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WASTE HEAT UTILIZATION OF HYDRO-POWER PLANTS

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Abstract
The paper covers the utilization of waste heat of hydro power plant (HPP) processes, with the aim of maximizing energy efficiency of energy generation facilities. Excess waste heat in HPP is formed in all energy generation processes and bearing systems. Operation of hydropower plants is mainly generating low temperature level waste heat stream that could be used in covering heating requirements of associated HPP buildings, nearby settlements, greenhouses and industrial applications. Due to the low temperature potential, the heat has to be moved to a higher temperature level i.e. over 60 °C, via heat pumps or other conversion technologies. The HPP waste heat stream is very much dependent on river flows and electricity generation plans, which are prone to adapt to fluctuation in electricity power markets (influence of solar and wind power generation). Recovery of waste heat in HPP is due to fluctuating operating regime associated with installation of additional heat storage systems, which additionally influences the investment size (costs).

The presentation is covering the existing waste heat investments into recovery of hydropower plant Mariborski otok generation units, where excessive heat is utilized in nearby DEM premises. The adequate waste heat utilization maximizes the total generators efficiency up to 1.5 %, which in turn lowers the energy needs for heating in the nearby power plant premises. The waste heat utilization provides a good alternative in both new and existing electricity generation facilities and as such represents a new opportunity for investors.

Key words: waste heat, hydro power plants, operation requirements

1. Introduction
In recent years the new industrial plants see improvement of the specific energy consumption through optimization of production processes. Energy consumption of industrial processes often affects the price of the product and therefore determines its competitiveness on the market. To this end, large scale investments have been invested recently in increasing energy efficiency, as the latter reduces the cost of energy supply.

Also in the operation of power plants there are often dilemmas how to improve the specific energy use in processes, how to increase efficiency, how to better convert energy, and how to utilize waste heat. Environment and landscape are gaining in importance; therefore they represent an important issue, also in the field of construction and heating, and the creation of a common approach with a new attitude towards the natural environment is demanded.

At global level there is a significant growth of energy demand (Figure 1). The increase is partly caused by the improved social welfare, as well as by industrial activities, especially in the developing countries, despite the parallel enhancement in energy efficiency. In the last fifty years, there has been an increase in the use of fossil fuels, in which petroleum products, coal and natural gas stand out.
For this reason alone, the main agreed measures are the reduction or at least slowdown of energy demand, its efficient use (while ensuring the same or higher life standards) and the use of renewable energy sources. Alongside with the increase in the consumption of primary energy, the amount of waste heat increases, which represents a greater potential for utilization with the corresponding technological systems.

According to a review of energy consumption at the global level, it is evident that most of the energy is derived from fossil fuels, where renewable sources account for less than a quarter of global consumption worldwide (Figure 2, 3).

With the tendency of improving energy policies in individual countries and the introduction of declared objectives of renewable sources in the energy supply system, the largest share of renewable electricity generation is represented by hydroelectric power plants (Figure 3). Currently (year 2016), the operational capacity of all hydroelectric power plants is estimated at approx. 1123 GW globally [3]. According to the size of the installation units in operation, the Asian countries are at the forefront; with the operational capacity of hydroelectric power plants reach-
ing half of all available global installations (Figure 4). The annual increase in hydropower capacity is estimated at approx. 150 GW and varies depending on the prices in the electricity market. The construction (implementation) of new production units is limited to the geographical characteristics, and the criteria for integrating new energy facilities into environment. Increase of installation units also increases the potential of waste heat recovery of hydroelectric power plants.

![Figure 4: Hydro capacity in operation (in 2016) - 1123 GW [3]](image)

1Other includes electricity from energy sources not defined above such as non-renewable wastes, peat, oil shale, and chemical heat.  
2Other renewables includes geothermal, wind, solar, tide.

### 2. Waste heat in industrial and energy processes

The share of waste heat in the industry depends on the type of industry and the technological processes applied [3, 4]. The temperature of the exit medium (waste heat) in industrial processes can reach over 1000 °C, here the iron, steel and the chemical industry really stand out (Figure 5).

