sometimes also called the shape number).

During the Life NEXUS project preliminary studies on selection of pumps from the Etanorm (KSB) series for energy recovery in selected water supply networks in Poland, the authors used the following formulas resulting from an analysis of 19 Etanorm pumps recently conducted by S.Fontanella et al. as a part of the REDAWN project [27]

$$\frac{Q_{\mathrm{tb}}}{Q_{\mathrm{pb}}}=1{,}3595\,\frac{n_t}{n_p} \tag{3}$$

$$\frac{H_{tb}}{H_{pb}}=1{,}4568\left(\frac{n_t}{n_p}\right)^2 \tag{4}$$

$$\frac{P_{tb}}{P_{pb}}=1{,}0403\left(\frac{n_t}{n_p}\right)^3 \tag{5}$$

In these formulas, the b subscript denotes the optimal operating point. The accuracy of calculations based on the above formulas is limited. An example is selection of PaT from the Etanorm series for the K20 chamber at the WTP Iskrzynia owned by MPGK Krosno (table 1).

The starting point were the parameters Q = 240 m^3/h and H =50 m, determined basing on the analysis of data provided by MPGK Krosno. Using formulas (3, 4), the expected pump parameters in pumping mode of operation were determined, and then, using the nomogram (Fig. 19), the type of pump meeting these expectations was selected in the first approximation. The impeller diameter and the optimal operating point in the pumping regime were determined from the available characteristics of the selected type. Since the optimal operating point in the pump mode of operation was only close to the assumed one, the formulas (3, 4) were used again to determine the resulting operating point in the turbine mode. Finally, a pump Etanorm 125-100-315 with an impeller of ∅ 318 mm diameter, operating at a rotational speed of 1550 rpm was selected. A pump of the same type was identified by the KSB specialist, based solely on the output data and the available characteristics of pumps in turbine operation. However, he has selected a pump with an impeller of larger diameter and indicated a significantly higher efficiency than that following from formula (5).

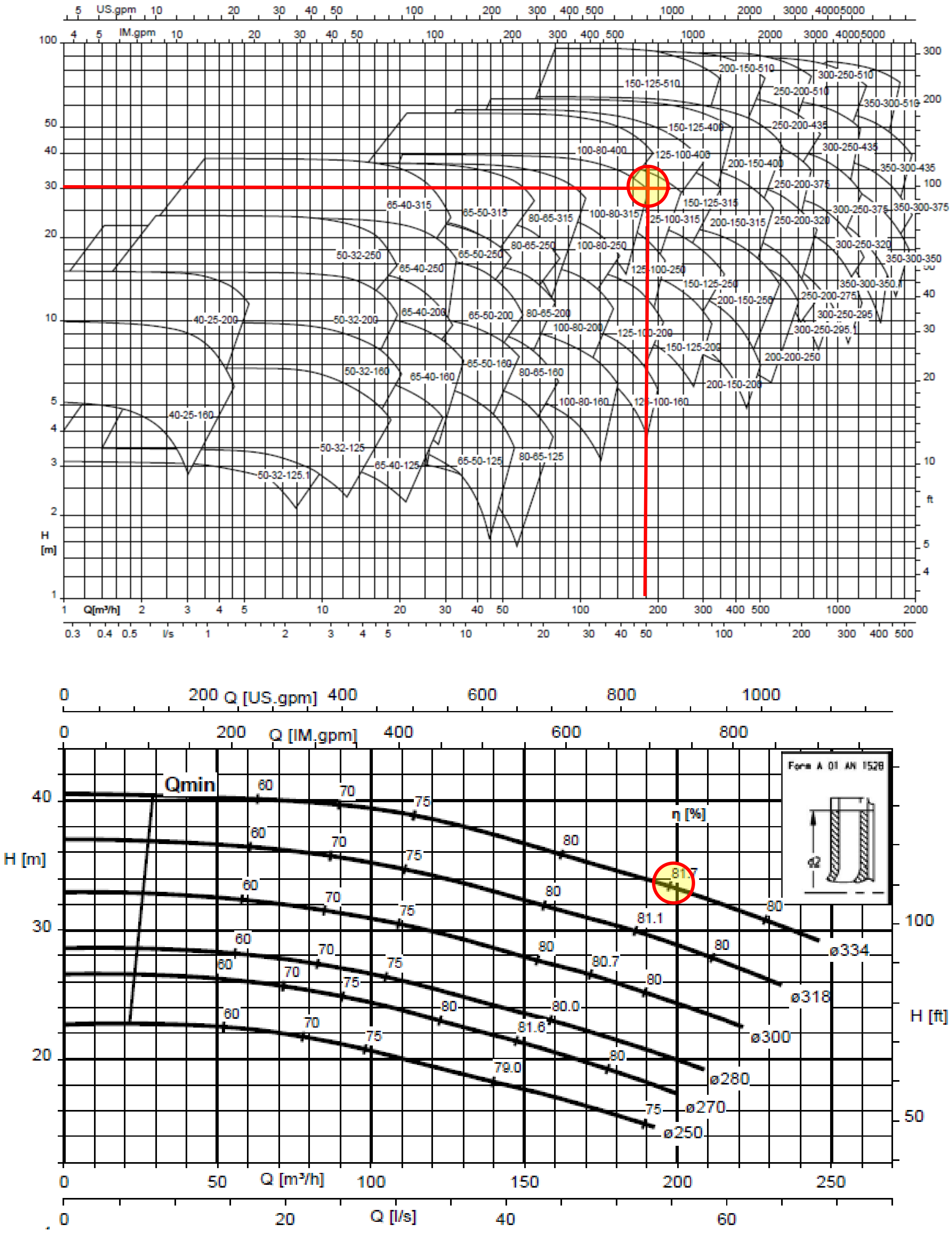


Fig.19 Selection of a pump of the Etanorm series (KSB) basing on parameters at the optimum operating point, nomogram and operating characteristics [26]

Table 1. Comparison of PaT selection results based on pump operation characteristics and formulas (3÷5) and turbine operation characteristics (KSB)

quantity	**pump**		**turbine**	
	calculation	reading	calculation	KSB
D, mm		318	318	334
n, rpm	1450	1450	1550	1520
Q, m^3/h	167	185	267	240
H, m	30,57	30,00	49,11	50,00
η, %		81,1	64,8	80,0
P, kW		18,6	23,1	25,0

It is also worth noting that when selecting a PaT basing on the characteristics in the pump mode of operation, the same motor/generator slip in both rotation directions was assumed (incorrectly). It is also to be noticed that carefully selected approximate formulas can be successfully used for preliminary analyzes. When making the final selection, however, it is always worth seeking access to characteristics determined experimentally for the pump in turbine mode of operation. The best idea is always to consult your supplier on this issue.

The large amount of experimental data having appeared in recent decades has also encouraged efforts to derive numerous empirical relationships describing the course of basic motor characteristics of PaT. In addition to the works already mentioned [25, 27], it is worth mentioning the frequently cited analyses of S. Derakhshan and A. Nourbakhsh [28], P. Singh and F. Nestmann [29], and recently also F.J. Lugauer et al. [30]. Despite the limited accuracy, these formulas allow to make a preliminary forecast of the operational properties of the installation. Of course, attention should be paid to using formulas based on the analysis of PaT properties with a structure similar to PaT under consideration. In the case of machines selected for the Life NEXUS project, the authors used the following formulas proposed by S.Fontanella et al. [27]:

$$\frac{H_t}{H_{tb}} = 1 + 0.9633\left(\frac{Q_t}{Q_{tb}} - 1\right)^2 + 1.4965\left(\frac{Q_t}{Q_{tb}} - 1\right) \quad (6)$$

$$\frac{P_t}{P_{tb}} = 1 + 2.7071\left(\frac{Q_t}{Q_{tb}} - 1\right) + 1.4326\left(\frac{Q_t}{Q_{tb}} - 1\right)^2 - 0.2405 + 0.03499\left(\frac{Q_t}{Q_{tb}} - 1\right)^4 \quad (7)$$

for $0.33 < \frac{Q_t}{Q_{tb}} < 6.25$

These formulas were used, among others, to assess the effectiveness of PaT speed control. As it can be seen from Fig. 20, the speed control capabilities are very limited when using the Etanorm 125-100-315 pump in the aforementioned K20 SUW Iskrzynia chamber. A similar conclusion was reached by the analysis of the operation of the Etanorm 150-125-510 pump for this object, as well as studies carried out for other objects analyzed by the authors as part of the Life NEXUS project. The final argument in each case turned out to be the power curves on the shaft and efficiency indicating a very dubious advantage of speed control in the optimal working area. Quite simple considerations lead to the conclusion that if it is necessary to obtain large changes in flow rate at a certain head, the use of throttling control, both parallel and serial, becomes necessary.

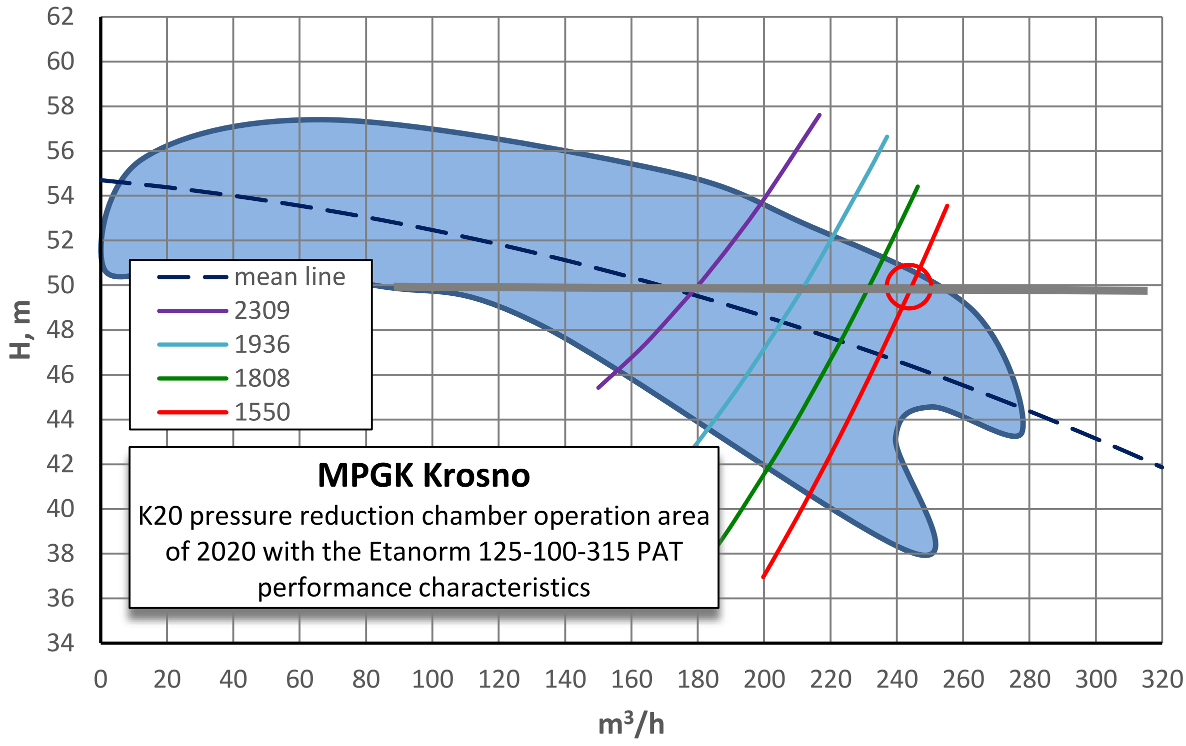


Fig.20 H-Q characteristics of the Etanorm 125-100-315 pump with ∅318impeller in turbine operation as predicted at different rotational speeds (2309, 1936, 1808, 1550 rpm) in the pressure reduction chamber K20 at the Iskrzynia DWTP (MPGK Krosno). In the background – chamber working area

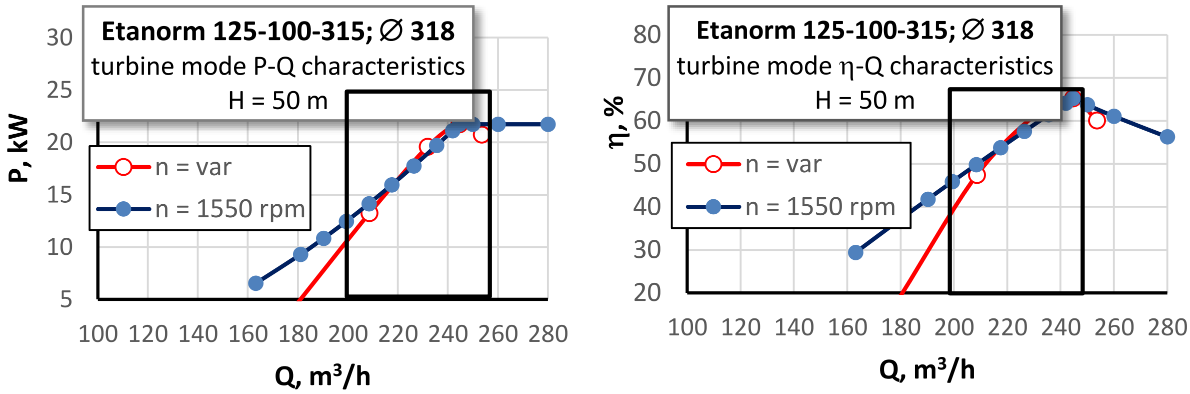


Fig.21 Performance characteristics of the Etanorm 125-100-315 pump with ∅318impeller in turbine mode with Q = 200÷250 m³/h discharge. Speed (red) and throttling control (blue). Pressure reduction chamber K20 at Iskrzynia DWTP. Head H = 50 m

Final remarks and conclusions

1) Due to their price and availability, pumps in turbine motion (PaT) are an attractive replacement for classic water turbines in many hydropower micro-installations. This applies primarily to energy recovery systems in municipal and industrial hydraulic circuits.

   The disadvantages of this solution include relatively low efficiency, steep course of some performance curves, and often - the lack of information about these curves.

2) In the case of equal or similar rotational speeds, the optimum operation point in turbine mode is displaced towards higher Q and H values in relation to the optimum operating point in the pump mode of operation.

3) In the absence of access to flow or performance characteristics in turbine mode of operation, the location of the optimum operating point as well as the course of the characteristics can be determined in the first approximation from the available approximate formulas. The accuracy and mutual compatibility of these formulas is limited. It is strongly recommended to use formulas based on the analysis of pump data with flow system geometry similar to the geometry of this system in the pump under consideration

4) Adjustable speed at a given head allows to achieve the optimum operating point, although the discharge is not necessarily within the set range.

5) In the case of centrifugal pumps in turbine motion, increasing the rotation speed at constant head leads to a decrease in the flow rate, while decreasing the speed shows the opposite effect. The situation is different for diagonal, mixed-flow and propeller pumps. (See efficiency hill diagrams of water turbines of different specific speed.)

