THE USE OF WASTE HEAT FROM WASTEWATER TREATMENT PLANT IN RURAL HOUSEHOLDS WITH HEAT PUMP

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Summary: *Wastewater is used on one hand as a source of energy for heating and, on the other, for cooling. The use of wastewater energy can further be subdivided into three categories depending on where the energy is extracted: In-house energy recuperation, energy recovery from raw wastewater (sewers) or energy recovery from cleansed wastewater by the sewage treatment plant.*

This paper describes a decentralized wastewater treatment system in rural households using heat extracted from wastewater using heat pumps.

Mathematical model of heat pumps and AB reactor plant are made in software package MathCAD®. Moreover, conceptual solution and a 3D model of this plant are made in the software package CATIA V5R20®. In the end, techno-economic analysis of such a solution is done.

Keywords: *wastewater treatment, heat pump, AB reactor*

1. INTRODUCTION

The main goal of wastewater treatment is to allow the removal of organic matter and industrial pollution, without dangering human's health and pollutioning the environment. The legal practice of the European Union in the area of wastewater treatment uses the term best available techniques of wastewater treatment. By definition, the best available techniques for wastewater treatment include a wastewater treatment processes that are related to the quality of raw wastewater, treated wastewater quality and convenience of use of wastewater treatment processes in practice. Conventional wastewater treatment, which is often used as a centralized system, represents a combination of physical, chemical and biological processes and operations to remove solid contaminants, organic matter, and sometimes, nutrients from wastewater. Wastewater treatment in small villages (with a population under 20,000) often uses a decentralized purification system which is now introduced globally as one of the most dominant.

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In the past, heat pump technology had been developing rapidly throughout the world, as a clean and efficient system both for heating and cooling. Wider use can be found in apartments, hospitals, office buildings. In recent years there is an increasing intensive development of heat pumps which use heat from wastewater in urban areas as a heat source [1]. Temperature that can be achieved this way is in the range of 44-50°C.

2. HEAT PUMPS

Heat pumps are devices whose working principle is based on the thermodynamic principle of raising the heat, and that represents bringing energy from a lower to a higher temperature with bringing an additional energy (work), using a circular process and appropriate media. For its work, heat pumps require two heat storage:

- Heat source (lower temperatures storage): a space or a medium which takes the heat, mostly immediate environment, for example surrounding air, soil, surface water or groundwater, waste heat, etc.
- Heat sink (higher temperatures storage): a space or a medium which gives off heat, for example rooms, the heating medium heating systems, hot water, etc..

Heat sources in relation to the origins and persistence of temperature can be divided into three main groups:

1. natural resources with largely variable temperatures:ambient air;

2. natural sources with constant temperatures: surface water (larger streams and lakes), seas and oceans, groundwater, soil;

3. artificial sources: used air from the premises or industrial process, wastewater etc. [2,3].

3. METHOD OF TREATMENT OF WASTE WATER IN RURAL HOUSEHOLDS

According to the type and location of sewage, wastewater systems can be divided into centralized and decentralized systems. The centralized system is a system that channels and in which the purified wastewater of an entire administrative or geographically limited space is treated. The last couple of years, the issue of centralized and decentralized systems for wastewater treatment (with or without a fraction of wastewater) represents a question of the making best varieties in ecological and economic terms [4]. Economic conditions include: investment costs, operating and maintenance costs, equipment location costs, the available techniques, the size and efficiency of the purification plant. Techno - economic analysis needs to respond to the demands of the economic suitability of the technical - technological solutions or in other words whether a centralized or a decentralized system is more favorable solution. On the other hand, environmental management includes environmental sustainability, which includes the protection of public health and protection of environmental quality through the implementation of state policies and regulations.

Decentralized wastewater purification system usually is consisted of:

- Primary treatment (mechanical filtration processes) - is used primarily for the removal of substances that can be easily collected from the raw waste water before they damage or block pumps and other devices used in the purification of the following steps (this is often called pre-treatment). Still, this treatment consists in the temporary custody of the sludge in the settling tanks, while oil, grease and easily soluble substance float on the surface.