The technology for the exploitation of waste heat in high temperature sources is definitely priority because of the economic indicators of the return of the investment is more favorable. Most commonly the waste heat is used within the industrial process, whereby the energy efficiency of the primary used sources is increased. In some cases, waste heat is used for processes that are separate from the industrial process itself and represent a stand-alone unit. In industrial processes, where a greater amount of “waste” heat is generated, the aggressiveness of the transmission medium (gases, liquids ...) and time-discontinuous operation often pose an issue in the exploitation.

![Figure 5: Range of Process Temperatures for Commonly Used Heating Processes (Industrial Heating Processes) [3]](image)

Low-temperature sources of waste heat are more common in terms of the amount of waste heat (MWh) available and therefore represent a high energy potential, while on the other hand the exploitation is often associated with high investment costs. In the last decade, however, novel technologies for the exploitation of low-temperature sources are emerging, thus increasing their use, as well as economic attractiveness / justification. The most com-
mon use of low-temperature sources is for heating industrial / commercial buildings, as well as for the co-supply of energy to the district heating system.

2.1 Waste heat in hydropower plants

Technologies exploiting the water potential of the rivers are relatively old, with only minor changes in improving the utilization of water potential in recent decades. When dealing with classical medium-sized power plants, the overall efficiency of the power plant is approx. 90%, with turbine efficiency up to 94%, and generators up to 98%.

In energy facilities (hydroelectric power plants), waste heat is generated as a result of energy transformation, whereby the waste heat is generated by mechanical, electrical and hydraulic losses. The main potential for waste heat utilization of hydroelectric power plants represents losses on generators (stator) and bearing systems (Figure 6).

Figure 6: Cross-section of the powerplant Fala

The resulting losses on the bearing and generator systems are diverted with the help of a cooling system, which ensures the stable operating temperature. The cooling system of the aggregate thus maintains the stator temperature between 60 and 90 °C, and the turbine bearings temperature between 50 and 60 °C. Liquid (water) is often used as secondary cooling medium, which reaches a temperature up to 40 °C. This secondary cooling medium is most often used as a waste heat source and can be exploited through a built-in heat exchanger.

The flow system of power plants is characterized by adaptation to actual hydrological conditions, which also affects the amount of “useful” waste heat. The fluctuation of the daily power of aggregates is conditioned by covering the needs of peak energy, as can be seen in Figure 7. Changing the load pattern of aggregates thus changes the amount of waste heat emitted, which presents a particular problem of waste heat exploitation.

Figure 7: Power fluctuation - MW at the hydroelectric power plant
Owing to the mode of operation, a compensating system of larger water heat storage systems is often used, to cover fluctuation of the waste heat. The waste heat of hydroelectric power plants may reasonably cover the heat demands of nearby buildings, whereby with the increasing distance from the sink (to source) the investment tends to get economically nonviable. As the waste heat of hydroelectric plants presents a low temperature source, it is therefore only reasonable to use a complementary technology i.e. heat pump to raise the temperature of the heating medium (water) to the higher level. The temperature difference makes demands to the heating system in use on the consumption side. A temperature should rise to approx. 60 °C. Due to the rapid development of new technologies; the use of heat pumps is becoming energy efficient and also environmentally friendly.

The key factors determining the use of waste heat are the distance to the consumer (sink) and the heat demand (in MWh). Since the majority of hydroelectric power plants operate automatically (without a crew), the heating of auxiliary HPP facilities is supercilious.

3. Review of waste heat utilization on HPP Mariborski otok

We provide an outline of waste heat recovery system of generators as carried out at the hydroelectric power plant Mariborski otok situated on River Drava in Slovenia (managed by DEM company). The hydroelectric power plant is of pillar type and is located at the city of Maribor. It exploits a 14.2 m drop and produces 270 million kWh of power at 60 MW annually. The construction was planned before the First World War and was started in 1942. The construction works were drastically delayed due to the World War 2 and until May 1945 only 30% of works were carried out. After the war, the works continued, so that the first aggregate was put in operation in 1948, the second in 1953 and the third in 1960.

As a part of the reconstruction of the aggregates / power station Mariborski otok in years 1997 - 2001, the construction of a system for the waste heat utilization of generators was carried out. The generated waste heat is thus used for covering heat demands of control center (DEM premises), which lies in the immediate vicinity of the mentioned power plant (Figure 8). The installed power of the waste heat recovery system is 500 kW.