6) In the case of centrifugal pumps in turbine motion, the change in rotational speed gives quite limited possibilities for discharge control. In the cases under analysis, throttling regulation seems to show a clear advantage.

Acknowledgements

This paper was prepared as an introduction to the training session during the Life NEXUS Project Symposium, which took place on October 27, 2022 at the "Witkowski" Hotel in Warsaw. The symposium was co-financed by the project as above. The authors would like to thank the project coordinator represented by Dr. Raquel Lopez (CARTIF, Valladolid, Spain) for the substantive and organizational support provided.

For providing the materials necessary to perform analytical work, as well as to prepare this text, we would like to thank all Project partners for whom we are preparing pre-preliminary studies of energy recovery installations, and above all Mr Grzegorz Wygoda from the Municipal Enterprise of Municipal Economy in Krosno and Mr Marcin Rafacz from SEWIK Zakopane.

Special words of thanks for substantive consultations and providing the necessary materials are addressed to KSB Polska Sp. z o.o. from Poland and Aquatec from Spain.

References

1. Zużycie paliw i nośników energii w 2020 roku. Tablice w formacie xlsx. GUS, Warszawa, 2021
2. Chen S., Chen B.: Net energy production and emissions mitigation of domestic wastewater treatment system: A comparison of different biogas–sludge use alternatives. Bioresource Technology 144 (2013) 296–303
3. Bousquet C., Samora I., Manso P., Rossi L., Heller P., Schleiss A.J.: Assessment of hydropower potential in wastewater systems and application to Switzerland. Renewable Energy 113 (2017) 64-73

4. Samaniego J., Bujedo L.A., López Fernández R.M., Serna González V.I., Mirete M., Pages J.: Energy recovery in a drinking water plant using an innovative micro-hydropower system based on the integration of a Pump as Turbine and an energy storage. HYDROFORUM 2022. XIth Polish Hydropower Conference & Life NEXUS Project Symposium. Book of Abstracts, TEW / IMP PAN, Warsaw/Gdansk (Poland), 2022
5. Kraftwerk Mühlau. Trinkwasser- und Naturstromkraftwerk. https://www.ikb.at/unternehmen/kraftwer-ke/kraftwerk-muehlau
6. Villagómez A.: Know-how for Small Power Hydro (SPH) development. Public sector company experience. EPMAPS case. HYPOSO Workshop on Small Hydropower Framework Conditions in Ecuador, Quito, 26 July 2022
7. Żaba T.: Odzysk energii na rurociągu magistralnym zasilającym krakowski system zaopatrzenia w wodę, Energetyka Wodna 2/2013, s. 37-41
8. Tomalik J.: Mała Elektrownia Wodna z turbiną Franci-sa jako system odzysku energii w oczyszczalni ścieków w Toruniu. V Polska Konferencja Hydroenergetyczna RENEXPO Poland, Warszawa, wrzesień 2015
9. van Vuuren S.J, van Dijk M., Loots I, Barta B. & Scharfetter B.G: Conduit Hydropower Development Guide, University of Pretoria, July 2014
10. Engeda A., Strate P., Rautenberg M.: Auswahl von Kreiselpumpen als Turbinen. Pumpentagung Karlsruhe'88, Sektion A6, Fachgemeinschaft Pumpen im VDMA, Frankfurt/Main, Oktober 1988
11. Choulot A., Denis V. Punys P.: Integration of Small Hydro Turbines into Existing Water Infrastructures. Hydropower – Practice and Application, Dr H. Samadi-Boroujeni (Ed.), InTech, March 2012, Available from: http://www.intechopen.com/books/hydropower-practice-and-application/integration-of-small-turbines-into-water-infrastructure
12. Casini M.: Harvesting energy from in-pipe hydro systems at urban and building scale. International Journal of Smart Grid and Clean Energy. vol. 4, no. 4, October 2015, pp.316-327
13. Tapping in-conduit hydropower as alternative renewable energy source, World Water, Vol.42, Issue 4, July/August 2019, pp.12-15
14. Harvesting renewable, low-cost electricity from gravity-fed water pipes. Lucid Energy Product Info. www.lucidenergy.com
15. Hergt P., Krieger P., Thommes S.: Die strömungstechnischen Eigenschaften von Kreiselpumpen in Turbinenbetrieb. Pumpentagung Karlsruhe'84, Fachgemeinschaft Pumpen im VDMA, Frankfurt/Main, Oktober 1984
16. Schmiedl E.: Serien-Kreiselpumpen im Turbinenbetrieb. Pumpentagung Karlsruhe'88, Sektion A6, Fach-gemeinschaft Pumpen im VDMA, Frankfurt/Main, Oktober 1988
17. Schnitzer V.: Pumpenantriebe mit regenerativer Energie; ihre besondere Anforderungen an Pumpen. Pumpentagung Karlsruhe'92, Fachgemeinschaft Pumpen im VDMA, Frankfurt/Main, Oktober 1992, Beitrag A5-11
18. Kirejczyk J.: Analiza przydatności pompy 400 UM 250 do pracy turbinowej. Opr. IMP PAN, Gdańsk, 1982
19. Reymann Z., Steller K., Litorowicz J.: Activities of the Polish Academy of Sciences' Institute of Fluid-Flow Machinery concerning development of small water power plants. Trans. IF-FM, 1989, vol. 90-91, pp.149-162
20. Steller K.: Pompy wirowe jako turbiny wodne. Zesz. Nauk. IMP PAN nr 297/1262/90, 31 s.
21. Steller K., Łojek A., Reymann Z.: Sprawozdanie z badan laboratoryjnych niskociśnieniowej pompy wirowej odśrodkowej jednostopniowej typu PJM. Opr. IMP PAN nr 173/92
22. Rduch J., Zarzycki M.: Badania laboratoryjne pomp wirowych wielostopniowych w ruchu turbinowym. HYDROFORUM'94. Straszyn, wrzesień 1994. Materiały Konferencji Naukowo-Technicznej. Suplement, Wyd. IMP PAN, Gdańsk, 1994., s. 11-18
23. Klein M., Łojek A.: Maszyna rekuperacyjna jako reduktor ciśnienia w instalacjach przemysłowych. Trans. IF-FM, 1996, z. 101, s.141-154

24. Steller J., Adamkowski A., Stankiewicz Z., Łojek A., Rduch J., Zarzycki M.: Pumps as turbines for hydrau-lic energy recovery and small hydropower purposes in Poland. Hidroenergia'2008, Bled (Slovenia), June 11-13th, 2008, Session 5A
25. Pérez-Sánchez M., Sánchez-Romero F.J., Ramos H.M. and López-Jiménez A.P.: Improved Planning of Energy Recovery in Water Systems Using a New Ana-lytic Approach to PAT Performance Curves. Water 2020, 12, 468; doi:10.3390/w12020468
26. Wassernormpumpe – 50 Hz. Etanorm/ Etanorm SYT/ Etanorm V/ Etabloc/ Etabloc SYT, Etanorm-RSY. Kennlinienheft. KSB SE & Co. KGaA, Frankenthal 07.06.2021
27. Fontanella S., Fecarotta O., Molino B., Cozzolino L., Della Morte R.: A Performance Prediction Model for Pumps as Turbines (PATs). Water 2020, 12, 1175; doi:10.3390/w12041175
28. Derakhshan S., Nourbakhsh A.: Experimental study of characteristic curves of centrifugal pumps working as turbines in different specific speeds. Experimental Ther-mal and Fluid Science 32 (2008) 800–80
29. Singh P., Nestmann F., An optimization routine on a prediction and selection model for the turbine operation of centrifugal pumps. Experimental Thermal and Fluid Science 34 (2010) 152–164
30. Lugauer F.J., Kainz J.,Gaderer M.: Techno-Economic Efficiency Analysis of Various Operating Strategies for Micro-Hydro Storage Using a Pump as a Turbine, Energies 2021, 14, 425. doi.org/10.3390/en14020425

Authors

Janusz Steller, DSc in mechanical engineering, graduated in 1977 from the Faculty of Mathematics, Physics and Chemistry of the University of Gdańsk specializing in theoretical physics. Since then, an employee of the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences (IMP PAN). In 2019 awarded with a DSc degree by the Senate of the Wroclaw University of Technology. Now senior specialist in the Centre for Hydrodynamics of the IMP PAN. President of the Polish Hydropower Association. Main professional interests include cavitation and cavitation erosion, methodology of hydraulic machinery design and exploitation, as well as that of the performance and diagnostic tests under field and laboratory conditions, general problems of hydropower development.

Mariusz Hajdarowicz, MSc, Eng., graduated from the Faculty of Ocean Engineering and Ship Technology of Gdańsk University of Technology in 1996. He started his professional career in 1996 at Zakłady Remontowe Energetyki Gdańsk Sp. z o.o. In the years 1999-2002 he worked at Gajek Engineering Sp. z o.o. Then, from 2002, he worked at ZRE Gdańsk Sp. z o.o. In 2006, he became the head of the newly created Development Department of ZRE Gdańsk, which he created and developed in the following years. M.Hajdarowicz was responsible among others for contacts and cooperation between ZRE Gdańsk and the world of science. Professionally, M.Hajdarowicz deals with broadly conceived hydropower, selection of water turbines and calculations of their parameters. Since 2021, he has been employed at IMP PAN as a senior specialist and at Remak Energomontaż Co.

Zbigniew Krzemianowski, PhD, Eng., graduated from the Faculty of Mechanical Engineering of Gdańsk University of Technology in 1998. In 2003 he obtained a PhD degree in technical sciences at the Gdańsk University of Technology. Since then, he has been employed at the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences – from the second half of 2022 at the Thermal Energy Center. Professionally, he deals with three-dimensional liquid flow analysis (CFD), design of water turbines, testing hydraulic machines in laboratory and in the field, as well as numerical modeling of the cavitation phenomenon.

5. Case studies

5.1. Recovery of energy lost in technological processes of industrial enterprises. Practical examples

The current geopolitical situation, the energy crisis caused by the war in Ukraine and the increasingly noticeable negative effects of global warming every year should be a serious impulse forcing actions aimed not only at finding ways to save energy and promoting the use of renewable energy sources, but also going towards the recovery of energy lost in production processes

One of the most energy-intensive branches of the economy is water and sewage management. Global energy demand from this industry accounts for more than 4% of total energy consumption, and the share of energy consumption in wastewater treatment plants alone is 1.5%. Hence, it is obvious that the costs of energy used in the activities of water and sewage companies are significant. This is particularly noticeable in the recent period, in which the increase in energy prices has had a strong impact on the budgets of these enterprises. Water and wastewater companies, as utilities, cannot cease their activities, hence rising energy costs must be compensated by restructuring measures, reducing operating costs and implementing innovations aimed at reducing energy consumption. One of the ways of such activities is the recovery of potential energy of water in the reduction nodes of the water supply network. Proper pressure management in the water supply network is one of the most important tasks of the strategy aimed at reducing the failure rate of the water supply network, which in turn translates into limiting water losses. Therefore, in many nodes of the water supply network, pressure reduction is required, which is mainly carried out by using gate valves, dampers and throttle valves.

The required degree of pressure reduction in the water supply network can also be achieved by incorporating a water turbine into the flow system, which will successfully and with high accuracy carry out this task, while using the lost energy of the flowing water to drive the generator and, as a result, to produce electricity.

The amount of installed capacity and energy produced can be significant, as demonstrated by the hydroelectric units already used in some water supply nodes. The Francis turbine used at the Raba Water Treatment Plant in Dobczyce drives a generator with an installed capacity of 440 kW, which annually produces over 2,800,000 kWh of energy. This represents 20% of the energy used to pump water in this installation and, according to the adopted limit values for energy consumption in households, would cover the annual energy demand for heating 1400 households. The presentation describes in detail another positive example of the use of lost energy in a water supply network reduction node implemented in 2019.

Effective methods of using biogas energy, which is a by-product in the technological process of urban wastewater treatment, are also widely known. The energy potential of biogas in over 1800 sewage treatment plants in our country is nearly 1,200 MW. Some wastewater treatment plants use this potential to cover their energy needs in full. An example of a fully passive sewage treatment plant is Tychy Wastewater Treatment Plant. In many wastewater treatment plants, there is also an additional possibility of partial recovery of energy lost on pumping wastewater by using the potential energy of treated wastewater discharged into reservoirs or watercourses. An example of the recovery of about 10% of the energy used for pumping sewage is Płaszów Wastewater Treatment Plant, where a Kaplan turbine with double flow regulation was installed at the discharge of treated wastewater driving a generator with an installed capacity of 85 kW. The annual production of this small hydroelectric power plant is 380,000 kWh. The presentation describes in detail another positive example of the use of lost energy in a water supply network reduction node implemented in 2019.

The use of energy, which is irretrievably lost in technological processes, is a very important element of climate care. It should be remembered that the production of 1 MWh of energy in this type of installations reduces CO_2 emissions to the atmosphere in the amount of at least 800 kg. This applies not only to water and sewage companies, but also to all those in which it is possible to recover energy lost for pressure reduction and the energy of water discharged after its use in the technological process. The presentation will show the practical possibilities of recovering energy lost in production processes also in other enterprises, apart from the water and sewage companies.

Authors

Maciej Kaniecki, Ph.D., Eng., graduated from the Faculty of Mechanical Engineering of Gdansk University of Technology in 1998. In 2005 he defended his PhD thesis in the field of flow modeling. In the years 1998-2013 employed at IMP PAN. In the years 2013-2020 employed at ZRE Gdańsk S.A. Currently an employee of T-G DNALOP. His scope of competence includes the design and testing of water turbines and pumps.

Mariusz Lewandowski, Ph.D., Eng., graduate of Gdańsk University of Technology. Currently a research fellow at the Department of Hydropower at the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences. His main professional interests include unsteady flows in closed conduits, testing of fluid-flow machinery.

Arkadiusz Kamiński, DSc., Eng., graduate of the Warsaw University of Technology. In the years 2000-2014 lecturer at this university, habilitation at the Academy of Mining and Metallurgy (AGH University of Science and Technology in Cracow). Currently, an expert at the PKN ORLEN in the operational area, environmental protection and natural resources, as well as water management and energy

Stanisław Lewandowski, MSc, Eng., graduate of the Faculty of Electrical Engineering at the Wrocław University of Technology. He has been working in the power sector since 1973. Currently, the main limited partner of Easy Serv sp. z o.o. sp. k. with a consulting profile in the field of hydropower. Member of the Board of the Polish Hydropower Association.

From the Editor:

More detailed information on the abovementioned hydraulic energy recovery installations is comprised in the presentation delivered to the Life NEXUS Symposium on October 27th 2022. All Symposium proceedings, including presentations and the Book of Abstracts are available from the following website of the Polish Hydropower Association: https://www.tew.pl/index.php/en/conferences-seminars.

