EFFICIENT USE AND CONSUMPTION OF WATER IN POWER GENERATION

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than necessary. The discharged water temperature may have limitations since a warm water discharge may have an adverse impact on the local ecosystem in the receiving water.

**Example:** 100 MWe engine driven power plant:
- Cooling requirement 54 MW
- Cooling water flow with 5 °C temperature rise 9300 m³/h
- Required pumping power approx. 900 kW (secondary circuit)
- Electrical consumption/produced power 9 kWh/MWh.

**COOLING TOWER**
The majority of the cooling tower makeup water is evaporated. To be able to keep the water quality in the cooling tower circuit acceptable, part of the cooling tower water has to be discharged as “bleed off”, which has a far greater concentration of impurities than in the cooling tower make-up water. For proper operation, the cooling tower needs a continuous dosing of chemicals to prevent scaling and fouling within the cooling circuit. Limitations on the effluent composition affect the selection of chemicals since they are also concentrated into the bleed off water. Here too, the warm and saline water discharge may have an adverse impact on the local ecosystem within the receiving water.

**Example:** 100 MWe engine driven power plant:
- Cooling requirement 54 MW
- Cooling tower circulation flow 3000 m³/h
- Evaporation and drift losses 86 m³/h
- Bleed off amount 21.5 m³/h (with concentration factor C.F. = 5)
- Water consumption for cooling circuit 1075 l/MWh
- Required pumping power approx. 300 kW (secondary circuit)
- Cooling tower fan power 45 kW
- Electrical consumption/produced power 3.5 kWh/MWh.

**RADIATOR COOLING**
In a closed circuit cooling system, water consumption is negligible. The heat is transferred to the airflow forced through the radiators by electrical fans.

*Fig. 1 – Principles of main cooling methods in power production applications.*
**Example:** 100 MWe engine driven power plant:
- Cooling requirement 54 MW
- Total fan power 930 kW
- Electrical consumption/produced power 9.3 kWh/MWh
- The electrical consumption of the fans

According to this document “an engine power plant has been estimated. In Wärtsilä power plants, dry cooling by radiators is clearly the most common solution. In engine power plants, cooling is necessary in order to maintain the charge air, lube oil, and jacket cooling water temperatures at the required levels. With gas turbines, on the other hand, the above mentioned cooling methods are used for intercooling, or for secondary cooling of the mechanical refrigeration and absorption chiller systems (used for inlet-air cooling).

Regardless of the power plant size and type, water use and consumption always have both economic and environmental impacts, especially when groundwater is used for cooling in drought sensitive areas. While large, centralized plants using once-through cooling systems have to be located near water sources, decentralized plants using radiator cooling have a very moderate water usage and can be located in areas with limited water sources available.

**Water consumption in Wärtsilä power plants**

Water consumption in Wärtsilä power plants is low since the cooling is normally via air-cooled radiators. In some rare cases, cooling towers may be used and this will naturally increase the water consumption, but even in this kind of installation water consumption is relatively low.

In the European Commission’s “Reference Document on Best Available Techniques for Large Combustion Plants” the water consumption of an engine power plant has been estimated. According to this document “an engine driven power plant usually preserves its water”. However, consumption in a Wärtsilä power plant is even lower than the document states. For example, for a 130 MWe power plant, the same size as that referenced in the document, water consumption is around 150 m$^3$/h using a cooling tower, whereas in the document it has been estimated to be 220 m$^3$/h.

As a comparison, the document gives a value of 500 m$^3$/h for a steam turbine plant of the same size. In the case of radiator cooling, the water consumption is negligible in comparison to these figures. The estimated total water consumption, including all the water needed in the plant’s operations, is around 9 l/MWh for a Wärtsilä HFO plant, and around 2.7 l/MWh for a LFO and gas plant. These values are based on the assumption that cooling is via radiators, which is the standard solution. The breakdown of water consumption in the plants is shown in Figure 2.

