Advanced solutions to improve heat recovery from wastewater in a double heat exchanger

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Abstract. One of the main challenges in the world today is reducing energy consumption and CO_2 footprint in existing buildings without major construction work. The main component of energy consumption in buildings is heating, but the demand for the domestic hot water is also very high, especially when daily consumption is high and especially for specific applications. The implementation of technologies using recovery sources for water heating has become very important and one of these technologies involves the recovery of the thermal energy from wastewater. Usually, heat recovery from wastewater is designed to recover residual energy from the hot drainage water and this recovered energy is used to preheat incoming cold water or to heat pumps. The paper presents numerical simulations using a SST k-ω turbulence model in order to compare a regular geometry with a helicoidal one. The second one provides a more turbulent flow that allows an intensification of the outer flow, thus allowing the enhancement of the heat transfer from the inner heated flow to the outer flow.

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1. Introduction

One of the main challenges in the world today is reducing energy consumption and CO2 footprint in existing buildings without major construction work. Many of these buildings represent heritage buildings and the intervention constraints on the original building are much more restrictive for these particular cases. The building sector is one of the world's largest energy consumers, so it is important to seek out and use recovery energies for individual consumers. One of the main component of energy consumption in buildings is the demand for the domestic hot water is also very high, especially when daily consumption is high and especially for specific applications (hotels or laundries for example) This is why the implementation of technologies using renewable energy and recovery sources for water heating has become very important and one of these technologies involves the recovery of the thermal energy from wastewater [1]. Usually, heat recovery from wastewater is designed to recover residual energy from the hot drainage water and this recovered energy is used to preheat incoming cold water or to heat pumps.

Wastewater heat recovery applications are becoming widespread in energy saving applications. This interesting technology is an efficient and inexpensive way to recover thermal energy for reuse also in facilities systems in buildings, such as the production of sanitary hot water or heating. Why do we need such a device? The answer to this question is very simple: even if we are trying now to build energy efficient buildings, we also have to reduce the energy consumption and the CO2 footprint in existing buildings without major construction work. These goals can be met only by using high performance materials, cost-effective energy efficient systems and systems based on renewable energy sources. One of the cost-effective energy efficient system could be the heat recovery system from wastewater.

2. State of the art

We present here a short state of the art of the heat recovery from wastewater as it known at the moment. The literature [2]–[6] stated that the concept of heat recovery from wastewater could be considered highly diversified and the ways of making use of the available heat are very different. The global system of heat recovery systems from wastewater could be divided into three levels. Level 1 represents the wastewater system, all the way upstream from the water consumption to the final effluent from the wastewater treatment plant, where the potential heat resource exists. Level 2 is the transferring system that connects Level 1 and Level 3, i.e. the technical system that provides heat from resource to the final demand. Finally, Level 3 is the receiving system, i.e. where the heat is finally to be reclaimed. Such a system could be used inside a building, outside on the sewer system upstream or downstream the wastewater treatment plant.

The energy recovered from a wastewater system can be used directly to a specific facility (this is the case for the heat exchangers installed just before the showers) or indirectly via a heat pump. Culha et al. [7] have conducted a review where the wastewater heat exchangers are classified in detail based on multiple features, including utilization and construction methodology. These heat exchangers can be used in different locations to recover the heat from the wastewater: the first location is inside the building, and it is called domestic utilization, the second location is outside and provides larger excess heat from the wastewater to ensure heating/cooling for multiple buildings. Apart from these two locations, waste water heat exchangers can be installed downstream of a wastewater treatment plant to efficiently utilize the energy in the treated waste water at a larger scale. The heat recovery at the sewage treatment plant is technically easier since the energy from the treated wastewater can be extracted more efficiently.

L.Ni et al. [8] proposed a grey water energy recovery system with a multiple function heat pump system. The authors have developed a numerical model for the investigation of the annual energy and water consumptions of the proposed system and the conventional building energy system with gas furnace space heating, package air conditioning and electricity water heater for hot water heating. Based on a case study of a typical residential house with four family members the results show that the proposed system can provide about 33,9% energy savings for space heating, cooling and hot water heating. The study is extended among 15 cities in various climatic zones in the US and the results show energy savings having ranges of 17% - 57.9 %.

Jorgen Wallin & Joachim Claesson [9] have studied the performance of a vertical inline drain water heat recovery heat exchanger. In this case the system recovers the heat with the aid of a heat pump. Investigation of the heat recovery ratio shows that the heat exchanger has the capability to recover more than 25% of the available heat in the drain water at the flow rates investigated.