![Figure 8: Aerial photo of HPP Mariborski otok (source) and control center (sink)](source)

The concept of waste heat recovery at the HPP Mariborski otok is designed as a regulated two-circuit cooling system of generators:

- an open cooling system, where the river water cools the air of the generators air-cooling system and then outflows back into the River Drava,

- a closed cooling system, where the water that cools the air of the generators air-cooling system is heated (raised to the higher level) and used for the heating of the office building.
The SIEMENS open cooling system of generators, type 1HD 7339, operates only during the summer, and the closed cooling system for generators (manual or automatic control) during the winter period when heating is required (Figure 9).

In the generator cooling regulation algorithm, there is practically no direct connection between the closed and the open cooling loops. The regulation of both cooling systems depends on the required average temperature of the stator winding of the generators. Among the systems, only the temperatures of the outlet cooling water are different. During the annual operation, the temperature of the stator winding is maintained between 50 and 60 °C only with an open cooling system. The closed system works the same, except that the temperature is set 20 °C lower.

Figure 10: Technological scheme of waste heat recovery system
The recovered (heat) energy can be used immediately with built-in heat pumps installed at the heat exchanger location (the control center and management buildings) and surplus stored in two storage tanks of 2 x 50 m³ (Figure 11).

For the regulation of the open cooling system, the regulator compares every 10 minutes actual with the optimal temperature of the stator winding and, if required, opens the control valve on the outlet pipeline. The opening depends on the deviation of the temperatures, while closing takes place at the same time interval, i.e. one second. The closed cooling system is much faster, as the actual and optimal/desired temperature is compared every 30 seconds, and the opening and closing are carried out according to the same program as the open system.

The connection between heat exchangers on generators and heat storage tanks is a two-way connection (length approx. 200 m). All connecting pipelines are adequately insulated to prevent increased heat losses during transport.

Figure 11: Photos of installed heat pumps and heat storage system (2 x 50 m³)

Also a heat exchanger, installed in the underground level of the control center is fully insulated.

For the transport of water to HPP heat exchangers and 2 x 50 m³ tanks, a dual pumping unit is used (operation of the pumps is alternating). The flow of water varies according to the number of operating aggregates in the HPPs and in relation to the openness of individual valves in front of heat exchangers. Due to the dynamic operating conditions of the generators, the pumps are equipped with frequency control. The rotational speed is regulated by the differential pressure (or depending on the available flow through the heat exchangers).

4. Conclusion

The exploitation of waste heat from low-temperature sources is becoming more interesting due to the development of novel technologies. The prerequisites for use of low temperature heat are sufficient annual waste heat potential (MWh), the temperature of the heat source, the distance from the source to the sink - the location, as well as the mode of the energy process in which waste heat is generated. When operating a hydroelectric power plant, the greatest amount of waste heat is generated when transforming mechanical power into electricity. For the hydroelectric plants in question, there is fluctuation in production capacity, which in parallel affects the fluctuation of excess heat at the hydroelectric power plant. The reason for the fluctuation in hydroelectric production is in covering peak demands, depending on consumption and the production of electricity from other renewable sources (sun, wind ...). The system of waste heat recovery at the hydroelectric power plant is made reliable by the use of intermediate heat storage, thus compensating for the heat source fluctuation. Use of heat pumps ensures an adequate rise in the temperature source.

The use of waste heat from hydroelectric power plants is viable in case when used in nearby facilities (locations), since it avoids construction of long pipelines and consequent transformational losses of heat, in turn providing a better economics. The capacity of heat generated could cover the heating demands of commercial buildings and hamlets, nearby greenhouses and recreational pool complexes. The waste heat may also be potentially used in connection with nearby district heating systems, preheated by high temperature heat pump or other available conversion technologies.

The system of waste heat exploitation at the hydroelectric power station Mariborski otok is already 15 years in operation. The design of the waste heat recovery system is independent of HPP operation as it acts as a parallel generator cooling system. In all cases of hydropower plants operation, the priority is given to the production of electricity, whereby the additional utilization of waste heat improves the efficiency of energy conversion. We estimate that the utilization of waste heat at hydroelectric power plants can improve the total efficiency of aggregates up to 1.5 %, which in case of hydropower equipment, represents a relatively high value.
References:


