THE DESIGN OF THE WATER DIFFUSER SYSTEM OF A TANK FOR A COGENERATION PLANT WITH RECIPROCATING ENGINES

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ABSTRACT

Integration of thermal energy storage systems into cogeneration plants plays a very important role in their technical and economic operation. The use of storage systems increases the efficiency of the cogeneration plant and its flexibility in operation. The efficiency of the heat storage systems can be improved if the water inside the tank is stratified. In time, water de-stratification results in energy losses. The paper presents the integration of a heat storage system into a cogeneration plant with a reciprocating engine by means of an existing fuel oil tank. At the same time, the water diffusion system is calculated considering a four-ring octagonal system.

1. INTRODUCTION

The heat supply of consumers is the main objective of the cogeneration plants, but nowadays heat and electricity production is affected by the electricity market that leading to inconsistencies between the demand of heat and the electricity produced [1]. The heat demand is usually discontinued when the heat demand is low; the cogeneration plant will produce electricity, and the excess heat is stored to be used later when the heat demand is higher [2, 3]. Water stratification is created by the difference in density between hot water and cold water. The intermediate region between the cold water at the base of the tank and the warm water is called thermocline. The formation of the thermocline zone is determined by the volume and geometry of the tank, the water flow, the thermodynamic properties of the water, and the dimensions of the slots. There are several water diffusion systems (radial, octagonal, "H", square) on the market. The water diffusion system in the tank selected in the present paper is octagonal.

2. INTEGRATING THE TANK IN THE COGENERATION PLANT SCHEME

The analyzed cogeneration plant is equipped with two piston engines, each with a power output of 6800 kW. The recovered thermal power is of 5560 kW, and the total hot water flow rate of the two engines is Qmain pipe = 480 m^3/h (0.133 m^3/s), with a temperature difference of 20 °C.The pipeline through which this hot water flow passes has a nominal diameter of 300 mm. To cover the peak of the heat load the cogeneration plant has two hot water boilers.

Even if in winter the heat demand exceeds the thermal power produced by the two engines in cogeneration operating at maximum load, for most of the the year the engines operate at partial load. There are also periods of time in spring and in autumn when the hot water boilers are used for covering the heat demand. In order to use the engines longer periods of time at

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maximum load and to reduce the utilization time of the hot water boilers are used heat accumulation is required. Thus, the fuel utilization and the engine lifetime can be improved.

Heat accumulation involves additional investments and seeking solutions for reducing them is always a priority. Taking into account the specific characteristics of the analyzed plant, the paper proposes that an existing fuel oil tank be adapted for heat accumulation. The tank has the following geometrical characteristics: 11.4 m radius and 11.8 m height, the volume being of about 5000 m^3. The material the tank is made of is OL37, and its insulation is made of fiberglass wool.

Figure 1 presents the variant that involves the tank's integration into the analyzed cogeneration plant. The storage system involves three steps: loading, storing and unloading. The hot water tank needs the following parts: distribution / take-up (diffuser) to insert / remove water into / from the tank without creating turbulence. During the tank loading, the hot water is taken from the engine and diffused by the top horizontal diffuser, and the bottom take-up part drains the water and reinserts it into the circuit. During unloading, the top part draws in the water and sends it to the consumer, while the lower diffuser returns the water from the return of the district heating network to the base of the tank.

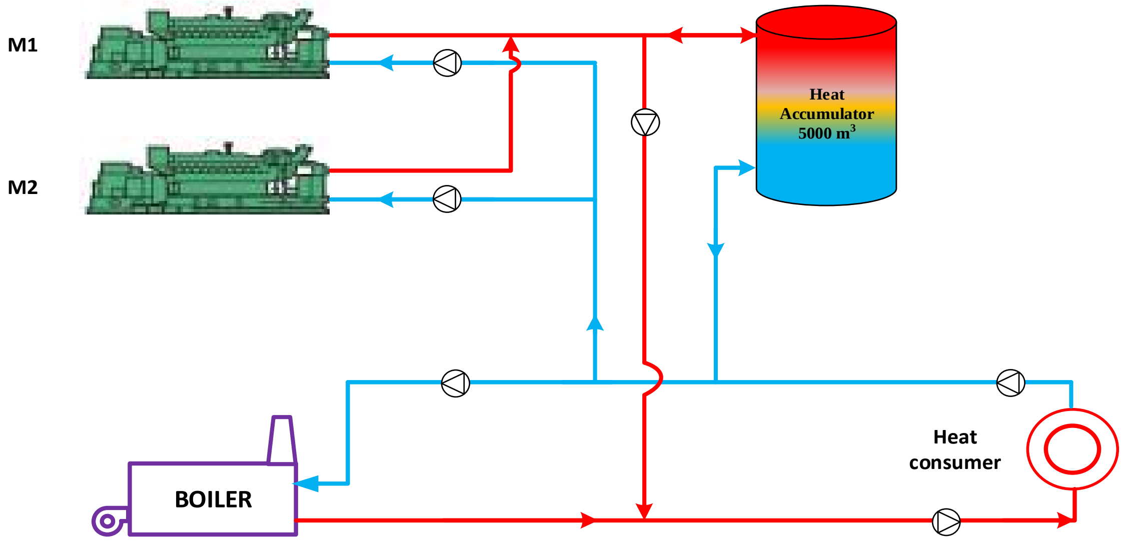

Figure 1: Integration of the tank into the cogeneration plant with piston engines