In HFO plants, water is consumed by the process water, boiler water and sanitary water. The process water consumption includes water used by the fuel oil and lube oil separators, turbo washing, the oily water treatment system, and workshop operations. Some minor amounts may also be used in engine cooling and by evaporation. Another consumer group are boilers. HFO plants have their own consumption boilers that are used to produce steam for plant operation purposes. The boilers consume water in the form of make-up water, and also in cooling blow-down from the boiler. The third and smallest consumer is sanitary use.

As opposed to HFO plants, in LFO and gas plants the majority of the water is consumed by the sanitary system. The process water consumption in these plants mainly consists of that used in workshop operations. As with HFO plants, engine cooling may also consume some minor amounts through leakages and evaporation. However, cooling is not the main factor in the water consumption of either type of plant, unlike in many other power plant types. A principal water flow diagram for a Wärtsilä HFO plant is shown in Figure 3.

**Comparison to gas turbine plants**

Wärtsilä power plants are well known for their excellent performance, even in difficult conditions, such as high ambient temperatures or altitudes. The performance of the plant remains high regardless of whether the plant is installed in tropical or arctic conditions, or if the plant is located at high altitude. Moreover, the installation’s location has no significant effect on the plant’s water consumption. Gas turbine performance is normally given in ISO conditions, meaning a dry bulb temperature of 15 °C, a relative humidity of 60%, and an atmospheric pressure of 1 bar (sea level). However, most gas turbine installations are not operating in such conditions.

The performance of a gas turbine decreases the more actual conditions...
differ from these norms. Comparisons of the derating factors due to site conditions between a Wärtsilä gas engine and a competing gas turbine plant are shown in Figure 4.

Changes due to locational conditions do not have a remarkable effect on the derating factor of a Wärtsilä engine. However, at high altitudes gas turbines lose their performance significantly. The same thing occurs in hot conditions, but this can be prevented partly by inlet-air cooling.

Several methods are used for inlet-air cooling in gas turbine plants. Possible options include media-type evaporative coolers, fogging systems, mechanical refrigeration systems, and absorption chillers. Of these methods, mechanical refrigeration systems and absorption chillers are the most effective, since their function is not limited by the ambient wet-bulb temperature. However, they have high initial capital costs, high operations and maintenance (O&M) costs, and relatively long delivery and installation times. Moreover, they require expertise to operate and maintain the plant. As an example, the initial capital cost of chillers is in the magnitude of 1 million USD for a gas turbine with an output of 41 MW ISO. A comparison of capital costs of the different inlet-air cooling systems is shown in Table 1.

The preferred solutions are in many cases media-type evaporative coolers and fogging systems. This is because of their relatively low capital and O&M costs, quick delivery and installation times, and easier operation. A media-type evaporative cooler consists of a wetted honeycomb-like medium, through which the inlet air is pulled. As the air flows through the medium, water is evaporated from the surfaces. The evaporation naturally requires energy, and thus the inlet air is cooled. The fogging system is also based on cooling air through the evaporation of water, but instead of using a medium, the water is atomized into fog-droplets. The media-type evaporative cooler is the most widely used cooling method, and the fogging system the second most frequent one. However, these methods also have drawbacks; the limitation on capacity improvement, and a high dependence of performance on the ambient wetbulb temperature. And last but not least, both these methods consume relatively large

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**Fig. 3 – Principal water flow diagram of an HFO plant.**
quantities of water. For fogging systems demineralized water is always needed, whereas for evaporative coolers, the requirements on water quality are less stringent, although bleed off is needed to remove concentrated impurities.

A fogging system supplier has published typical water consumption values for 11 °C inlet air cooling. When the ambient temperature is 38 °C and the wet-bulb temperature 20 °C, the water consumption for an industrial gas turbine with 41 MW ISO output is 30.3 l/min. Without the inlet air cooling the output would be as low as 25,310 kW, whereas with cooling it can be increased by 8165 kW (32.3%) to 33,475 kW.

However, as the figures show, even with cooling the output remains clearly under the ISO value. The water consumption of a media-type evaporative cooler is in the same magnitude.