You can also use the following direct link to this particular presentation:

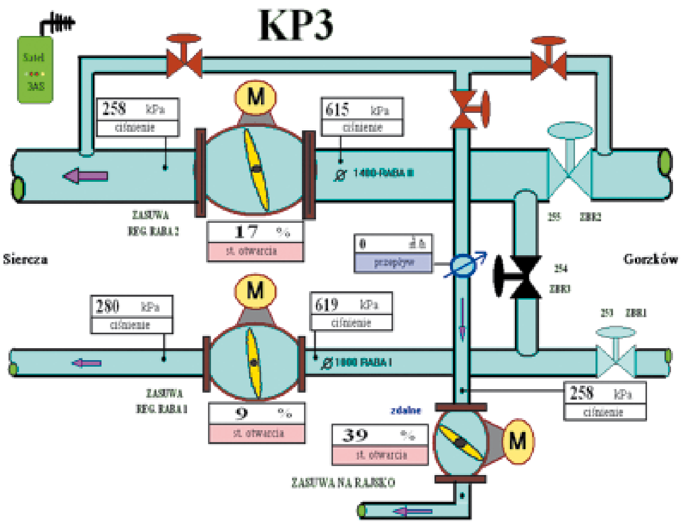
https://drive.google.com/drive/folders/1TSZOp73CL589pcOZYKwzgjN2c94_17r9

Below find please excerpts from the mentioned presentation together with some Authors' notes reproduced by the Editor with Authors' consent. The notes are not available from the website!

Water pressure reduction node in water network installation
of Cracow Water Supply and Sewage Enterprise

DWTP Raba
https://wodociagi.krakow.pl/historia.html

ZECO Hydraulic unit
Rated capacity Pn=440 kW
Budownictwo Inżynieryjne
November/December 2012



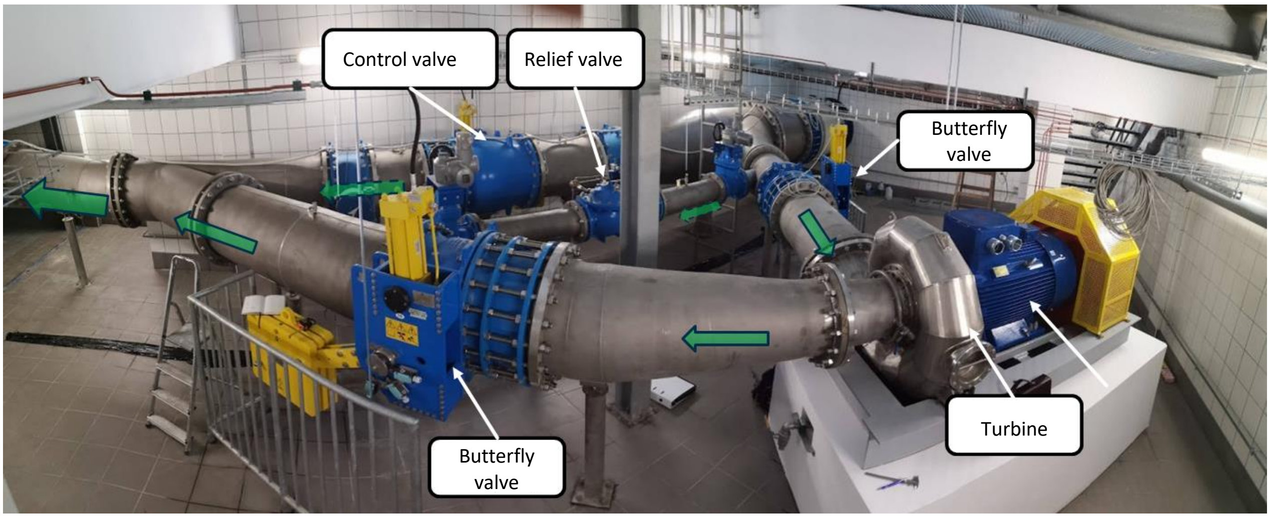
Technologic schematic
of the pressure reduction node.
Energy recovery water turbine
installation site

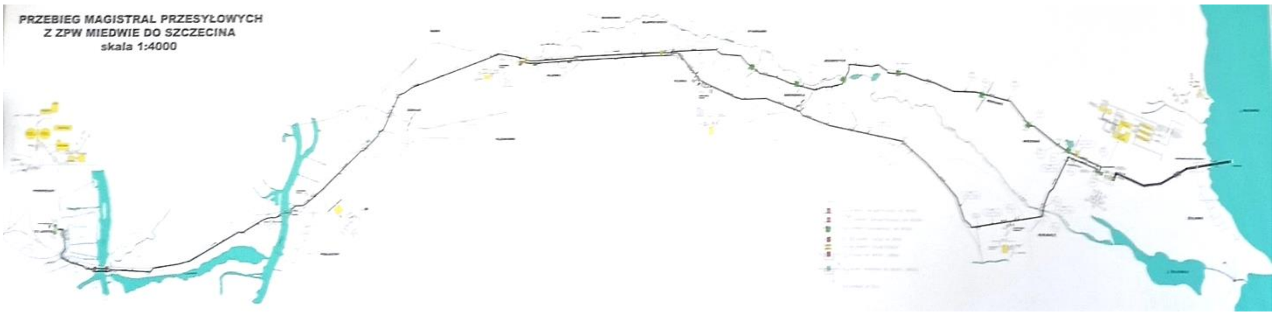
Budownictwo Inżynieryjne
November/December 2012

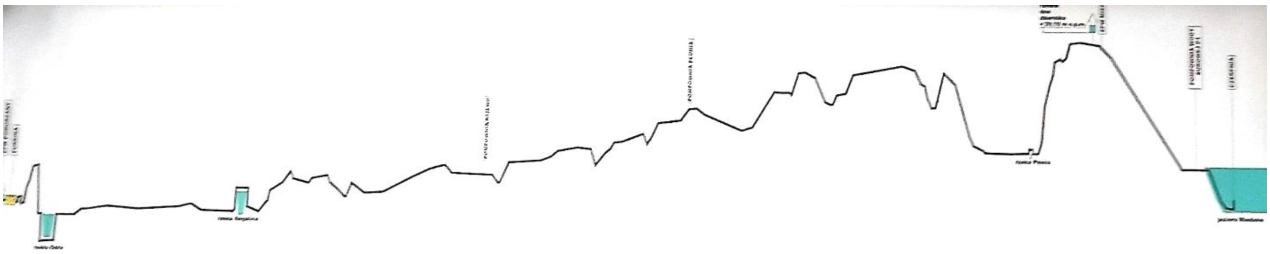
Water pressure reduction node in Szczecin Water Supply and Sewage Enterprise

„Pomorzany" Water Treatment Plant – Installation Characteristics

- Water is taken from the reservoir (Miedwie Lake) and pumped to the Miedwie WTP.
- Water taken from Miedwie WTP reservoir is transported through a ca. 33 km pipeline to the "Pomorzany" WTP buffer reservoirs.
- Maximum water level in Miedwie WTP reservoir: 44,10 m a.s.l.
- Elevation of the shaft spillway in the WTP buffer: 7,36 m a.s.l.
- Discharge variability of water delivered to the reservoirs. Between ca. 500 m^3 /h and ca. 3000 m^3/h.
- The maximum hourly discharge in 2 latest years before developing the project (2017 -2018) was 2738 m^3 /h (0,761 m^3 /s).



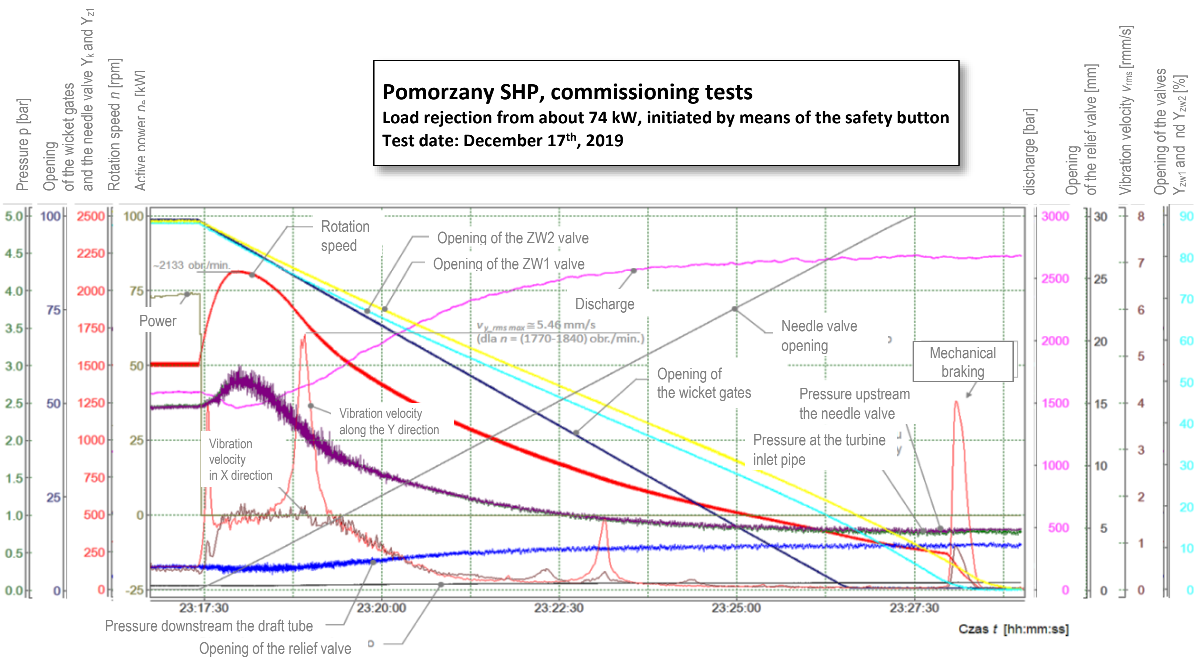




The unit has been equipped with a Francis turbine with the following technical parameters:

- Power at the shaft: $P_{t,max}$ = 142 kW (under typical hydrological conditions)
- Maximum/rated head: H_{max} = 32,9 m
- Nominal discharge: Q_t = 0,525 m^3/s (under available head H_{max})
- Nominal rotation speed: n_n = 1500 rpm
- Runaway speed: n_r = 2500 rpm
- Impeller diameter: D = 300 mm
- Number of impeller blades: Z_b = 13
- Number of guide vanes: Z_v = 20

The turbine has been connected directly (without a gear) with asynchronous generator

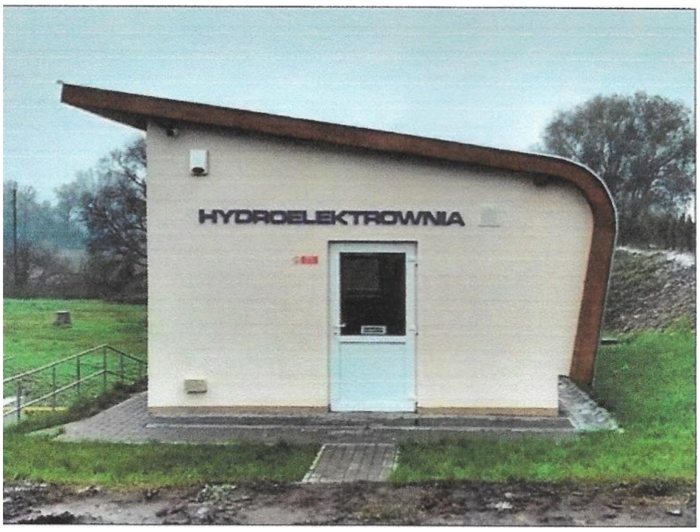


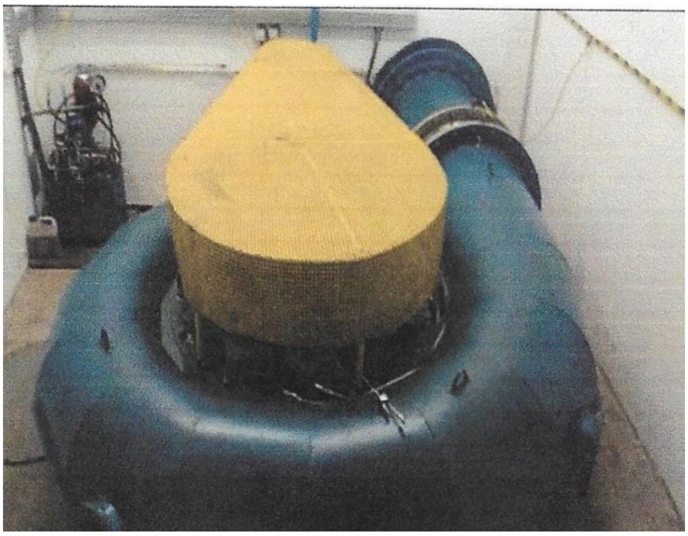
When planning modernization of water supply systems aimed at recovery of energy lost during pressure throttling in reduction nodes, in addition to assessing the available hydropower potential and hydrological conditions (variability in time of water flows and the available pressure difference before and after the turbine) and selection of technical parameters of the hydroelectric unit, it is required to have a good understanding of the technical parameters of the operation of the entire water supply system.

This is particularly important whenever long main pipelines supplying water to storage tanks operating at a large pressure difference are used. First of all, the appropriate selection of turbine control parameters is necessary, including in particular the setting of limit rates of the wicket gate opening angle adjustment, so as to prevent the occurrence of a hydraulic hammer with excessive destructive pressure leading to pipeline cracking, burst or collapse.

Commissioning of the installation should confirm correctness of the applied operating parameters and possibly allow to introduce some additional adjustments For this purpose, the schedule of commissioning works should also include the scope of measurement and research works.

Hydropower Plant in the Central Water Treatment Plant in Toruń





Toruń Waterworks planned to build a small hydroelectric power plant already in 2003, but it was physically started only in 2013. The implementation of the investment lasted 24 months. The hydroelectric power plant was commissioned in mid 2015. At that time, it was one of the first projects in Poland (previously used gravity discharge of treated wastewater discharged from the industrial sewage treatment plant at the Płock refinery) concerning the use of a water turbine for energy recovery at the sewage treatment plant. Only four such pilot projects were in operation in Europe at the time, including one in Brussels.

In the "Centralna" sewage treatment plant in Toruń, a small hydroelectric power plant was launched on the canal discharging treated sewage to the Vistula River. Treated wastewater is discharged through an overflow channel and through the drainage channel reaches the outlet chamber where it is directed through the DN1000 pipeline to the Francis turbine with a capacity of 55 kW. The turbine operates on a 7 m head in a wide flow range between 0.25 and 1.2 m^3/s. The turbine set is run under fully automatic control, responsible for maintenance-free operation and control of the electricity generation process. The power plant operates in a regime of maintaining upper water at a constant level. The electricity generated is used to cover the demand of the wastewater treatment. However, in exceptional cases, when the demand for electricity in the plant decreases and the turbine produces excessive energy – then it is possible to transmit the surplus to the grid.

Treated wastewater, after passing through the turbine, is discharged to the Vistula River.

Hydroelectric power plant at Płaszów Wastewater Treatment Plant in Cracow

The hydroelectric unit was installed in 2016 in the Treated Wastewater Measurement Chamber. The natural level difference of 3.7 m between the outlet of treated sewage and the receiver - the Drwina River (Vistula tributary) was used here.

The supplier of the hydroelectric unit equipped with a Kaplan turbine and the contractor of all works was Gajek Engineering Sp. z o.o. from Gdańsk.

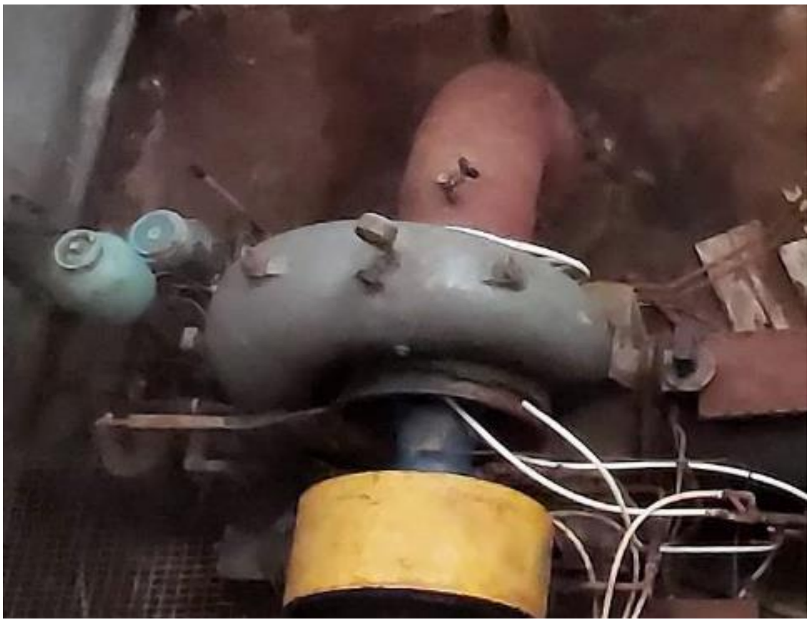
The turbine drives an 85 kW generator. All energy is practically used to supply the wastewater treatment plant own needs.

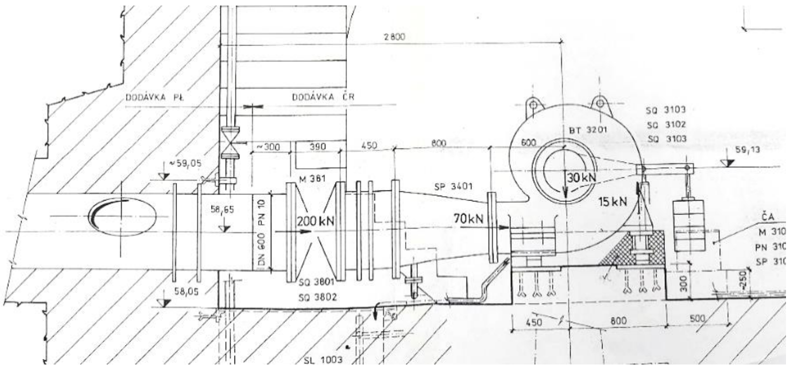
The hydroelectric has been equipped with an automation and control system, which ensures maintenance-free operation in a wide range of treated wastewater flows from 2 800 m^3/h up to 13 750 m^3/h.

The turbine as prepared for mounting

Mikrohydropower plant in Płaszów WWTP. Nowoczesne Budownictwo Inżynieryjne . March/April 2017.

Płock Hydropower Plant





As part of the Life NEXUS project, IMP undertook to develop a study in which possible and technically and economically justified variants of hydropower plant modernization will be developed, along with a recommendation of the most advantageous option from the point of view of optimizing the use of the available hydropower potential.

In August 2020, the Easy Serv company developed the "Preliminary Feasibility Study of works necessary to resume hydraulic energy recovery at the discharge of water from the sewage treatment plant of the PKN Orlen Oil Refinery".

The treated wastewater from the industrial treatment plant is supplied by the DN1500 main to the distribution pit, from which – via the DN600 pipeline with a length of approx. 600 m - it is delivered by gravity to the turbine located in a free-standing power plant building on the right bank of the Vistula. If it is necessary to decommission this pipeline, the treated wastewater is directed directly to the Vistula River via the DN1500 bypass pipeline.

The difference in levels between the distribution pit and the turbine inlet is 32.2 m and the average annual average flow of treated wastewater has been determined as: SSQ = 0.5 m^3/s (43,200 m^3/day)

Significant flow fluctuations are observed over short periods of time. Both the change in the volume of flow and the dynamics of these changes are very large. In the absence of the retention capacity of the hydraulic system, this meant that it was necessary to use a hydroelectric unit designed to work in a wide load area with the highest possible efficiency.

The hydroelectric unit was installed in the hydropower plant building in 1993 and equipped with a Francis turbine in a horizontal configuration produced by CKD Blansko a.s.

Technical parameters of the turbine:

type	FR 625
power at the shaft	P_T = 158 kW
rated head	H_n = 26 m

The "Prefeasibility Study" analysed five variants of hydroelectric power plant modernization, differing in technical equipment and technological system. Ultimately, the owner of the power plant decided to choose a variant of the power plant equipped with one unit with the installed capacity of 160 kW and a Francis turbine operating in the flow range from 0.18 m^3/ s to 0.68 m^3/s and the optimum operating point featured by discharge of 0.5 m^3/s at net head of 22 m

The hydroelectric unit will be installed in the existing civil engineering infrastructure and will use the hydropower potential of treated wastewater, which is currently discharged from the sewage treatment plant to the Vistula River. The unit will be connected to the distribution network of ENERGA Operator

The predicted annual electricity generation is ca. 2.000 MWh/a.

Investment outlays estimated in the prices of 2020

Variant	Average annual generation	Investment outlays*
	MWh	kPLN
Variant I	939.910	1854.450
Variant II	885.350	1616.700
Variant III	940.000	1902.000
Variant IV	1023.000	2092.200
Variant V	1050.000	2139.750

Economic parameters in option 2 (energy sale according to the FIT tariff)

Variant	NPV	IRR	Simple payback period	Payback period with discount	LCOE
	kPLN	-	years		PLN/MWh
Variant I	2363.379	25.1%	4.2	5.6	334.35
Variant II	2369.593	27.1%	3.9	5.1	311.69
Variant III	2311.390	24.5%	4.3	5.8	342.12
Variant IV	2490.948	24.2%	4.3	5.9	345.47
Variant V	2565.145	24.3%	4.3	5.9	344.35

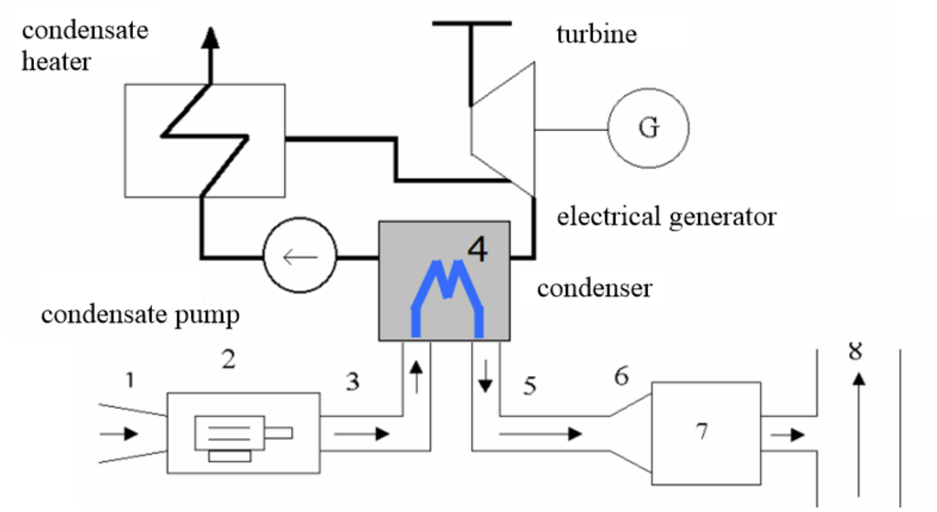
Skawina II SHP

The use of hydropower potential of discharge water from the cooling system of power unit condensers of the Combined Heat/Power Plant CEZ Skawina

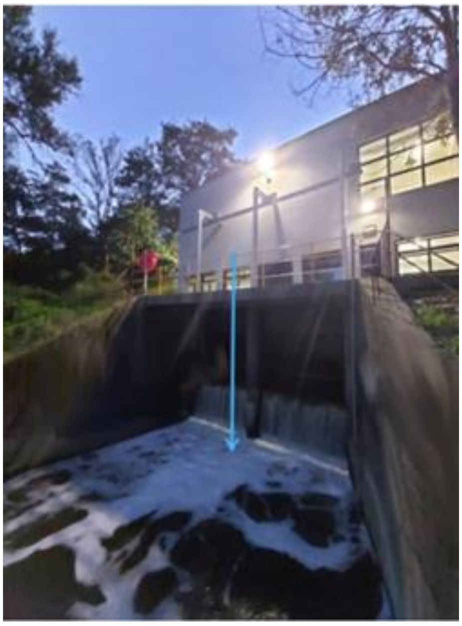
Characteristics of the installation

The Vistula waters divide at the Łączany barrage into the Vistula original river bed and the Łączany Navigation Canal. Water flowing through the Canal is supplied to the barrage in Borek Szlachecki, where it is divided again into the part directed to the Vistula and the other one - directed through a concrete channel to the "Skawina" power plant cooling system.

Water flowing through the mentioned concrete canal is supplied to the pump station (2) that increases the cooling water pressure to overcome losses in the condenser. Then it is directed to condensers (4) and a relief channel (5) and feeds the Skawina II hydroelectric power plant (7) by gravity. Water discharged from the power plant flows directly into the Skawinka River bed - Vistula tributary.



The Skawina II hydroelectric power plant was built in the place of the previously existing hydropower plant. In 2018, the demolition of the old powerhouse began, all equipment was removed and the civil engineering works began. The new powerhouse was built on the foundations of the previous one, the turbine installation system was thoroughly rebuilt – including the inlet spiral case and the draft tube, a new power plant building was built, a new unit with equipment was installed. The work was completed in 2019.



Manufacturer	ZRE Gdańsk S.A.
Production year	2019
Kind of turbine	Kaplan
Maximum power	880 kW
Head	9,45 m
Maximum discharge	10,5 m^3/s
Rotation speed	375 rpm
Runner diameter	1400 mm

Summarisation and conclusions

1) Experience from the operation of water supply networks, industrial and municipal wastewater treatment plants, as well as various other industries in which water resources are used, has shown that there are significant opportunities to improve the energy balance of companies operations through energy recovery, including the use of micro-hydropower technology.

   There are known examples of companies operating sewage treatment plants, achieving full energy self-sufficiency and even surplus energy produced which is fed into the power grid. Implemented Integrated Energy Efficiency Systems, such as the one in Płaszów Wastewater Treatment Plant, bring excellent results in the form of not only the amount of recovered waste energy, which is used for the needs of the treatment plant, but also, and perhaps above all the reduction of greenhouse gas emissions such as CO_2, SO_2 and NO_x, in view of the progressing global climate change at an ever faster pace,.

2) In order to take full advantage of waste energy discharged uselessly to the environment, it is necessary first of all to precisely recognize its potential and determine the technical possibilities of its recovery, taking into account the specificity of the company's operations and the technical and technological solutions used in it.

   An excellent example is the activity of the Regional Centre for Water and Sewage Management in Tychy. Innovative solutions used in the Tychy–Urbanowice Wastewater Treatment Plant, in which the production of heat and electricity produced primarily from biogas obtained in sewage sludge fermentation processes is one and a half times higher than the sewage treatment plant own energy demand. This was also possible thanks to the implemented projects, as a result of which energy consumption was reduced in the technological process of wastewater treatment.

   Thus, projects of installations aimed at the recovery of waste energy should be carried out in parallel with projects aimed at reducing energy consumption for own needs as well as the implementation of additional installations using other sources of renewable energy, such as solar radiation or wind

3) The designed waste energy recovery installations must in no case interfere with technological processes or limit their efficiency and production capacity. First of all, they must not reduce the safety of the installations operation and the security of media supply to the public, in particular drinking water.

   Particular attention should be paid to the safe operation of the installation, especially in such cases when a water turbine is included in the system of the water supply network. The hydraulic unit, like any other electro-mechanical device, may unexpectedly be switched off operation due to interaction of the internal or external protection devices and subsystems. Improper application of the response times of the fittings in the reduction node to such events can even lead to a structural catastrophe. The experience of Easy Serv start-up team indicates the absolute need to pay attention to this aspect already at the design stage of the installation

   The existing design and technological solutions used in water supply systems or wastewater treatment plants should not be taken for granted and accepted without a critical approach. It should be taken into account that the solutions used did not take into account the possibility of waste energy recovery. Therefore, the introduction of changes aimed at enabling the recovery of as much of the lost energy as possible is most advisable, provided, however, that the proposed changes do not interfere with the main technological process or reduce the operational safety of the installation. A good example of such a solution is the proposal to introduce changes in the collection of treated wastewater from secondary settling tanks, so as to use the maximum difference in water levels between the intake of treated wastewater and the place of its discharge to the receiver.

4) Innovative solutions aimed at waste energy recovery should be focused on maximizing the recovery of lost energy, taking into account the minimization of investment expenditures. Feasibility studies should take into account both different options for possible technical solutions and different options for managing recovered energy.

   Where possible, the recovered energy should be used for the own needs. It is beneficial if it is possible to use the largest part of the recovered energy for own needs in periods when the cost of energy received from the energy system is the highest. Such possibilities exist when installations have a certain reservoir retention in which they can accumulate potential energy of the medium used to produce electricity. It is also necessary to analyse whether in specific technical and field conditions it is possible to create such an energy store. The possibilities of energy storage in electrochemical batteries should also be explored.

   Bearing in mind the high variability of the flow of treated sewage or water in the water supply system, turbines with the widest possible flow regulation band should be used, while maintaining acceptable efficiency of energy generation and maintaining the proper technical and dynamic condition of the hydroelectric unit. In the case of very large flow variations, the possibility of installing two turbines with different permissible operating areas should be considered.

5) The most significant factor limiting the possibilities of implementing waste energy recovery projects are high investment outlays, the size of which affects the effectiveness of the project, often blocking this direction of development.

   The costs of hydroelectric units with full protection automation and control equipment are relatively high. Including the costs necessary to modernize the external hydraulic civil engineering, technical and technological infrastructure, it often turns out that the project does not close economically. In the business activity of water and sewage companies, the cost that will be passed on to the recipients of services provided by these enterprises, and thus generally to society, must be taken into account. When developing their approach to net zero, these companies should ensure that their plans are clear, transparent and understandable to the wider public. This is crucial as it will allow stakeholders to adequately support and challenge companies on their path to net zero, with a focus on achieving the best value for their service consumers and the environment.