3. SYSTEM DIFFUSER DESIGN

The proposed diffusion system is octagonal, with a number n_{rings} = 4 diffusion rings, resulting in a number of $n_{diffuser\ pipes} = 8 \cdot n_{rings} = 32$ diffusion ducts. The diffusion system dimensioning must take into account the maximum operating regime. This is obtained by considering that the sale of electricity takes place at the top of the consumer curve when the price is high and in the conditions of a deficit of thermal consumption. This case involves the accumulation of heat produced in cogeneration by both engines at full load. Thus, the flow of hot water through each side of the octagons can be calculated by means of the relation:

$$Q_{diffuser\ pipe} = Q_{main\ pipe} / n_{diffuser\ pipes} \quad (1)$$

The water flow in the diffusion system is influenced by the inlet Reynolds number (Re_i) [4],[5],[6]

$$Re_i = q / \nu \quad (2)$$

where: - q is the volume flow rate per unit of length of the diffuser into the circumferential direction (m^2/s) (3), and
- ν is inlet kinematic viscosity (m^2/s).

$$q = Q_i / L \quad (3)$$

where: - Q_i is the inlet volumetric flow rate (m^3/s).
- L is the characteristic length of diffuser (m).

In relation (3), if $Q_i = Q_{main\ pipe}$ then L is the characteristic length of the whole diffuser system, and if $Q_i = Q_{main\ pipe} / n_{rings}$, then L is the characteristic length of one ring of system diffuser. L is calculated as the double of the perimeter of the octagon [4, 5].

Table 1: System diffuser characteristics

Design inlet temperature during charge cycle [°C]	90
Inlet kinematic viscosity, ν [m^2/s]	3.25719E-07
Length of each diffuser pipe in octagon #1 [m]	3.3
Length of each diffuser pipe in octagon #2 [m]	5.6
Length of each diffuser pipe in octagon #3 [m]	7.3
Length of each diffuser pipe in octagon #4 [m]	8.6
Characteristic length of diffuser for octagon #1 [m]	52.8
Characteristic length of diffuser for octagon #1 [m]	89.6
Characteristic length of diffuser for octagon #1 [m]	116.8
Characteristic length of diffuser for octagon #1 [m]	137.6
Re_i for octagon #1	1938
Re_i for octagon #2	1142
Re_i for octagon #3	876
Re_i for octagon #4	744

Re_i is heavily influenced by water temperature, through the strong variation with it of kinematic viscosity. Figure 2 shows this dependence. From the point of view of the flow, the cold storage installations are more advantageous than the heat storage ones, the laminar flow being easier to obtain at low temperatures.

Different diameters of the diffuser water supply pipe have been considered (0.273 m, 0.219 m, and 0.168 m) (nominal diameters by 250 mm, 200 mm, respectively 150 mm), and their corresponding water velocities have been computed obtaining the following values: 0.0712 m/s, 0.1105 m/s, and 0.187 m/s.

Considering that the ratio between the length of the diffuser pipe cross-section and the slot length is 4 the slot length (21.4 mm, 17.2 mm, and 13.2 mm) has been computed. By selecting a slot width of 1 mm, the slot area is determined. At the same time, by imposing the slot inlet/outlet velocity (for example 0.2 m/s), the flow rate of each slot can be computed and a total number of slots in diffuser pipes is obtained.

Then the number of slots in each diffuser pipe is computed. By rounding the obtained values and recomputing with the total number of slots in diffuser pipes the final number of slots in each diffuser pipe can be obtained: 10, 13, respectively 16.

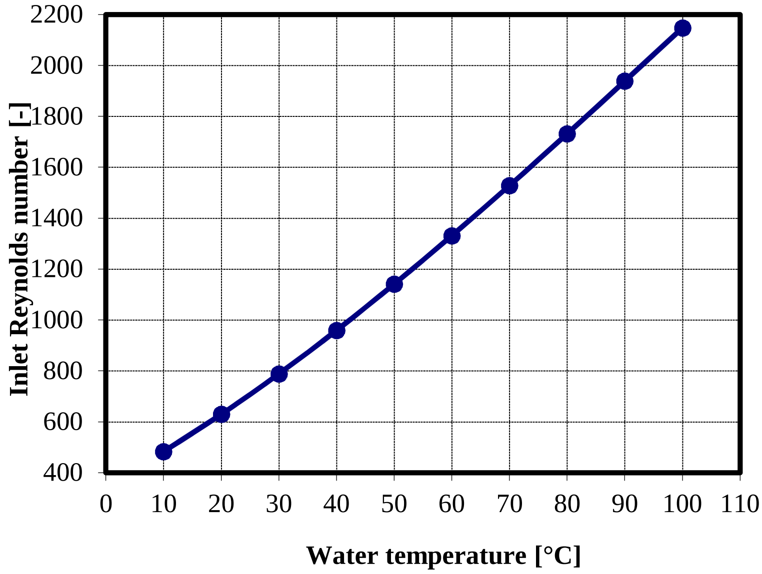

Figure 2: Inlet Reynolds number (Re_i) vs. water temperature

4. CONCLUSIONS

The paper analyzes the adaption of an existing fuel oil tank from a cogeneration plant with piston engines for storing heat. An octagon water distribution system with four water diffusion rings has been dimensioned, determining the inlet Reynolds number to establish the laminar flow and the dimensions of the water diffusion system. The highest inlet Reynolds number (Re_i = 1938) has been obtained on the inner water diffusion ring.

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