S. Torras et al [10] investigated also the performance of a vertical drain water heat recovery system as an interesting household technology to reduce energy costs and environmental impact. A specific drain water heat recovery storage-type based on a cylindrical tank with an internal coiled pipe has been built and both numerical and experimental tools have been used to design and study the performance of the device. The DWHR storage had the capacity to recover from 34% to 60% of the energy available in the drain water for the investigated flow rates. However, this type of vertical heat exchangers is not easy to use because of the lack of space and the integration of the horizontal heat exchangers could be interesting from this point of view.

L.T. Wong et al. [11] investigated the potential for shower water heat recovery from bathrooms equipped with instantaneous water heaters in high rise residential buildings of Hong Kong. They proposed a single – passed counter flow heat exchanger horizontally used for preheating the cold water before a water heater. The thermal energy exchange is evaluated in terms of effectiveness-number of transfer units approach and the results indicate that 4 to 15% shower water heat could be recovered through a 1.5 m long single pass counter flow heat exchanger for a drainage pipe of 50 mm diameter. Aonghus McNabola and Killian Shields [12]have also pointed out that the recovery of the waste heat from the domestic wastewater flows is a viable method of improving the energy efficiency of buildings. Their study is of great importance for the proposal here, because they have analysed the efficiency of such a heat exchanger. They have proved that even if many of the existing systems only operate satisfactorily when the heat exchanger is in a vertical orientation due to the nature of wastewater flow within the drainpipes, this orientation requirement presents a barrier to the full-scale implementation because of limited space especially in dwellings. The paper outlines the experimental analysis of a horizontal drain water recovery system for domestic showers and the possibility of increasing the efficiency of such systems. The results also demonstrate that such a system may be economically viable depending on several external factors such as the price of energy, the local climate, the capital cost of the device and the national incentives for energy saving technology. In this case improving the efficiency of such a heat exchanger could be the solution to make them more usable.

There are lot of classical methods to improve the heat transfer through an interface inside a heat exchanger. For example, S. Liu and M. Sakr [13] provide a very detailed state of the art. The passive method generally uses surface or geometrical modifications to the flow channel by incorporating inserts or additional devices, for example, inserts extra component, swirl flow devices, treated surface, extended surface, displaced enhancement devices, coiled tubes, surface tension devices and additives for fluids. There are also active methods to improve the heat transfer such as the use of magnetic fields, surface vibration, fluid vibration, electrostatic fields or impinging jets which require an external activator/power supply to bring about the enhancement. The two cited categories could be used in combinations such us rough surface with a twisted tape swirl flow device, or rough surface with fluid vibration, or rough surface with twisted tapes. For the convective heat transfer, one of the ways to enhance heat transfer rate is to increase the effective surface area and residence time of the heat transfer fluids. The passive methods are based on these principles by employing several techniques to generate the swirl in the bulk of the fluids and disturb the actual boundary layer to increase effective surface area, residence time and consequently heat transfer coefficient in existing system. The characterization of the heat exchange properties for this kind of interfaces could be done using non-intrusive methods as PIV measurements techniques. There are studies already performed [14], [15] using PIV experimental studies or numerical approaches [16] regarding the flow pattern over rough surfaces in open channel with applicability to the turbulence increasing methods that can be used to enhance the heat flux over an interface.

3. Methodology

The specific goal of this paper is to find a way to improve the efficiency of an horizontal heat exchanger dedicated to recover heat from waste water. We have realized this heat exchanger in the laboratory. The photo of the experimental setup is presented in figure 1a and the schematic of it in figure 1b:

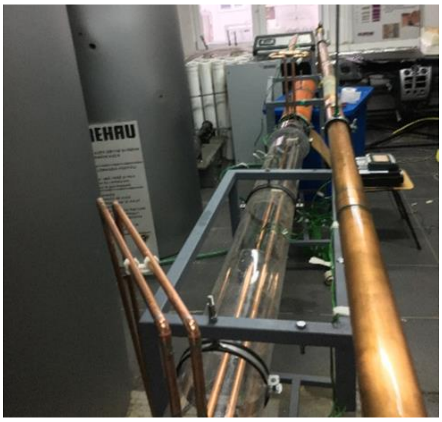

Fig. 1a – Horizontal heat exchanger

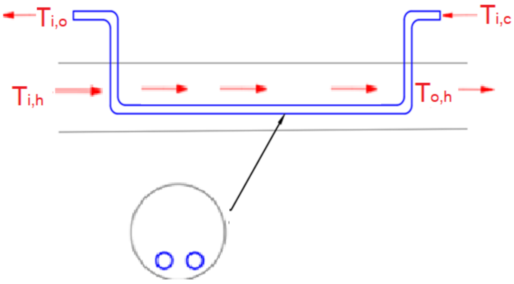

Fig. 1b - Schematic of the heat exchanger

The device is conceived to recover the heat from wastewater from domestic fixtures. There is a circular pipe where the water flows gravitationally which represents the grey water at high temperature coming from sanitary fixtures and two cold water pipes immersed in the greywater flow. This work presents a numerical model of the heat exchanger mentioned above. Several scenarios have been calculated considering flow rates between 3.5 m^3/h and 5 m^3/h for the grey water (free surface flow) and between 0.2 m^3/h and 0.4 m^3/h for the cold water inside the pipes. We will not show all the results in this paper but we have chosen to outline only one scenario in order to explain the results. The main parameters used for our example in this work and their values are the following: $T_{i,h}$ = 40,5°C and $T_{o,h}$ are the inlet and outlet temperatures for grey water and $T_{i,c}$, =10°C $T_{i,o}$ are the inlet outlet temperatures for the cold water. The inlet temperatures have been considered as boundary conditions and the outlet temperatures resulted from calculus. For the flowrates we have considered 4,94 m^3/h for the greywater which correspond to a velocity of 0,17m/s and 0,37 m^3/h for the water inside the copper pipe which correspond to a velocity of 0,7m/s We have envisaged two cases: for the first one we have considered two simple copper pipes for the cold water and for the second one we have added a helicoidal fin on the copper pipes. We have performed numerical simulations to see the difference between the two cases and how much heat recovery is improved by adding the helicoidal layer.

4. Numerical Model

The geometries were created in SolidWorks and after that were imported in DesignModeler under Ansys Workbench 19.2 software. In figure 2a a regular geometry can be seen and in figure 2b is presented the novel helicoidal geometry. At this stage, the geometry was prepared for the numerical simulation.

Fig. 2a – A regular geometry for heat exchanger

Fig 2b. – The novel helicoidal geometry for the heat exchanger

The numerical grid was created for both studied cases in Ansys meshing. Given the fact that the helicoidal geometry is very complex mainly due to the very low thickness of the helicoidal fin (0.4mm) the number of the elements necessary for the numerical simulation was 102 million elements (see figure 3a). A mesh independence test was carried out for this geometry (60, 102, 122 million tetrahedral cells). The main difficulty in creating the mesh was related, as it was stated earlier due to the very low thickness of the helicoidal fin. Because the helicoidal fin is causing the disturbance in the flow, it was needed to create a very good mesh around the sharp edge of the fin. Also, a boundary layer of eight cells was created on all the walls in the studied geometry. Due to the long geometry this caused the increased number of cells. We created more meshes with a low number of cells but there were not suitable for the numerical simulation.

The numerical grid for the regular geometry was much simpler to be generated because it does not have any complication. Due to the simplicity of the geometry, was even possible to create a polyhedral mesh in this case (see figure 3b). In this case, was also performed a grid independence test which revealed that the numerical grid of 2.66 million polyhedral cells was appropriate for this case (among 1.2, 1.8, 2.66, 3.8 million polyhedral cells). Also, a boundary layer of eight cells was created on all the walls in the studied geometry.

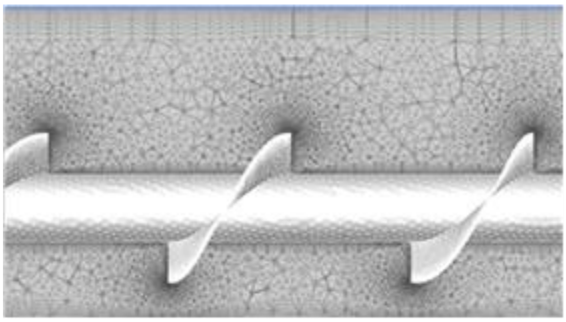

Fig 3a – Numerical grid details for the helicoidal case

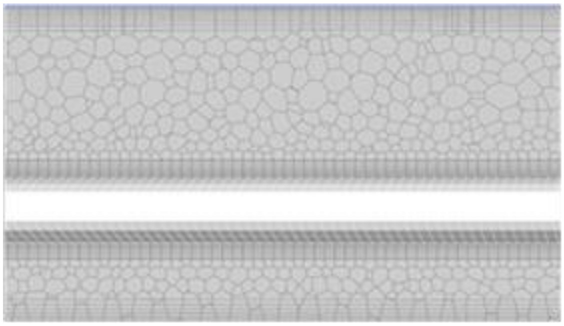

Fig 3b – Numerical grid details for the ordinary case

The numerical simulations were performed in Ansys Fluent 19.2. The turbulence model used for the numerical simulation was SST k-ω due to the high capacity of this model to accurately simulate the flow both in the boundary layer and in the far field [1]. The y+ number had values under 5 on all the wall surfaces from the studied domain which is considered acceptable when using the SST k-ω turbulence model [2].