   It is also necessary to strive to minimize investment outlays by looking for innovative technological and construction solutions. Appropriate adaptation of pump units to turbine operation, optimization of the operation of reduction nodes, pumping stations and sewage treatment plants can ultimately result in high energy and investment savings.

6) One of the most effective ways to accelerate activities aimed at reducing energy consumed in technological processes of water and sewage companies and recovery of waste energy in these processes is to use EU programs creating sustainable development, energy and climate policy. The LIFE NEXUS programme, which outlines the objective of improving the energy balance of the municipal water cycle, including energy recovery in water systems using micro-hydropower technology, is an example of programmes that open up such opportunities

   It is also necessary and justified to reach for external funds, such as those of the Polish Centre for Research and Development (Narodowe Centrum Badań i Rozwoju, NCBR) funds or subsidies covered by EU programs. The participation of IMP PAN in the LIFE NEXUS program makes it possible to draw on European and world experience in the field of energy recovery lost in technological processes of water supply and sewage companies

5.2. Energy recovery in a DWTP using an innovative micro-hydropower system based on the integration of a Pump as Turbine and the energy storage

Introduction

European hydrological planning policies have traditionally been based on increasing the availability of water resources and the capacity to regulate them. In the case of the urban water cycle (UWC), these approaches have led to a gradual depletion of the resource (overexploited aquifers), loss of quality of water provisioned, deterioration of aquatic ecosystems and conflicts between users motivated by the existence of conflicting interests. In recent years, water and sewage treatment operators across Europe have been forced to use more energy intensive processes as a consequence of expanding water quality legislation [1]. Metropolises around the world are also facing global change pressures due to climate change and water scarcity, which are making it a challenge to continue to deliver core urban water services without increasing the impact on the natural environment. In addition, much of the water and wastewater infrastructure in the developed world is now over 50 years old and needs replacement, upgrade or repair. The importance of water losses in the overall total distributed water is well known. The amount of water leaked in water distribution systems varies widely between different countries, regions and systems, from 3–7% of distribution input in the well-maintained systems to 50% and even more in some undeveloped countries and less well-maintained systems [2]. Extreme temperatures due to climate change and infrastructure aging will enhance the problem of water leakage and confirm the need to control and reduce leakages in the drinking water networks.

In general, all the above-mentioned threats looming over the UWC shown imply an increase in the energy consumption and operating cost. However, to date, limited analyses of the energy implication of water strategies have been undertaken and energy use is rarely mentioned in urban water strategies, despite considerable public commitment and efforts from individual utilities. It is clear that planners must now consider the energy implications in decision making on the water system. Sustainable solutions to these challenges need to be sensitive to long-term investment needs, but also to increasing energy prices, demands for low carbon intensity solutions, and the need to reduce greenhouse gas (GHG) emissions from urban activities.

The potential of energy savings in the UWC, and in the water transport in particular is very significant. Water is a natural carrier of heat and energy gradients, which could be re-used to improve energy efficiency in several ways. The water-energy needs to be considered at all levels, from the overarching water management (combining smart-water and smart-energy), to new solutions in various steps of the water chain.

LIFE NEXUS project is focus on the energy harvest from the UWC stages than implies water movement: catchment, distribution, collection and discharge. The project is evaluating the technical / economic and environmental feasibility of the energy recovery potential available in the previous mentioned four types of locations by means of Small Hydropower Plants (SHP). Among the different available machines (traditional turbines or adapted machines) LIFE NEXUS demonstration will be focus on the innovative Pump as Turbine (PaT), a type of adapted machine, that is be-coming the technological solution for micro-hydraulic projects (≤ 100 kW). The main advantages of these machines are their immediate availability for installation and lower cost compared with conventional ma-chines.

A cutting-edge integration of a PaT machine together with battery storage is being carried out to enhance the possibilities of the energy management. This innovative system will be installed at the entrance of the Porma Drinking Water Treatment Plant (DWTP) located in Valdefresno, a small village nearby the city of Leon (Spain). Once they will be fully operating the energy generated will cover the total energy demand of the installation. This paper is focus on (1) the design of the PaT prototype, including the selection of the pump, (2) the definition of the hydraulic operation and (3) analysis of energetic production and optimization of energy scenarios.

Materials and Methodology

The demosite is located at the DWTP of Valdefresno in León (Spain). The plant is supplied by a diversion of water from the Porma River with a height difference of 16 m. The transport pipe between the diversion dam and the DWTP is approximately 33 km long. The PaT prototype will be located at the entrance of the DWTP, replacing an existing PRV (see Fig.1). The DWTP consists of five treatment stages: (1) Pre-oxidation, carried out with sodium hypochlorite, (2) Coagulation/ Flocculation, carried out by adding aluminum polychloride, (3) Flotation, sludge separation is done in the eight floats, not in decanters, (4) six sand filters (see Figure 1) and (5) final disinfection with sodium hypochlorite. The DWTP annually treats an average volume of 8.146 hm^3/year.

Results and Discussion

PaT prototype design and pump selection

The pump was chosen considering the resistance curve at the entrance of the DWTP, with 25.5 kW of nominal power (45 kW maximum power). The information from the projected installation and the estimation of annual energy generated is shown in the table below:

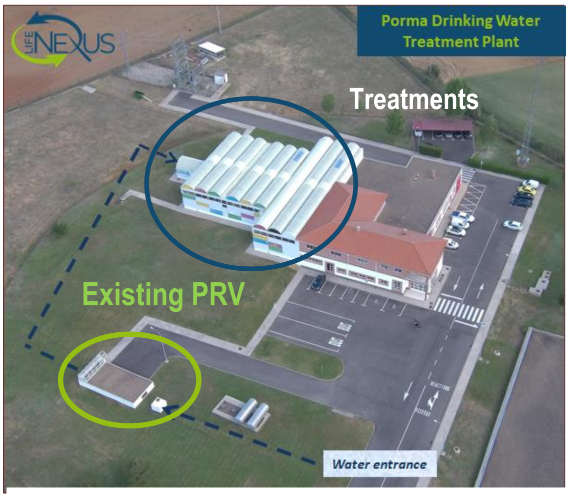
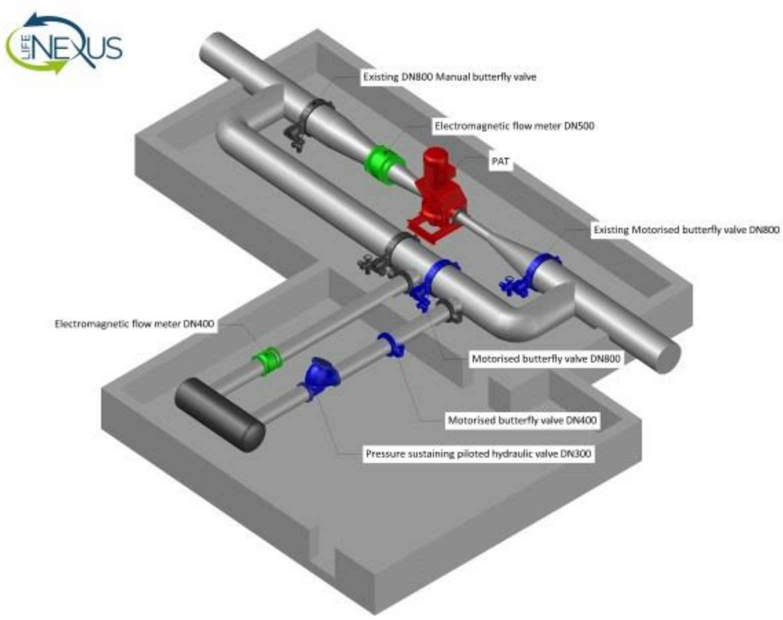


Fig.1. Porma DWTP demosite

Table 1. Data of projected installation and annual energy generated

Parameter	Value
Average available flow (m^3/h)	853
Average available hydraulic jump (mwc)	18.3
Average hydraulic energy available (MWh/year)	372
Average power generated hourly P2 (kW)	28.9
Hours of work per year	8,724
Annual energy generated (MWh/year)	252
Performance with respect to potential	68%
Performance PaT	81%
Averaged turbined flow (m^3/h)	738
Average hydraulic jump in PaT (mwc)	16



To operate the system, it will be necessary to install an inline valve (PRV) downstream of the PaT connected in series with it, and another pressure sustaining valve which enables the regulation of the flows in the PaT's bypass (see Fig.2):

Fig.2. PaT prototype

Proposed installation and hydraulic operation

The pressure sustaining valve in the by-pass has the function of diverting excess flow in the main line. By diverting part of the flow, it manages to fix the flow rate through the PaT, fixing at the same time the jump in this machine and the power generated whilst maintaining the network pressure o within the current operating range. The inline valve has the function of ensuring the necessary downstream pressure, therefore, de-pending on the scenario; it will regulate its opening to achieve the necessary pressure (see Fig.3):

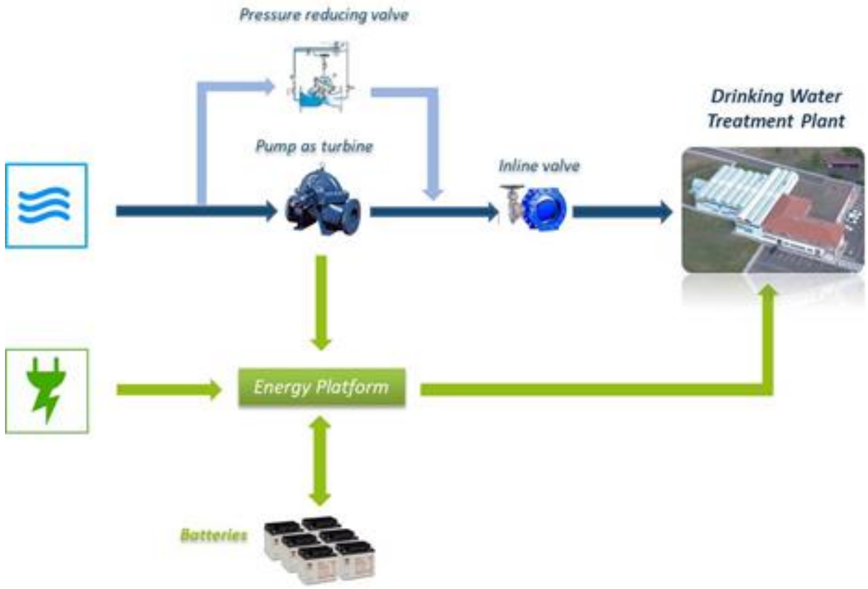


Fig. 3. Hydraulic operation of the PaT prototype

Two hydraulic scenarios of operation have been defined depending on the flow needed by the installation and the averaged turbined flow of 205 l/s (738 m^3/h):

Scenario 1 (Inlet flow ≤ 205 L/s): all flows between 115 l/s and 205 l/s will pass through the PaT and the in line valve, which will be regulating until it can maintain the necessary downstream pressure of 3 m w.c. (Fig.3). This opening will depend on the demand flows of the plant, but will always guarantee the pressure consigned at the plant inlet. In this scenario, no water will enter the by-pass and, therefore, the pressure sustaining valve in the by-pass will be completely closed.

Scenario 2 (Inlet flow > 205 L/s): in this scenario, a stable flow of 205 l/s (738 m3/h) will pass through the PaT and the valve in-line will be completely open, being 100% open this valve will not regulate. The downstream pressure of this valve should be 3 m w.c., the same as in the previous scenario. In this case, all volumes greater than 205 l/s (738 m3/h) will go through the by-pass. The pressure sustaining valve situated in the by-pass will regulate its opening depending on the flow which goes through the by-pass and its down-stream pressure. This valve's operating range will vary between 54% and 29% of opening.

Analysis of energy production and simulation of energy scenarios

The analysis of the operation of the PaT system was established together with a system of batteries that accumulate the energy in periods when more energy is generated than consumed by the DWPT. The objective is to study the energetic advantage when renewable energy can be accumulated for its later consumption in the facility, leading to less consumption from the grid, a greater degree of energetic self-sufficiency and a reduction in energy costs. For that, the charge curve (energy demand) of the Porma DWTP was analysed (Fig. 4). As it can be seen, in the Quarter hourly-charge curve over the year, powers of 50 kW are consumed sporadically every two days approximately and mean between 20 and 30 kW of extra consumption on the immediate consumption. This periodic peak consumption takes place in the equipment related to the sand filters washing: backwash pumps and blowers.

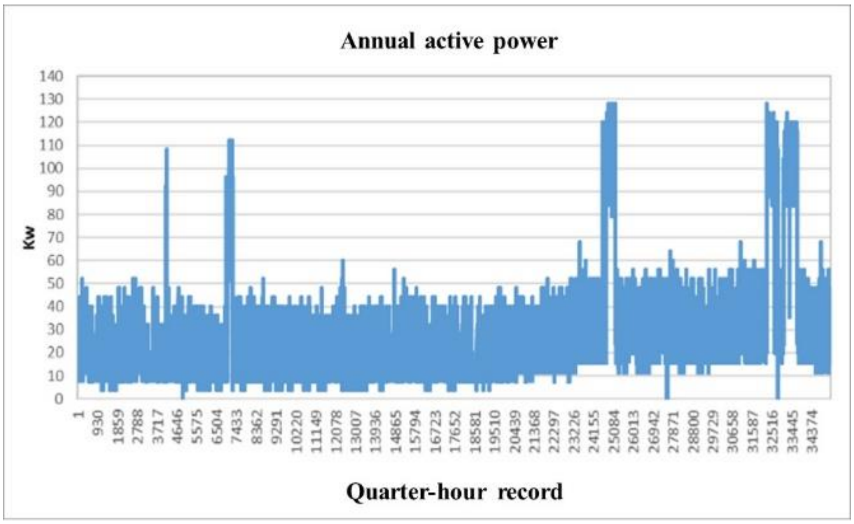


Fig. 4. Load curve for the DWTP

These machines start up every time it is necessary to clean the filters, which is approximately every two days and they work for 6 minutes, first the pump and afterwards the blower for 6 minutes. As the washing filter system is integrated by 2 lines (pump and blower) which operate alternately, demand is not exactly the same every day. It is about avoiding these consumption peaks, taking advantage of the energy generated in the turbine, which will normally be greater than the immediate energy consumed in the DWTP, accumulating that excess energy in the batteries to make the most of it during that occasional periodic demand. By doing so, it is believed that it would be possible to reduce the peak power required in the DWTP the majority of the year, which means a benefit for the electric grid given that it stabilises demand and a possible benefit for the DWTP reducing the need to contract high powers and thus reducing the energetic cost.

In conclusion, a hybridisation via batteries has been designed, modifying the system through the incorporation of a frequency converter in the head of the four units (2 backwash and 2 blower pumps). A charge regulator has also been included which will be responsible for slowly the batteries slowly and discharging them in in a matter of minutes. Lastly, the batteries have been dimensioned so they can supply the demanded energy for the equipment over the time they are operating.