The water consumption of 30.3 l/min means around 1800 l/hour. In the form of specific consumption, the value is 54 l/MWh. As mentioned earlier, the estimated total water consumption for a Wärtsilä HFO plant is around 9 l/MWh, and for a LFO and gas plant, 2.7 l/MWh. A comparison of these values shows that the water consumption in Wärtsilä engine plants is outstandingly lower than in a gas turbine installation using a wet cooling method. Moreover, the consumption figure in the gas turbine installation is only for inlet-air cooling, and is thus missing other consumers, such as sanitary facilities, the workshop, washing water, etc.

In conclusion, when compared to gas turbine installations, the main benefits of Wärtsilä engine plants are their high tolerance to extreme conditions, and their low water consumption regardless of the prevailing conditions. The more conditions deviate from “standard”, the greater the difficulty is for competing gas turbine plants to maintain output of the plant at a satisfactory level. To minimize the drop in output, they are obliged to use inlet-air cooling systems. Such systems are either both expensive and difficult to operate, or they consume significant volumes of water. It seems that in gas turbine applications, water consumption is closely related to the economical optimization of the plants. Currently, water consuming cooling methods are more common because of their lower initial capital and O&M costs. High water consumption anyhow makes them environmentally questionable. In this regard Wärtsilä power plants offer a big advantage.

Because of their low water consumption, Wärtsilä plants have a minimal discharge of waste water. Another factor is their low usage of water treatment chemicals, which therefore means only a minor risk of chemical spillages. The amount of waste water produced in a HFO plant is approximately 4 l/MWh. This process waste water, usually called oily waste water, is produced for example, in fuel and lube oil separators, and in plant area washing. The oily waste water is

**Other benefits of low water requirements**

Because of their low water consumption, Wärtsilä plants have a minimal discharge of waste water. Another factor is their low usage of water treatment chemicals, which therefore means only a minor risk of chemical spillages. The amount of waste water produced in a HFO plant is approximately 4 l/MWh. This process waste water, usually called oily waste water, is produced for example, in fuel and lube oil separators, and in plant area washing. The oily waste water is
treated within the plant to comply with World Bank Guidelines for Thermal Power before being discharged. The separated oil is collected in a sludge tank and then utilized or disposed of in an environmentally sound way. In a gas plant there is basically no process waste water produced.

Clean water production

In many cases there is no high quality water available, and the water needed is produced locally by taking the water from the nearest water source and treating it to fit the criteria for power plant use. Most commonly, the process water treatment system supplied by Wärtsilä is built in an insulated and air conditioned container. The system can then be factory-assembled and tested, thus minimizing the onsite installation time and thereby both reducing the commissioning time, and ensuring the high quality of the work. The normal treatment process includes sand filtration, ion exchange softening, and reverse osmosis. Optionally, the system can be equipped with raw water chlorination, activated carbon filtration, and anti-scalant dosing for the reverse osmosis. Experience has shown that these selected processes can cope with a wide variety of incoming raw water with relatively small modifications.

HEAT EMISSIONS TO SURFACE WATER

In cooling applications, all heat that is discharged from a power plant will eventually end up in the air. If water is used as the cooling medium, the heat will be transferred into the air either from the surface of the radiator fins, from the water droplets in the cooling tower, or from the surface of the receiving water. However, before leaving the surface water, the heat may influence the aquatic ecosystem. Once-through cooling systems form the largest source of heat released into the surface water, since the heat is discharged completely via the cooling water. Cooling towers, on the other hand, release the majority of the heat into the air, with only approximately 1.5% of the heat being discharged to the surface water. In totally closed radiator cooling systems, all the heat is discharged directly into the air.

It is known that the discharge of cooling water into the surface water affects the aquatic environment. Although there is not much information about the effects of heat emissions on aquatic life, there are experiences of high temperatures and small receiving waterways. Temperature rise has a direct effect on all life forms and their physiology, and it also results in increased rates of respiration and eutrophication.

It is important to realize that in the cooling process, all heat will finally end up in the air, and thus the surface water is just an intermediate medium. The environmental impact of heat discharge can be minimized by choosing the cooling method whereby more heat is discharged to the air and less into the surface water. Minimization of heat release to the surface water is also linked to the minimization of water use.

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Figure 5 – Containerized water treatment system.

Table 2 – Comparison of different cooling methods applied in Wärtsilä power plants.
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