5. Results

The results are shown in terms of contours of temperature in the exit plane of one of the heated pipes in both analyzed cases. They can be seen in figure 5a,b. Considering the fact, that for both analyzed cases the inlet temperature and flow rate was identic and the single difference between these two cases being the helicoidal fin, it is very clear the great impact in the heat transfer, this fin is adding. The mean temperature at the exit for the helicoidal case was 18.1°C and for the standard case was 13.87°C.

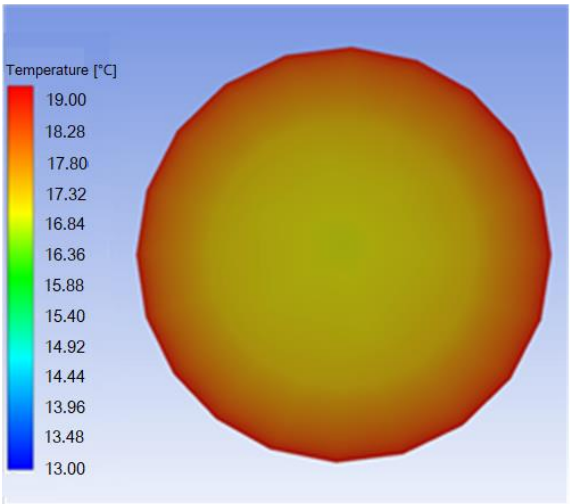

Fig 5a - Contours of temperature in the exit plane of one of the pipes with heated water for helicoidal case

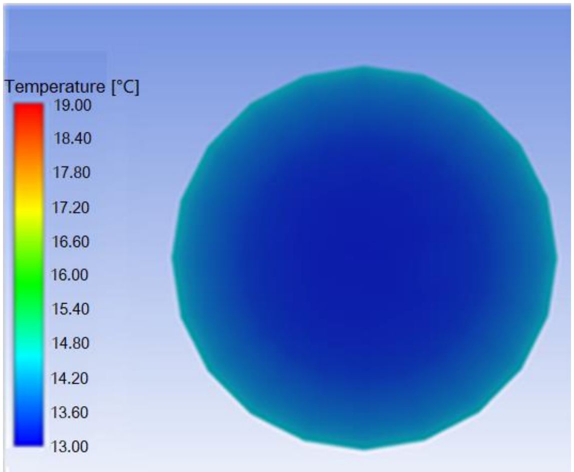

Fig 5b - Contours of temperature in the exit plane of one of the pipes with heated water for the ordinary case

We can show a comparison between the results obtained through numerical simulation for the two studied configurations (the regular geometry and the novel helicoidal geometry) considering the temperatures values and the velocity distributions at several section inside the channel. The previous figures outlined temperatures values inside the cold water pipes while next figures show temperatures values and velocity distribution outside the cold water pipes in the core of the free surface flow.

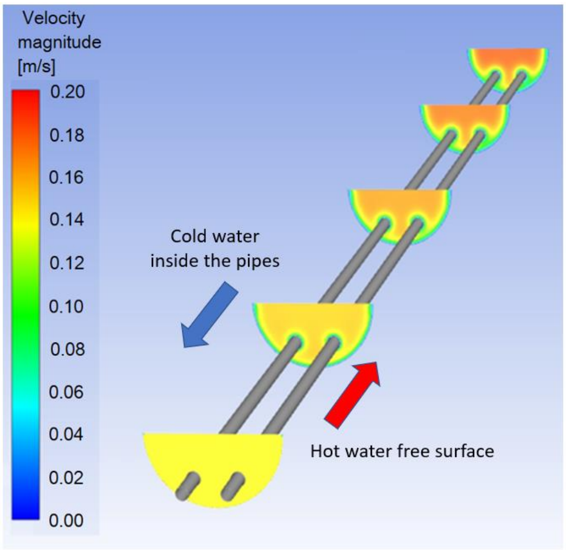

Fig. 6a - Contours of velocity magnitude in subsequent sections of the channel with heated water for the regular geometry