Simulation of energy scenarios

Usually the energy generated in the PaT is greater than the instantaneous energy consumed in the DWTP so the production will be used to cover this demand (See Fig. 4). The excess energy will accumulate in the batteries to take advantage of it during that periodic punctual demand that corresponds to the consumption peaks of the washing filter system. With the aim of minimizing the network contribution and optimizing the use of energy storage, the behaviour of the PaT-storage system has been evaluated in a dynamic simulation environment (TRNSYS) by carrying out a series of models that represent different configurations and operating scenarios.

First, a PaT model has been generated, which, depending on the flow rate and its operating restrictions, provides the power and energy generated and, on the other hand, the outlet pressure. For this, we have started from the information of the operating curves provided by the manufacturer:

$$P=0.0001 \cdot Q^2-0.0079 \cdot Q-2,3928 \quad (1)$$

$$\Delta H=0.000029 \cdot Q^2-0.012776 \cdot Q+7.949 \quad (2)$$

with P as the electrical power output (kW), Q - water flow (m^3/h) and ΔH (m w.c.) - head. As operating restrictions, it has been considered that the turbine operates in the flow range that goes from 115 l/s and 205 l/s. For higher flow values, the bypass branch is opened to limit the maximum flow that passes through the turbine as explained in the hydraulic scenario 2.

The model input data are the flow records that enter the DWTP and the hourly energy demand values collected over a year (simulation period, Fig. 4). The model generates as outputs the energy balances and the operating status of each of the systems (operating regime, load level, etc.) including the needs for energy exchange with the grid.

Then, it has been carried out the development of a model of the total system. In the TRNSYS dynamic simulation environment, the different models of the elements of the DWTP installation have been integrated: PaT, batteries and different loads (backwash pumps, blowers, lighting, etc.). In this model, the inter-connections between the elements have been made and the controllers that guarantee the safe operation of the system have been included.

Two basic operation schemes have been established, depending on the interaction between storage and the rest of the installation (see Fig. 5):

- In the first case (Fig. 5a) it is considered that the battery system exclusively supplies the demands of the pumps and the blower of the cleaning equipment (as initially planned).
- In the second case (Fig. 5b) the battery power can be used to cover the overall needs of the system.

In both cases, the PaT discharges its energy into the internal network of the system, allowing it to power the different loads and charge the battery. Energy imbalances are exchanged with the grid:

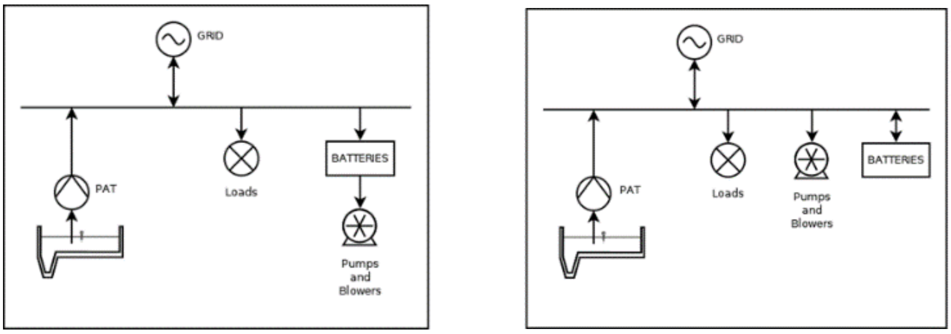


Fig. 5. Basic operation schemes

Figure 6 shows the TRNSYS model used. In each of the cases considered above, the internal control programming is modified to establish the energy flows and the final balances

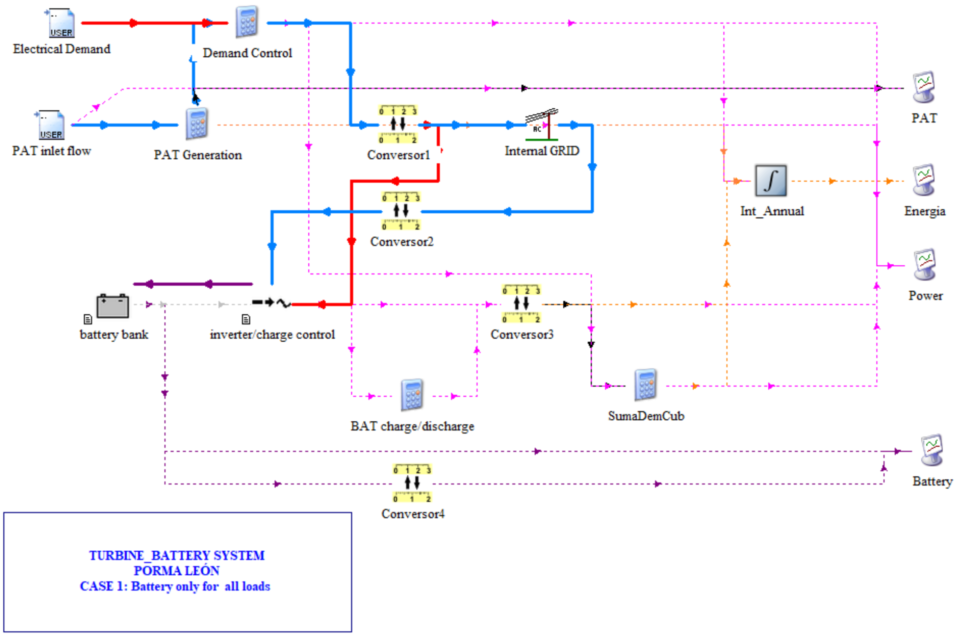


Fig. 6. TRNSYS model. Case 1

Finally, from the simulation of the developed models, a sensitivity analysis is being carried out, varying the key design and operation parameters (battery size, hours of use of the equipment, weather conditions, etc., allowing the analysis of the flows of energy produced in the different scenarios. This phase is currently under development and will allow establishing the best operating strategies for the system and identifying improvements in the implementation of battery-powered PaT systems in other locations. Note that the simulation data will be verified with the measurements obtained from the data of the real system when it is operational.

References

1. Zakkour, P.D., Gaterell, M.R., Griffin, P., Gochin, R.J. and Lester, J.N. Developing A Sustainable Energy Strategy for A Water Utility. Part II: A Review of Potential Technologies and Approaches. J. Environ. Manag. 2002, 66, 115–125.
2. Covas D., Ramos H. Practical methods for leakage control, detection and location in pressurised systems. 1999. www.civil.ist.utl.pt/~hr/bhrgroupEdin.pdf.

Authors

1. **Luis Angel Bujedo** is industrial engineer and MEng. It has over 25 years working in the efficient use of energy in CARTIF. Participates in several energy platforms PTE-EE, Task 38, and has experience in energy facilities, both industrial and buildings. He has given conferences and training on solar cooling energy efficiency in buildings. Has the capacity to provide training of trainers on energy efficiency in buildings.
2. **Jesús Samaniego** received the Electrical Engineer´s Degree in 2002, and the MEng in the Automatic Control and Systems program in 2004, both from the University of Valladolid. He has worked as R&D engineer and Project Manager in the Energy Division of CARTIF since 2002, where he has participated in several National and European R&D projects in the fields of energy efficiency, renewable energies simulation and integration in buildings and in the electrical grid, demand response programs and power quality energy. He is author of several publications about energy efficiency and renewable energies.
3. **Raquel López Fernández.** PhD in Chemistry. In 2005 she became full-time staff in the Environment Division of CARTIF Technology Centre and leaded the research line related to water and wastewater treatment. In 2015 she moved to the Energy Division in CARTIF and since then, her work is related to water-energy Projects and Smart Cities initiatives. Currently she is the Coordinator of the LIFE NEXUS project.
4. **Víctor Iván Serna González**. MSc in Telecommunications Engineering. He has been working in the Environment Division of CARTIF Technology Centre from 2007 as Project Manager and R&D engineer participating in several National and European R&D projects related to the use of ICT technologies and data analysis applied to energy efficiency management, in particular in ICT solutions for energy efficiency, renewable energy systems integration in buildings and Smart Grids and development of tools for energy planning.
5. **Mariano Mirete**. Expert in design, execution and commissioning of pumping installations, solar pumping, photovoltaic solar installations for self-consumption and turbine installations in drinking water networks. Energy audits and bill optimization in AQUATEC.
6. **Josep Pages.** Expert in design, execution and commissioning of pumping installations, solar pumping, photovoltaic solar installations for self-consumption and turbine installations in drinking water networks. Energy audits and bill optimization in AQUATEC.

5.3. Water turbine application in MPEC Cracow heating networks

Extensive district heating systems require monitoring, telemetry and connection of heating chambers to the SCADA system. In order to properly manage the district heating network, technical services should know the current situation in the heating network. Transferring information to the control room allows you to take quick and effective action, and thus reduces the possibility of failure and limits its consequences. To ensure proper operation of the monitoring and control system of the heating network, electricity should be supplied to the heating chambers. It should be noted that introducing a voltage of 230 V or 400 V into a room that may be flooded with water is risky.

The solution that has been used in MPEC Cracow is installation of TPC systems (Turbine Pressure Regulators) to generate electricity for the needs of the 24V DC heating chamber. Using the energy of flowing water, electricity is generated in the hydraulic unit. The AC current in the rectifier unit is converted into DC current and directed to the voltage regulator and then to the battery where energy is stored for the needs of the chamber operation.

In 2021, the TPC system installed in the 1WKVII1A chamber was put into operation. The chamber has no connection to the power grid and the generated current supplies the devices in the chamber. The chamber is fully autonomous, regulates the available pressure on the heating main branch, has communication and telemetry in the SCADA system, lighting, flood sensors, etc. The effects of the autonomous chamber work will be presented in the planned article and paper

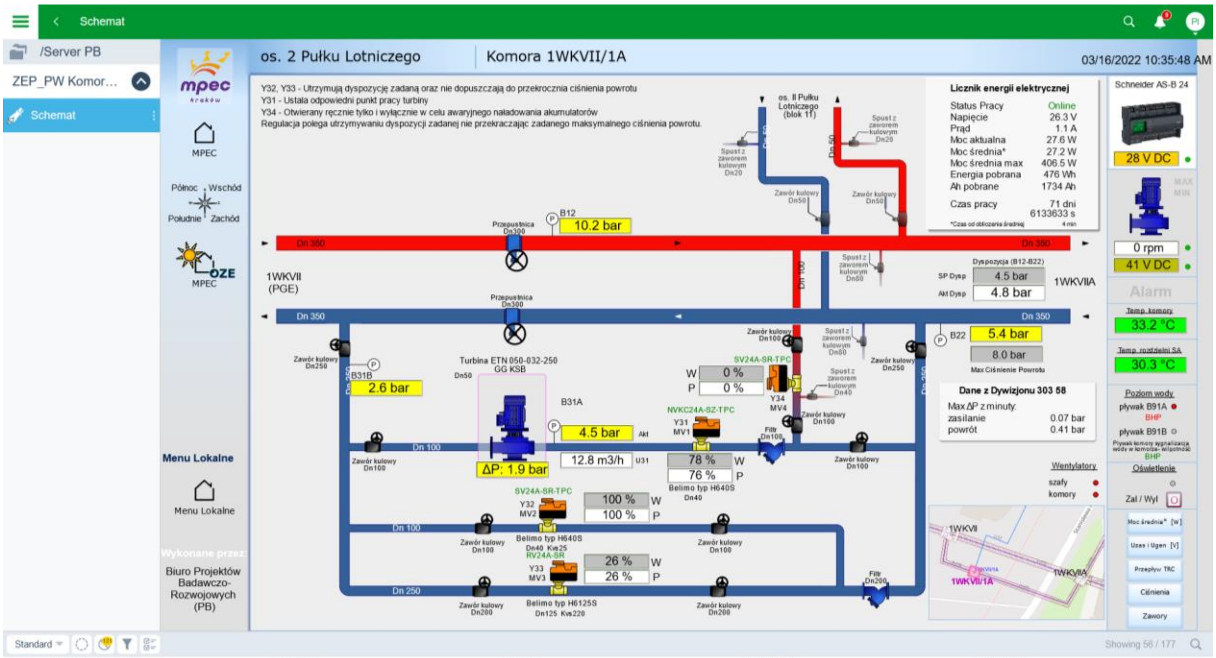


Fig.1

Kombatantów 18 is a building of the old disused network pumping station, which after refurbishment of the heating network was decommissioned several years ago. Currently, an automatic return support system is installed there. Because the district heating network supplies residential buildings on a hill and there exists some fear of too low pressure on the return, the above-mentioned control system has been installed.

The Kombatantów 18 building is passed through by the DN 500 district heating network (Fig. 1). A return support with a control valve has been installed here. A system with two turbines 200 T/h and 400 T/h has been deployed. If flow greater than 600 T/h is required, an additional bypass of the system is used. The experience gained from previous TRC installations indicates that it is better to undersize the turbine than to oversize.

At the moment this text is being written (November 2022), the work on the construction of the system is advanced in about 80%. The hydraulic system and most of the electrical system have been already assembled.

Fig.2

Author

Mariusz Piękoś, M.Sc., Eng., graduated from the Faculty of Mechanical Engineering of the Cracow University of Technology in 1987. Since 1989 he has been employed at the Municipal Thermal Energy Company (MPEC) in Cracow, working in the Technical Analysis Department. Since 2019, he has been working in the Research and Development Project Office of MPEC Kraków. In 2019 he started his doctoral studies. In 2012, he patented the invention "System of distribution of liquids and gases" describing the method of using turbines recovering energy from flowing media.

6. Research activities and innovative technologies - The analysis of flow phenomena taking place in a centrifugal pump run in turbine mode of operation

Introduction

Hydropower is one of the oldest energy sources used in the world. It is renewable, ecological and independent of fossil fuels. The technology of energy production from water, both mechanical and electrical, due to the fact that it has been developed for a long time, stands at a very high technical level. In the global generation balance, hydropower accounts for about 16% of global production [1]. Despite many advantages, it also faces many problems, especially larger hydropower plants, the construction of which often requires very large financial outlays, which translates into long payback periods. In addition, it involves the need to flood large areas, which brings with it many social and ecological problems. Therefore, the possibility of building large hydropower plants, although beneficial due to economies of scale, cannot always be implemented for economic, social, political or ecological reasons. As a result, interest in small-scale hydropower use, including the possibility of recuperating hydraulic energy using pumps, has increased rapidly in the last decade.,

The paper presents the results of numerical modeling of flow phenomena occurring in a centrifugal pump operating in both the pump and turbine regimes. Full performance characteristics, both in pumping and turbine mode of operation, have been determined. In addition, on the basis of the obtained results, an analysis of available models of conversion of pump characteristics into turbine ones was carried out.