- Secondary treatment (biological treatment processes) – in which dissolved and suspended biological matter is removed. This procedure is generally performed by indigenous microorganisms in controlled aquatic habitats.
- Tertiary treatment – purified water is sometimes chemically or physically disinfected before discharging into waterways, lagoons or swamps, or used to irrigate golf courses, parks and green spaces. If the water is completely clean, it can be used for agricultural purposes, and the recharge of groundwater reservoirs.

The application of such treatment processes is based on the principle of minimum maintenance, so that critical parts of the system work smoothly and continuously. This technology enables the application of the treatment in domestic and industrial (non-toxic) sources, while wastewater treatment capacity is in range from 1 to 1,000 m^3 per day [5].

3.1 Anaerobic baffled reactor (ABR)

ABR reactor (anaerobic baffled reactor) is an improved septic court which has barriers where the wastewater is further purified (Figure 1). The increased contact time between biomass and barrier provides better treatment. Most deposed solids are removed from the sedimentation chamber at the beginning of ABR, which represents 50% of the total volume of solids. The following chambers generate additional removal and digestion of organic matter. Since that the mud is created during the treatment, its removal is necessary in every two to three years [6].

Biological reactors based on activated sludge are cylindrical plastic tanks with integrated separation, aeration system and a compressor. The final sediment reservoir is divided into two units: casting (denitrification) and display (ESR). Wastewater flows into the active zone through a mechanical filter that removes wastes that are of larger grain size. It is then mixed with activated sludge where microorganisms begin the purification process. Water is from mud in the precipitator and let out outside, while unrefined water and sludge are returned to the first part of the reactor by pump.

The reactor can be installed in the basement, or can be placed in the yard. When installing it, there must be gravity drop that allows inflowing and outflowing. Ground water level limitates reactors burial in the ground. The bottom should be cast in concrete with no wrinkles. The reactor is placed at the base and strengthened with the ring and should be positioned so that it is not exposed to the sun and rain.

ABR reactor design is simple and easy to use, highly resistant to hydraulic and organic shock, and is suitable for a wide range of waste water treatment, industrial wastewater including the one of high hardness and its efficiency increases with higher organic load. Sludge and wastewater require further treatment. ABR is commonly used in decentralized wastewater treatment systems in combination with some other method of treating wastewater. A decentralized system can have 5 components of the system. The first three parts are usually anaerobic, in which biogas / digestion are extracted, the following is ABR reactor with anaerobic filter, and then aerobic treatment of wastewater is performed.

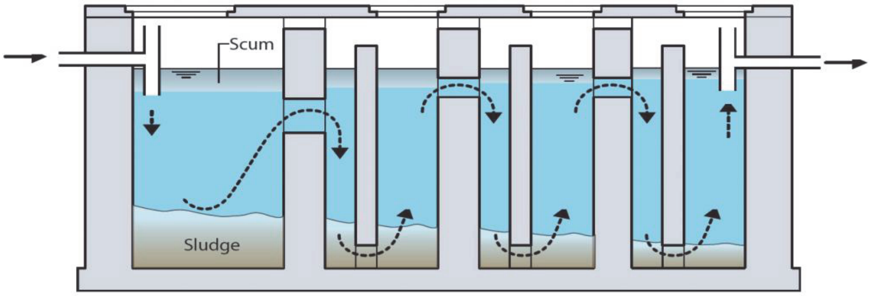

Fig. 1 *ABR reactor*

4 MATHEMATICAL MODEL

Calculation of heat pumps used for heating is made on the basis of mathematical models in software package MathCAD. It is selected that the system has 2 heat pumps: one that warms the living space (floor heating) and the second heats the tank.

To perform the calculation of the heat pump that uses the wastewater heat for the rural household, it is first necessary to dimension the tank, ie. ABR reactor. According to the standard BS6297 the size of the reactor is calculated or the reactor volume compared to the population equivalent:

$$C = 180 \cdot P + 2000 = 180 \cdot 12 + 2000 = 4160 \text{ l}$$

where is:

C – the size of the reactor in liters;

P – the potential number of people.

