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Application of eco-efficiency in a coal-burning power plant benefitting both the environment and citizens: Design of a 'city water heating' system

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HIGHLIGHTS

- Proposal for a waste heat recovery system, 'city water heating' system, is introduced.
- Conditions for its implementation are defined.
- Two 'city water heating' systems are subjected to both technical and economic analysis.
- Benefits for inhabitants, mainly reduced costs, are described and evaluated.
- Benefits for the environment, mainly CO_2 emissions reduction, are quantified.

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ABSTRACT

In this work, the concept 'city water heating' is introduced. It consists in bringing a significant amount of residual thermal energy (waste heat) from a power plant to a city by means of heating the potable water supplied to this city. For this purpose (i) a great amount of the city water has to be supplied through a single aqueduct, (ii) the aqueduct has to pass near the power station, and (iii) the water supplied to the city has to be colder than the cooling circuit water in the power plant.

The hot water generated in the power plant cooling circuit (which is usually dissipated in the cooling tower) is conducted through a pipe to a place near the aqueduct and, by means of a heat exchanger, part of the cooling water heat is then transferred to the colder potable water supplied to the city. This has the great advantage of using the existing city water network itself to transport the heat to the houses.

Based on data from a coal power plant located in Asturias (Northern Spain), two city water heating systems of different sizes are described and analysed. The following advantages were found: (i) energy saving and cost reduction for inhabitants, (ii) reduction in global warming and (iii) CO_2 emissions reduction.

1. Introduction

During the last century, a large proportion of electrical energy was produced in power stations in which different kinds of fossil fuels, mainly coal, were burnt. These power plants had been greatly improved and had become more efficient. Nevertheless, during the 70's the first warning on the negative impact of those old power stations on the environment was given. There were two important negative effects.

One is the consequence of the fact that, due to the thermodynamics of the process itself, the average gross efficiency of a coal power station is about 33%. This means that, from the total energy generated in the boiler, only 33% is transformed into electricity whereas 67% is lost mainly as residual heat. This 'waste heat' or 'excess heat', on a global scale, has a significant environmental impact, which contributes to global warming. The other negative effect is the production of CO_2 during the burning of fossil fuels, which is not compensated for in any way; this fact led to an increase in the total amount of CO_2 in the atmosphere producing the known greenhouse effect, which also contributed to global warming.

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This paper is mainly concerned with the waste heat released from a coal power plant into the atmosphere. Scientific literature on these topics is rather extensive and only a few papers will be referenced here as representative examples.

During the latter third of the XX's many studies were limited mainly to pointing out the negative influence of waste heat on global warming [1–6]. More recently, this specific topic has been widely researched in order to study and quantify the phenomenon [7], to develop mathematical models [8] or to propose solutions [9].

Nevertheless, other early research was focused on how to recover and use this excess heat [10]. Significant investigations have been carried out over the course of the last years in order to better define and organise the knowledge concerning the topic of waste heat recovery. Consequently, papers concerning a redefinition of 'waste heat' [11] and others related to technologies proposed for use in the evaluation and utilisation of industrial excess heat [12–16] are cited here.

In the case of large coal-power generation plants, process waste heat is commonly rejected into lakes or rivers, or through the use of cooling towers. These waste heat rejection methods are effective; nevertheless it is desirable to put some of the waste heat to good use, both from the standpoint of improved plant efficiency as well as reduced environmental impact [17,18].

There are two main solutions for the use of this waste heat. The first is to recover the heat within the plant itself from an optimization of the steam generation cycle known as Heat Recovery Steam Generator (HRSG) with the aim of producing steam to be used in industrial processes, combined cycles or heating systems.

The second one is the direct use of this waste heat in processes which need thermal energy or, the most extended application known as 'District Heating' (DH), used in the heating of buildings such as public or institutional buildings, shopping centres and residential blocks (multi dwelling unit). Hundreds of papers have been published on DH; [19–24] are only a few recent representative studies concerning the development of DH solutions. A review of DH systems can be seen in [22]. Examples of well-developed DH systems can be found, for example, in Sweden, Finland, Denmark, Poland and Germany.

Finally, it can be highlighted that in parallel, a number of economic studies have been carried out (for example [25–31]). In these investigations, it is pointed out how the objective of diminishing environmental impact leads in many cases towards an economic improvement of the system due precisely to this whole improvement in the energy generation process. Nevertheless, as is shown in [32], although 'citizen–consumers' are in favour of the idea, this support is conditional on a range of conventional purchasing criteria being satisfied, including acceptable cost, heat controllability, reliability and flexible contractual arrangements.

In this article, a novel solution for waste heat recovery named 'city water heating' is proposed, described and analysed. It consists mainly in bringing a significant amount of waste heat from an industry to a city by means of heating the potable water supplied to this city. This system presents some original characteristics that make it interesting:

(a) A large amount of waste heat can be recovered even working at a rather low temperatures (as shown, a heating source temperature of 35 °C can be sufficient).
(b) The system is not complex and it is relatively easy to implement: it uses well-developed and well-known technology mainly based on heat exchangers.
(c) The proposed system is useful for any industry producing waste heat; furthermore, the system can be adapted to any amount of waste heat.
(d) New potential industrial areas can be defined; locations near city water supply pipes (which would be not considered if the city water heating system was not taken into account) would become attractive for these industries.
(e) The possibility of implementing this system contributes to the acceptance of these industries by local inhabitants because they receive the benefits directly. Moreover, the size of city or town is not too relevant.

Although the system could be applied to different industries producing waste heat, in the following it will be applied to a coal power plant.

2. The 'city water heating' concept: novelty and differences from other systems

As stated above, 'city water heating' consists mainly in bringing a significant amount of waste heat from a power plant to a city by means of heating the potable water supplied to this city. For this purpose three conditions are required:

(1) A great amount of the city's potable water has to be supplied through a single aqueduct.
(2) This aqueduct has to pass near a power station.
(3) The potable water supplied to the city has to be significantly colder than the water used in the power plant cooling circuit.

The procedure is simple: the hot water generated in the power plant cooling circuit (whose heat is usually dissipated in the cooling tower) is conducted through a pipe to a place near the aqueduct. At this point and by means of a heat exchanger, part of this hot-water energy is transferred to the colder potable water which is supplied to the city.

In conventional district heating systems (DHS), high temperature water or steam is routed from a power station to the buildings where it is going to be used. That is, a quantity of hot water is supplied to a specific district. For this purpose, a pipe network leading from the plant to the end-consumers is necessary. These buildings have heat exchangers which allow the transfer of heat from this water or steam to the hot water of the building which will be used in common facilities. In this way, the heat interchanger works as a water boiler. Once the heat is transferred, the water or steam returns to the power station.

In the case of the city water heating system (CWHS), the potable water for common use in a large number of buildings of the city (theoretically all the buildings) is heated before it is supplied. The objective is to moderately increase the temperature of potable water instead of obtaining the facilities' hot water. Increases in water temperature are obviously smaller than in a conventional district heating.

This CWHS has the great advantage of not requiring the construction of complex networks through the city in order to supply a large quantity of heat to end consumers. Only one pipe, from the plant to the heat exchanger near the aqueduct, is necessary.

3. Description of the proposed city water heating system

The research described here has been carried out considering the city of *Oviedo*, Spain (although a small village, *Soto de Ribera*, could also use the same system). In this case, almost all the water supplied to the city comes from nearby mountains (*The Aramo Range*) flowing through an aqueduct which runs past the *Soto de Ribera* power station at a distance of about three kilometres. In

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