Investigation goal

The aim of the research was to identify and analyze flow phenomena in a centrifugal pump operating in the pump and turbine regimes. The research was carried out using numerical flow simulations. The simulations of the pump in normal operation mode were the basis for verification of conversion algorithms available in the literature. In addition, the pump characteristics provided by the manufacturer were used as a basis for verification of numerical simulations. The study contains a summary of the results of numerical simulation research and their analysis along with comparisons and assessment of the accuracy of conversion models available in the literature [2], [3].

Analysed object

The subject of research is a typical impeller pump - single-stage, centrifugal. The pump model is shown in Figure 1. The pump has not undergone any geometry modifications. Tests of the pump unit, both in pumping and turbine operation, were carried out in the entire range of operating characteristics, which was assumed from $0.2Q_n$ to $1.4Q_n$. The nominal flow (Q_n) has been determined separately for both operating modes

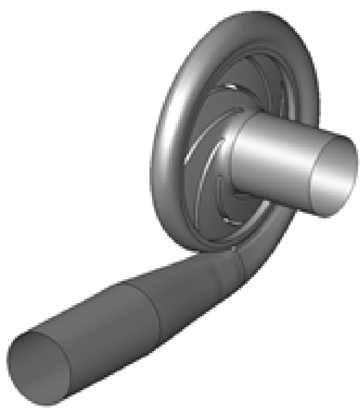


Fig.1 Pump geometry model

Numerical model

The simulations were carried out for a model divided into two domains: stationary (spiral case) and moving (impeller). The numerical grid was developed according to all recommendations of the selected turbulence model (k-Omega SST). The Y+ values in the boundary layer of both the impeller and the spiral case were below 1. The calculations were carried out as stationary. The SIMPLE calculation algorithm was used, all discretization methods were selected as the second order ones. The turbulence model and solver settings were selected based on the recommendations available in: A Performance Prediction Method for Pumps as Turbines (PAT) Using a Computational Fluid Dynamics (CFD) Modeling Approach [4].

Results of numerical simulations for the optimum operation point

The optimal point was employed to establish the reference discharge value used to assess the quality of the pump in turbine mode of operation. Visualizations of simulation results are presented in Figs 2, 3 and 4. In the case of turbine operation, there are much more intense recirculation zones in the optimum point compared to the pump operation mode (Fig. 4). The pressure distribution in the impeller (Fig. 2) is definitely more stable and does not show large anomalies. Areas with dead flow zones are imperceptible.

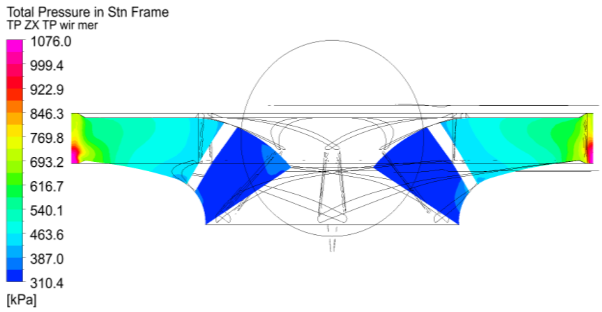


Fig. 2 Total pressure distribution – impeller – turbine operation

Summarisation

The conducted analyses allowed for qualitative and quantitative analysis of the tested pump in turbine regime. Numerically determined characteristics allowed for the verification of conversion methods available in the literature. In most cases, they allow for a rough determination of potential pump characteristics in turbine motion. Based on the conclusions from other publications, it can be concluded that different calculation methods have variable accuracy of calculations, which is a function of the specific speed. Future work should focus on developing a uniform, more accurate calculation method that is valid for a wide range of specific speeds.

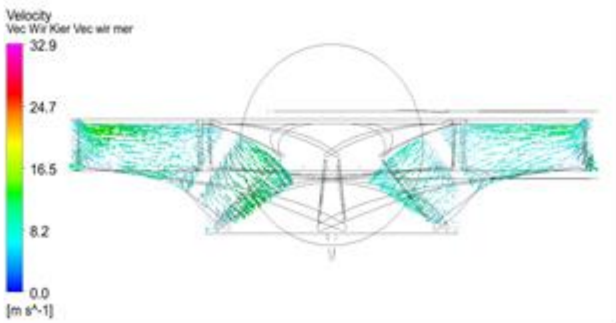


Fig. 3 Velocity vectors – impeller – turbine operation

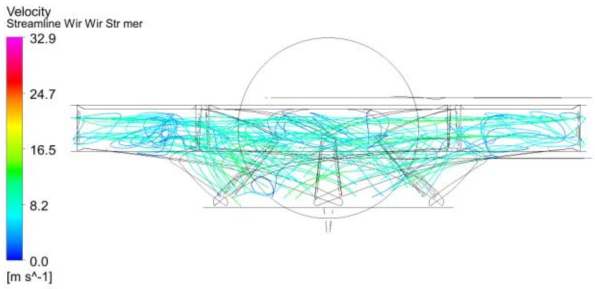


Fig. 4 Stramlines – impeller – turbine operation

References

1. Statistical Review of World Energy, 69th edition 2020
2. Sanjay V. Jain, Rajesh N. Patel: Investigations on pump running in turbine mode: A review of state-of-the-art, Renewable and Sustainable Energy Reviews 30 (2014) pp 841-868.
3. S. Stelzer, R. N. Walters: Estimating Reversible Pump-Turbine Characteristics, Engineering Monograph No. 39
4. Emma Frosina, Dario Buono, Adolfo Senatore: A Performance Prediction Method for Pumps as Turbines (PAT) Using a Computational Fluid Dynamics (CFD) Modeling Approach, Energies 2017, 10, 103; doi:10.3390

Authors

Artur Machalski, Ph.D., Eng., in 2022 he was granted the PhD degree in technical sciences by the Wrocław University of Science and Technology. Professionally deals with flow machines and hydraulic systems

Janusz Skrzypacz, DSc., Eng., graduated in 1997 from the Faculty of Mechanical Engineering of the Wrocław University of Science and Technology. In 2002 he was granted the PhD degree in technical sciences. Since 2000 he has been associated with the Faculty of Mechanical and Power Engineering of the Wrocław University of Science and Technology which granted him the doctor of science (DSc) degree in 2015. Professional interests include hydraulic fluid-flow machines and their systems, piping and pressure equipment

Przemysław Szulc, Ph.D., Eng., graduated from the Faculty of Mechanical and Power Engineering of the Wrocław University of Science and Technology. In 2014 he was granted the PhD degree in technical sciences. Professional interests include hydraulic fluid-flow machines and their systems

Marcin Janczak, Ph.D., Eng., graduate of the Faculty of Mechanical and Power Engineering of the Wrocław University of Science and Technology. In 2009 he was granted the PhD degree in technical sciences. Currently Head of the Research and Development Department of Hydro-Vacuum S.A, Grudziądz, Poland.

Witold Lorenz, Ph.D., Eng., graduate of the Faculty of Mechanical and Power Engineering of the Wrocław University of Science and Technology. In 2011 he was granted the PhD degree in technical sciences by the same University. Currently, the chief specialist for numerical calculations in the Research and Development Department of Hydro-Vacuum S.A. Grudziądz, Poland.

Fundusze Europejskie Inteligentny Rozwój
Rzeczpospolita Polska
Narodowe Centrum Badań i Rozwoju
UNIA EUROPEJSKA EUROPEJSKI FUNDUSZ ROZWOJU REGIONALNEGO

The project is co-financed by the European Regional Development Fund
under the Smart Growth Operational Programme 2014-2020

7. Final remarks

The research conducted so far within the Life NEXUS project shows beyond any doubts that there exists still a significant untapped and only partially identified hidden hydropower potential in European municipal and industrial water circuits. The Life NEXUS project has provided an excellent tool for storing the relevant data on this potential. However, the data comprised so far in the project database is by far not complete. Therefore it is recommended to develop the database further on also within the next EU projects and other contracts.

Investing in energy recovery micro-hydropower installations in municipal and industrial water circuits shows numerous techno-economic advantages in comparison with classic installations of the same size. However, there are some important features that may increase the outlays required for an installation. Firstly, one should always bear in mind that most locations in the municipal water circuits are of critical nature. The principal task of the existing installation is to transport safely drinking or wastewater. Electricity generation is always of secondary significance and therefore the energy recovery unit is often installed on a bypass pipeline in order to ensure unaffected water transport in case of unit failure or overhaul. In case of long conduits special precautions are needed to make dangerous hydraulic transients due to any malfunction of the unit or the grid. Due to these and other reasons the simplified solutions are needed to keep the micro-installation projects economically viable. These include specialised in-conduit hydroelectric units and pumps in turbine mode of operation (PATs). In-conduit units are often well suited for low and medium head installations whereas centrifugal PATs are typically used for medium and high heads. Cross-flow hydrokinetic units are sometimes recommended for installations at WWTP discharge.

The potential energy recovery sites in municipal water and sewage networks are usually featured by variable discharge. In case of some intake to the drinking water reservoirs or treatment plants also the head may show substantial variability. Therefore proper regulation of the whole installation is quite essential. In case of a centrifugal PAT used as a hydraulic unit the throttling technique is often the only one available. This means regulation valves have to be applied both upstream the unit and on the main pipeline (parallel to the unit). Due to variation of operating parameters one may count that 60 to 70 % of the raw energy available can be often further converted. Annually averaged efficiency of converting the total energy available in cases under considerations by the IMP PAN is between 40 and 50 %.

The efficiency of energy conversion can be increased sometimes by using the storage capacities in the installation. In case of feeding the internal grid, electrochemical batteries as planned in Porma plant may be a good choice. The batteries can also increase installation safety in case of grid failure. However, using a relief pipeline with swift relief valves, e.g. membrane ones, is often the only reliable safeguard against hydraulic transients following a failure resulting in hydroelectric unit runaway.

Appendicies

- HYDROFORUM and Life NEXUS Symposium poster
- Invitation sent to Polish Stakeholders
- Invitation sent to International Stakeholders
- Symposium Agenda
- List of Symposium Participants

HYDROFORUM and Life NEXUS Symposium poster

HYDRO FORUM

Towarzystwo Elektrowni Wodnych

IMP PAN GDAŃSK

TRMEW

Polish Hydropower Conference

HYDROFORUM 2022

Warsaw, Witkowski Hotel, 26-28th October 2022

The provisional programme includes, but is not limited to:

- legal/economic constraints and development strategy
- HYDROFORUM Debate:
  Hydropower and energy system safety
- experience on design, erection and operation of hydropower plants, machinery and equipment
- technical innovations and research&development activities
- study visit to Dębe Hydropower Plant

Please reserve the date and follow our websites: www.tew.pl, www.imp.gda.pl, www.trmew.pl. Registration and further information are available at the following address: **Polish Hydropower Association Office**, ul. Piaskowa 18, PL 84-240 Reda, phone: +48 58 678 79 51, e-mail: biuro@tew.pl. Proposals and abstracts of contributions to the HYDROFORUM 2022 event are to be submitted to the **Szewalski Institute of Fluid-Flow Machinery of the Polish Academy of Sciences**, ul. Fiszera 14, PL80-231 Gdańsk, phone: +48 58 5225 139, e-mail: steller@imp.gda.pl

PAN POLSKA AKADEMIA NAUK | SEP | JEN | Faculty of Building Services, Hydro and Environmental Engineering, Warsaw University of Technology | PGE Energia Odnawialna S.A. | Państwowe Gospodarstwo Wodne Wody Polskie

LIFE NEXUS

Harvesting energy in municipal and industrial water cycles

International Symposium of the Life NEXUS project, Warsaw, October 27th, 2022

The provisional programme includes, but is not limited to the following topics:

- hidden hydropower potential
- technologies of hydraulic energy recovery
- good practices and case studies
- economic aspects

CARTIF | IMP PAN GDAŃSK | VYTAUTAS MAGNUS UNIVERSITY MCMXXII | AQUATEC | Aguas de León

The symposium will constitute a component of the HYDROFORUM 2022 event, planned for the afternoon, 27th October 2022. For further details please follow the IMP PAN, TEW and Life-NEXUS websites as well as those of some of our partners.

Izba Gospodarcza WODOCIĄGI POLSKIE | zek | ENERGETYKA WODNA

The Life NEXUS project is co-funded by the European Union within the framework of LIFE Environment and Resource Efficiency programme (contract no. LIFE17 ENV/ES/000252)

document HF 0_2E

Invitation sent to Polish Stakeholders

HYDRO FORUM

Polska Konferencja Hydroenergetyczna

HYDROFORUM 2022

Sympozjum Projektu Life NEXUS

Towarzystwo Elektrowni Wodnych

TRMEW

iha affiliate member

Hotel „Witkowski", Warszawa, 26-28 października 2022 r.

Do Przedsiębiorstw Gospodarki Komunalnej i Wodno-Kanalizacyjnych

Do właścicieli i użytkowników instalacji wodociągowych i oczyszczalni ścieków

Do osób i instytucji zainteresowanych w odzysk energii rozpraszanej w tych instalacjach

ZAPROSZENIE

Szanowni Państwo,

Jak mieliśmy już okazję informować, Instytut Maszyn Przepływowych PAN, wspólnie ze swoimi partnerami hiszpańskimi, litewskimi i krajowymi, realizuje już od kilku lat projekt *Life NEXUS*, którego celem jest inicjowanie działań zmierzających do odzysku energii traconej w miejskich instalacjach wodociągowych i kanalizacyjnych. Jak wskazuje pełna nazwa projektu,

Boosting the sustainability of the urban water cycle:
energy harvest in supply networks using micro-hydropower systems,

chodzi o poprawę bilansu energetycznego poprzez odzysk energii traconej w węzłach redukcyjnych sieci wodociągowych lub na odprowadzeniu wody do zbiorników naturalnych i sztucznych (np. na odpływie wody w oczyszczalniach ścieków). Odzysku tego dokonuje się zwykle poprzez zastosowanie hydrozespołów stosowanych w małej energetyce wodnej. Szczególne miejsce wśród dostępnych technologii zajmują pompy w ruchu turbinowym. Instytut Maszyn Przepływowych PAN dysponuje w tej dziedzinie dość sporym doświadczeniem, sięgającym jeszcze początków lat osiemdziesiątych.

Projekt Life NEXUS (LIFE17 ENV/ES/000252, *https://www.lifenexus.eu/*) jest koordynowany przez Centrum Technologiczne CARTIF (Valladolid, Hiszpania) i współfinansowany ze środków instrumentu finansowego LIFE Komisji Europejskiej. Jednym z zadań jest budowa bazy danych o lokalizacjach, w których odzysk energii w obiegach wodnych jest możliwy lub już ma miejsce. Innym – budowa instalacji pilotowej, a także opracowanie szeregu przedwstępnych studiów wykonalności dla instalacji wykorzystujących taką samą lub podobną technologię.