Required heat for heating living space of 300 m^2 is:

$$Q = f_{oh} \cdot A_z \cdot 3{,}6 = 0{,}062 \cdot 300 \cdot 3{,}06 = 66{,}96 \ \frac{\text{MJ}}{\text{h}},$$

where:

f_{oh} – medium thermal insulation,

A_z – heating surface,

and the overall thermodynamic efficiency level of the first heat pump is:

$$\eta_{cop} = \frac{q}{e} = \frac{185}{30} = 6{,}617.$$

Required amount of heat for heating the reservoir is:

$$Q = k \cdot A_1 \cdot \Delta T_L \cdot 3{,}6 = 0{,}667 \cdot 1{,}882 \cdot 60 \cdot 3{,}6 = 271{,}042 \ \frac{\text{MJ}}{\text{h}},$$

where:

k – thermal conductivity,

A_1 – tank surface,

T_L – temperature difference,
and the overall thermodynamic efficiency:

$$\eta_{cop} = \frac{q}{e} = \frac{208}{48} = 4{,}875.$$

5. 3D MODEL OF SYSTEM: HEAT PUMP AND ABR-REACTOR

This chapter presents a 3D model of the entire plant, used for wastewater treatment in rural households. 3D model of the entire plant and components of the system are designed in CATIA V5R20 software package.

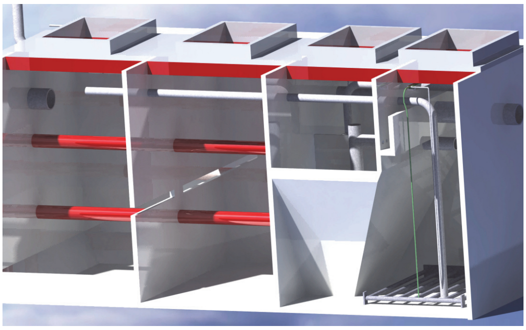

Fig. 2 *3D model of reactor*

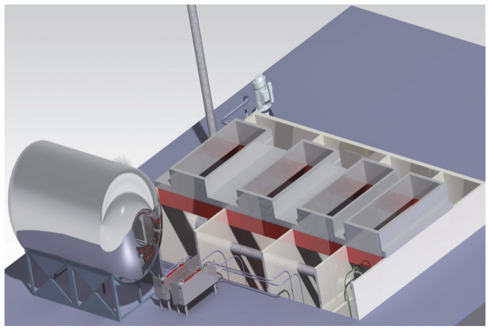

Fig. 3 *View of the whole plant*

6. CONCLUSION

Hundreds of thousands of heat pumps in the developed European countries (Germany, Sweden, Switzerland, etc.) have been built in the past few years. In Sweden, there is even a tendency to uninstall existing heating systems and replace them with heat pumps.

The cost of installing a heat pump and labor cost for the purposes of air conditioning/refrigeration facilities are several times lower than the cost of using gas system (whether for heating or cooling) and electricity. The concept of decentralized wastewater treatment in small settlements aims to develop treatment systems that are financially accessible, socially responsible, and environmentally more benign than conventional centralized system. This approach allows the wastewater treatment in terms of separation of large urban areas, leading to the use of small, low-cost facilities that are directly related to the reuse of system components for water treatment. Both systems can work in symbiosis, allowing the increase of energy efficiency in rural households.

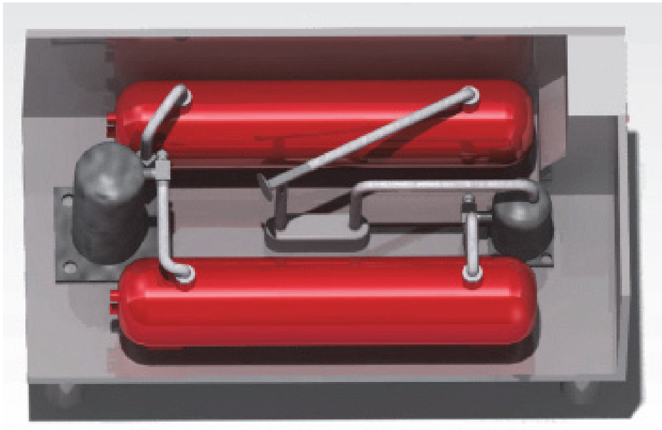

Fig. 4 *Top view of the heat exchanger*

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