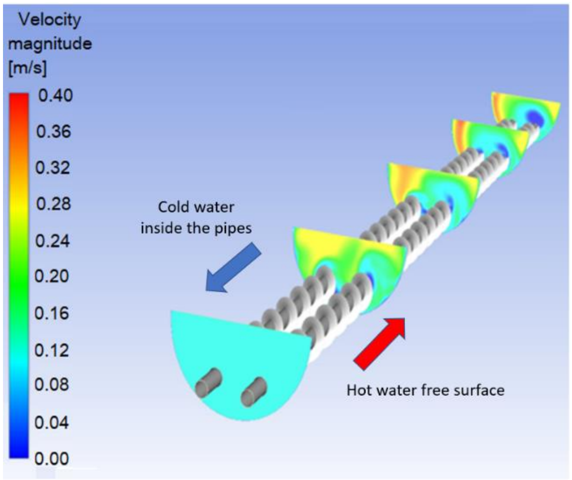

Fig. 6b - Contours of velocity magnitude in subsequent sections of the channel with heated water for the novel helicoidal geometry

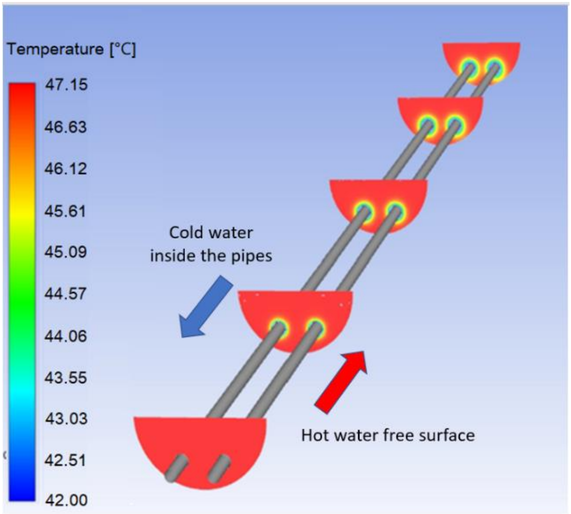

Fig. 7a - Contours of temperature in subsequent sections of the channel with heated water for the regular geometry

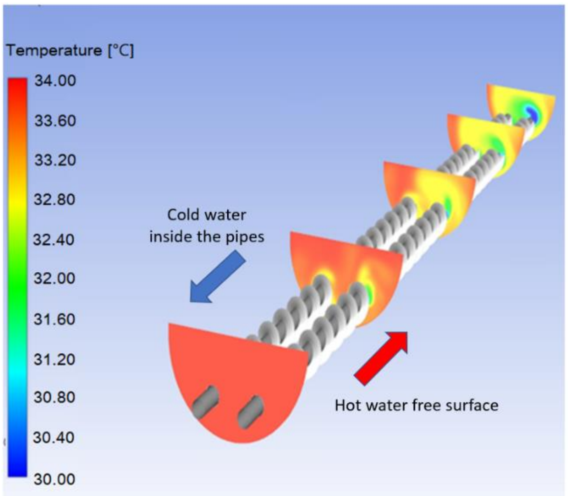

Fig. 7b - Contours of temperature in subsequent sections of the channel with heated water for the novel helicoidal geometry

The same observations as previous might be done, the case with the helical tape provides a more turbulent flow that allows an intensification of the outer flow, thus allowing the enhancement of the heat transfer from the inner heated flow to the outer flow. This is observable on the global distributions of the temperature for the case studied. The evolution of the temperature along the heat exchanger for the cold water inside the pipe considering the helicoidal geometry is shown in figure 8.

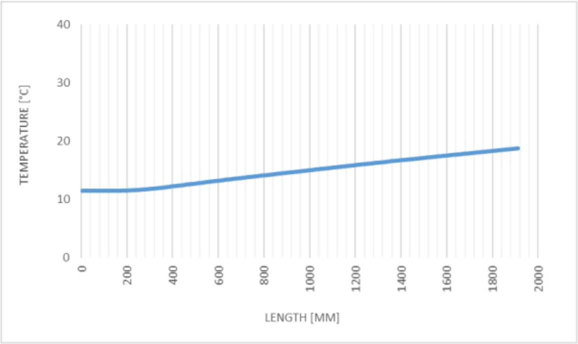

Fig. 8 - Evolution of the temperature along the heat exchanger for the cold water inside the pipe considering the helicoidal geometry

6. Conclusions

The purpose of this study is to develop a water-water heat exchange interface allowing a higher-rate heat flux from the wastewater flow to the cold-water flow to recover maximum of the waste energy.

A regular geometry was compared with a helicoidal one by numerical simulation. The second one provides a more turbulent flow that allows an intensification of the outer flow, thus allowing the enhancement of the heat transfer from the inner heated flow to the outer flow. The heat flux exchanged between the grey water and clean cool water was 6161.5kW for the helicoidal case and 3206.8kW for the standard case so by adding the helicoidal fin, the performance of the standard heat exchanger was improved by 92.14%.

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8. References

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