Sekretariat Konferencji
Biuro Towarzystwa Elektrowni Wodnych
ul. Piaskowa 18, 84-240 Reda
tel.: 58 67 87 951, kom.: 605 56 55 86
e-mail: biuro@tew.pl

Informacje dla autorów
Instytut Maszyn Przepływowych Polskiej Akademii Nauk
ul. Fiszera 14, 80-231 Gdańsk,
tel. 58 52 25 139; kom.: 608 19 71 85
e-mail: steller@imp.gda.pl

W ramach tego samego projektu przewidzieliśmy również organizację sympozjum międzynarodowego, którego cele sformułowaliśmy następująco:

a) rozpowszechnianie idei i technologii odzysku energii rozpraszanej w miejskich i przemysłowych obiegach wodnych;

b) wymiana doświadczeń i opinii między dostawcami technologii i projektantami instalacji odzysku energii w miejskich i przemysłowych obiegach wodnych;

c) podsumowanie i rozpowszechnienie wyników już osiągniętych w ramach projektu;

d) omówienie wyników prac badawczo-rozwojowych.

Sprawa odzysku energii rozpraszanej w komunalnych i przemysłowych instalacjach hydraulicznych ma charakter interdyscyplinarny i jest bliska reprezentantom szeregu sektorów gospodarki i dziedzin techniki – w szczególności reprezentantom sektora gospodarki komunalnej, inżynierii sanitarnej, inżynierii środowiska, hydroenergetyki. Ostatecznie zdecydowaliśmy się na organizację sympozjum jako części wydarzenia HYDROFORUM 2022, obejmującego zarówno Polską Konferencję Hydroenergetyczną o tej samej nazwie, jak i sympozjum projektu Life NEXUS. Kierowaliśmy się przy tym związkami tematyki Sympozjum z energetyką wodną, utrwaloną pozycją konferencji HYDROFORUM w kalendarzu spotkań hydroenergetyków w Polsce i w regionie, kontaktami jakie nawiązaliśmy z sektorem wodociągowo-kanalizacyjnym w trakcie realizacji projektu Life NEXUS, jak i presją czasu związaną z harmonogramem realizacji tego projektu.

Liczymy na Państwa udział w naszym wydarzeniu. Mamy nadzieję, że tematyka sympozjum okaże się dla Państwa interesująca, a dyskusja będzie ożywiona. Wciąż oczekujemy na zgłoszenia udziału oraz zgłoszenia Państwa wystąpień, w których podzielicie się z innymi uczestnikami swoja wiedzą i doświadczenie. Zapraszamy również do udziału w całym wydarzeniu HYDROFORUM

Z wyrazami szacunku i serdecznymi pozdrowieniami

dr hab. Janusz Steller

Przewodniczący Komitetu Organizacyjnego
Polskich Konferencji Hydroenergetycznych

Prezes Zarządu
Towarzystwa Elektrowni Wodnych

zał.:

komunikat HYDROFORUM 2022,

formularz rejestracyjny,

wskazówki dla autorów,

oferta sponsoringu

Invitation sent to International Stakeholders

HYDRO FORUM

Polish Hydropower Conference
HYDROFORUM 2022
Life NEXUS Project Symposium

Towarzystwo Elektrowni Wodnych

Witkowski Hotel, Warsaw, October 26-28th, 2022

iha affiliate member

Gdańsk, 17 October 2022

To Municipal Management Enterprises

To Owners and Users of Water Supply and Wastewater Treatment Installations

To persons and institutions interested in the recovery of energy dissipated in these installations

INVITATION

Dear Stakeholders,

It is since the fall of 2018 that the Szewalski Institute of the Fluid-Flow Machinery of the Polish Academy of Sciences (IMP PAN) together with its Spanish, Lithuanian and Polish partners is involved in the *Life NEXUS* project aimed at initiating activities oriented on recovery of energy lost in municipal water supply and sewage installations. As shown by the full name of the project,

Boosting the sustainability of the urban water cycle:
energy harvest in supply networks using micro-hydropower systems,

the final goal is to improve the energy balance by recovery of energy lost at pressure at water supply network pressure reduction sites and water outlets to the natural or artificial reservoirs (e.g. at the water outlet of waste water treatment plants). Typically, the energy recovery takes place by means of hydraulic units usually applied in the small hydropower sector. Due to various reasons, the use of pumps in turbine mode of operation is of particular significance. The experience of Szewalski Institute of Fluid-Flow Machinery of Polish Academy of Sciences in this field dates back as far as the beginning of 1980-ies..

The Life NEXUS (LIFE17 ENV/ES/000252, *https://www.lifenexus.eu/*) project is co-ordinated by the CARTIF Technological Centre in Valladolid, Spain. The project is co-funded by the LIFE financial instrument of the European Commission. One of the main tasks is development of a database on potential and already existing energy recovery sites in municipal and industrial water cycles. The other task is development of a pilot installation, and a number of prefeasibility studies for installations using the same or similar energy recovery technology.

Conference Secretariat
Polish Hydropower Association Office
ul. Piaskowa 18, 84-240 Reda, Poland
phone: +48 58 67 87 951,
mobile: +48 605 56 55 86
e-mail: biuro@tew.pl

Information for authors
Szewalski Institute of Fluid-Flow Machinery, Pol.Ac.Sci.
ul. Fiszera 14, 80-231 Gdansk, Poland
phone: +48 58 5225 139;
mobile: +48 608 19 71 85
e-mail: steller@imp.gda.pl

Within the framework of the same project we have envisaged also an international symposium with goals formulated as below:

a) spreading the idea and technology of harvesting the energy dissipated so far in the municipal and industrial water cycles;

b) exchange of experience and opinions between the technology suppliers, designers and developers of the energy harvesting installations in the municipal and industrial water cycles;

c) summarization and spreading of the results already achieved within the project

d) discussing the results of research and development studies.

The problem of harvesting the energy dissipated in the municipal and industrial water cycles is of multidisciplinary nature. Its significance remains quite clear for representatives of a number of industry and technology sectors – especially those coming from the municipal management, environmental, sanitary and hydropower engineering. Eventually, we have decided to arrange the symposium as a part of the HYDROFORUM 2022 event, which will encompass both the Polish Hydropower Conference, traditionally bearing the HYDROFORUM naming, and the Life NEXUS Symposium. Our motivation followed from the links of Symposium main topic with hydropower sector, well established positioning of HYDROFORUM conferences in the annual calendar of Polish and regional hydropower events, contacts established with the water supply and treatment sectors as established in the course of Life NEXUS project, as well as the pressure of Life NEXUS time schedule.

We allow ourselves to expect the symposium topics to be of high interest for you. We count on your presence and contributions, and on a lively discussion. Your contributions will be still highly appreciated within the next few days. Please consult the attached documents for further details. You are cordially invited to take part in the whole HYDROFORUM event as well.

With kind regards and looking forward
to see you in Warsaw

Janusz Steller

Chairman of the Organising Committe
of Polish Hydropower Conferences
an Life NEXUS Symposium

Chairman
of the Polish Hydropower Association

encl.:

1. HYDROFORUM 2022 bulletin,
2. registration forms,
3. guidelines for authors,
4. sponsorship offer

Symposium Agenda

27 October 2022

9:00	**Welcome addresses and opening of the Symposium**

Session LN1: Life NEXUS: assessment of the hidden potential

Session chaired by: **Janusz Steller**, IMP PAN, Chairman of the HYDROFORUM 2022 Organising Committee

9:00 **J. Steller** (IMP PAN/TEW): Welcome address and information from the Organising Committee.

9:10 **P.Sikorski** (IGWP): *Polish Waterworks Commercial Chamber* (PL)

9:30 **R.M. Lopez Fernandez, V.I. Serna González, L.Á. Bujedo, J.Samaniego** (CARTIF), **J. Steller** (IMP PAN), **P.Punys, A.Radzevičius** (Vytautas M. University), **M.Mirete** (Aquatec)**:** *LIFE NEXUS: First European inventory of micro-hydroenergy recovery potential in the water industry*

10:00 **P. Punys, A. Radzevičius** (Vytautas M. University, Kaunas): *Assessment of Hydropower Potential in Wastewater Systems in a Lowland Country, Lithuania*

10:20	**Coffee break**

Session LN2: Technology – fundamentals and examples (training session)

Session chaired by: **Petras Punys** (Vytautas Magnus University, Kaunas, Lithuanian Hydropower Association)

10:40 **J. Steller, Z. Krzemianowski, M. Hajdarowicz** (IMP PAN): *Recovery of energy dissipated in the municipal and industrial water cycles – selected technological aspects* (PL)

11:40 **M. Lewandowski, A. Adamkowski** (IMP PAN), **M. Kaniecki** (TG DNALOP), **A. Kamiński** (Orlen Group)**, S. Lewandowski** (EasyServ): *Recovery of energy lost in technological processes of industrial enterprises. Practical examples* (PL)

12:10 **J. Samaniego, L.A. Bujedo, R.M. López Fernández, V.I. Serna González** (CARTIF); **M. Mirete., J. Pages** (Aquatec): *Energy recovery in a DWTP using an innovative micro-hydropower system based on the integration of a Pump as Turbine and an energy storage*

12:30 **M. Piękoś** (MPEC Cracow): *Water turbine application in MPEC Cracow heating networks* (PL)

13:00	**Lunch break**

Sesja LN3: Research activities and innovative technologies

Session chaired by: **Waldemar Jędral** (Warsaw University of Technology)

14:00 **A. Machalski, J. Skrzypacz, P. Szulc** (Wroclaw University of Technology): **M. Janczak, W. Lorenz** (Hydrovacuum SA): *Flow phenomena analysis in a centrifugal pump running in turbine mode of operation* (PL)

14:20 **D. Liszka, D. Borkowski, D. Cholewa** (Aqua-Tech, Cracow University of Technology, BC POWER): *Improving energy conversion effectiveness in small hydropower plants using the available technical infrastructure* (PL)

14:40 **A. Olszewski, K. Rafał** (Institute of Technology Optimisation): *Hydrokinetic turbine unit prototype* (PL)

15:00 **J. Tomalik, K.A. Bloom** (Hydroresonance)**:** *Regenerative environmental approach to the design of SHPs. Small hydro power plant as a river water treatment station* (PL)

15:30	**Closing of the Symposium**

IGWP	- Polish Waterworks Commercial Chamber	SEP	- Association of Polish Electrical Engineers
IMP PAN	- Institute of Fluid Flow Machinery, Pol.. Ac. Sci.,	TEW	- Polish Hydropower Association
IOZE	- Institute of Renewable Energy Sources, Kielce	TRMEW	- Polish Association for Small Hydropower Development
MPEC	- Municipal Heat Energy Enterprise	WAT	- Military University of Technology, Warsaw
PGW	- the State Water Holding		

List of Symposium Participants

1	Jerzy	Badura	ANGA Uszczelnienia Mechaniczne Sp. z o.o.
2	Leszek	Bajorek	ZEW Niedzica SA
3	Jacek	Bieńkowski	TAURON Ekoenergia sp. z o.o.
4	K. Athan	Bloom	Hydroresonance, USA
5	Dominik	Błoński	Instytut Optymalizacji Technologii sp. z o.o.
6	Dariusz	Borkowski	AQUA-Tech Sp. z o. o., Trzebinia
7	Luis Angel	Bujedo Nieto	CARTIF Centro Tecnológico, Hiszpania
8	Arkadiusz	Czarnecki	ZEW Niedzica SA
9	Marta	Gajewska	Hydro-Invest, Warszawa
10	Agnieszka	Galicka	MPWiK Warszawa
11	Adam	Góralczyk	Instytut Optymalizacji Technologii sp. z o.o.
12	Wiesław	Grzesiak	TB Hydro sp. z o.o., Poznań
13	Mariusz	Hajdarowicz	Instytut Maszyn Przepływowych PAN, Gdańsk
14	Kamil	Jabłoński	Energoprojekt Warszawa SA
15	Łukasz	Kalina	Instytut OZE, Kielce
16	Maciej	Kaniecki	TG DNALOP sp. z o.o., Redzikowo
17	Piotr	Kołat	TB Hydro sp. z o.o., Poznań
18	Piotr	Kowalewski	TG DNALOP sp. z o.o. Redzikowo
19	Zbigniew	Krzemianowski	Instytut Maszyn Przepływowych PAN, Gdańsk
20	Michał	Krzyszkowski	ZEW Niedzica SA
21	Michał	Kubecki	Instytut OZE, Kielce
22	Michał	Lis	Energetyka Wodna, Kielce
23	Damian	Liszka	AQUA-Tech Sp. z o. o., Trzebinia
24	Witold	Lorenz	Hydro-Vacuum S.A., Grudziądz
25	Raquel M.	López Fernández	CARTIF Centro Tecnológico, Hiszpania
26	Mariusz	Łabuń	TAURON Ekoenergia sp. z o.o.
27	Janusz	Łobacz	PGE Energia Odnawialna SA, Oddział EW Żarnowiec
28	Artur	Machalski	Politechnika Wrocławska
29	Krzysztof	Majcher	PGE Energia Odnawialna SA o/ZEW Solina-Myczkowce
30	Ewa	Malicka	Towarzystwo Rozwoju Małych Elektrowni Wodnych
31	Grzegorz	Nawodziński	ENEA Nowa Energia Sp. z o. o.
32	Aneta	Nycz	Politechnika Wrocławska
33	Artur	Olszewski	Instytut Optymalizacji Technologii sp. z o.o.
34	Mariusz	Piękoś	Miejskie Przedsiębiorstwo Energetyki Cieplnej sp. z o.o., Kraków
35	Piotr	Plichta	BELSE Sp. z O.O., Bielsko-Biała
36	Petras	Punys	Uniwersytet Witolda Wielkiego, Kowno, Litwa
37	Algirdas	Radzevičius	Uniwersytet Witolda Wielkiego, Kowno, Litwain the Symposium
38	Krzysztof	Rafał	Instytut Optymalizacji Technologii sp. z o.o.
39	Ireneusz	Rogala	Energa Wytwarzanie SA, Gdańsk
40	Jesús	Samaniego Muñoz	CARTIF Centro Tecnológico, Hiszpania
41	Paweł	Sikorski	Izba Gospodarcza "Wodociągi Polskie"
42	Janusz	Skrzypacz	Politechnika Wrocławska
43	Henryka	Stachowicz	Towarzystwo Elektrowni Wodnych, Reda
44	Zbigniew	Stachowicz	Instytut Energetyki o/Gdańsk

45	Janusz	Steller	Towarzystwo Elektrowni Wodnych/ IMP PAN
46	Irena	Steller	wolontariusz
47	Robert	Stępień	Gajek Engineering Sp z o.o.
48	Przemysław	Szulc	Politechnika Wrocławska
49	Jarosław	Tomalik	Hydroresonance, Wrocław
50	Filip	Tor	TG DNALOP sp. z o.o. Redzikowo
51	Krzysztof	Wrzosek	PGW Wody Polskie / Politechnika Warszawska
52	Edyta	Zalewska	Uponor Infra Sp. z o.o.
53	Edward	Ziaja	Instytut Automatyki Systemów Energetycznych, SEP

Please note that only the persons having signed the list and those remembered by the organisers are listed. We apologize the persons having taken part and not included in the list.