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Solar drying of a solid waste from steel wire industry

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HIGHLIGHTS

- A solar dyer was used to dry industrial solid waste.
- It was used a renewable source of energy.
- Reduction of the product mass reduced transport and disposal costs.
- Water activity was reduced from 68% to 11% in about 8 h.

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ABSTRACT

The solid residue coming from the treatment of effluents generated in pickling steel wire has an inorganic nature. This residue, after the process of moisture removal by a filter press, has high moisture content 70% wet basis. Transport costs and landfill could be significantly reduced with the products drying. The use of solar energy to promote drying of the residue is technically and economically feasible. Environmental benefits are presented, due to its renewable characteristic and exemption for emission of greenhouse gases. This study aimed to evaluate the drying of industrial solid waste, using an active integrated solar dryer. The thermal properties and the thermal efficiency of operation of the device in different operating conditions were studied. Experimental tests were developed to evaluate the operation of the solar dryer, until a moisture content (wet basis) of 30% is reached. The instantaneous thermal efficiency of the dryer varied from 9.7% to 29.5%. In the drying experiments, the drying efficiency ranged from 5.2% to 7.2%. Thermal efficiencies presented suitable values for air heaters. Nevertheless, drying efficiencies were low, but they can be improved if the load is increased.

1. Introduction

Waste generations vary from one country to another, but as gross domestic product per capita increases, per capita solid waste generation and other types of wastes also increases. Hence, waste management is a must for conservation of natural resources as well as for protecting the environment in order to approach sustainable development. The rate of waste generated is increasing with population rate and social standards, i.e. the more advanced and wealthy societies (individuals) produce more waste. As a result, many landfill sites are reaching their stated capacities [1] The cost of safe disposal of waste is escalating exponentially and even locating waste disposal sites is becoming more difficult [2].

In the last few decades, large quantities of sewage sludge have been produced, which requires proper and environmentally accepted management before final disposal. The drying of wastewater sludge, sewage sludge or sludge from treatment plants was studied by several researchers, e.g. Refs. [3–9]. Salihoglu, Pinarli and Salihoglu [3] investigated an economical solution to the sludge management problem found in Bursa, Turkey. They concluded that solar drying is a viable alternative, reducing the transportation, handling and landfilling costs. Bennamoun [5] conducted a review of the solar drying of wastewater sludge, focusing on the behavior of the sludge during drying, and on the study of cases. The author stated that in all cases of wastewater treatment, the drying process is considered a basic stage after the mechanical dewatering, which may be done by filtration or centrifugation.

Kelessidis and Stasinakis [7] reviewed published reports on sludge management, in order to outline the current situation and discuss future perspectives for sludge treatment and disposal in EU countries. The authors concluded that a great variety of

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technologies are used: in terms of treatment, anaerobic and aerobic digestion seems to be the most popular stabilization methods; regarding final disposal, sludge reuse seems to be the predominant choice, followed by incineration. Quina, Bordado and Quinta-Ferreira [8] stated that municipal solid waste incineration has been increasingly used in most of developed countries, with the advantages of energy recovery and high reduction in mass and volume of the initial wastes. Nevertheless, the main drawback is the negative impact on environment resulting from emissions to air.

Nemerow [10] states that the easiest way to treat and ultimately dispose of solid waste is not generating it in the first place. However, when there are no further means of waste treatment and no options for waste reduction, solid waste must be handled. To comply with Brazilian environmental legislation, the solid waste generated in the production of steel wires must be deposited in landfill and licensed. This waste has a moisture content of approximately 70%, salts (calcium, iron, chlorides and sulphates) and metals (zinc, copper and lead), as described by Oliveira [11]. The costs of transportation and disposal of this waste are significant for the industry, and they are proportional to its mass. Reduction of the moisture content would reduce the product mass and consequently reduce transport and disposal costs.

Natural sun drying requires little investment, but it is very slow and may present moisture absorption by the product in wet periods and incomplete drying. Solar or artificial dryers could significantly contribute to improving the quality and reduce the duration of the drying process. Artificial dryers promote fast drying. Nevertheless, they consume a considerable amount of energy (fossil, electric or otherwise) to heat the drying air and have high costs. Future energy systems need to be based on renewable energy technologies in order to minimize environmental impacts and account for the finite supply of fossil fuels [12]. In this context, solar dryers arise as an interesting alternative. They promote faster and more effective drying than natural sun drying, with significantly lower costs than artificial drying, since solar energy used for heating the air flow has no direct costs. However, due to seasonal solar availability and the randomness of climatic conditions, the drying airflow is liable to vary. Purohit, Kumar and Kandpal [13] developed a simple framework to facilitate a comparison of the financial feasibility of solar drying as against open sun drying.

According to Belessiotis and Delyannis [14], solar dryers are more or less simple equipment, generally of small capacity, used mainly for drying of various crops either for family use or for small-scale industrial production. Until today, they have not been standardized and/or widely commercialized and in many cases they are constructed on experience base rather than in scientific design and technical calculations. For such reasons, it is important to study this subject. In the recent past, there has been considerable interest among researchers in the design, development and testing of several types of solar dryers. Sharma, Chen and Lan [15] conducted a comprehensive review of the various designs, details of construction and operational principles of the wide variety of practically realised solar-energy drying systems used to dry vegetables, fruit, coffee and other crops. Ramana Murthy [16] reviewed various aspects of solar dryers used for the drying of food products on a small scale. VijayaVenkataRaman, Iniyan and Goic [17] presented the status of solar drying technologies in developing countries. The authors reviewed the various designs of solar dryers, their types and performance analysis. Nevertheless, the analysis is focused on solar drying technologies for crops. El-Sebaii and Shalaby [18] presented a review of solar dryers for agricultural products. The authors presented detailed description, fundamentals and previous work performed on solar dryers and solar air heaters, as the vital element for the indirect and mixed modes of solar dryers. Prakash and Kumar [19] presented a study of the state-of-the art of greenhouse dryers.

Recently, several solar dryers have been developed and used for drying food [20–22]. Alternative configurations of solar dryers have also been proposed in the literature [23–31]. The proposed solar dryers have different configurations. The standard method for testing any equipment is necessary to provide guarantee of quality, safety and reliability to the ultimate customer. Singh and Kumar [32] developed a thermal test procedure that can assist performance comparison between various solar dryer designs on common basis, for 16 different test conditions in terms of single generalized drying curve.

In order to achieve sustainable development, resource use aims to meet human needs while ensuring the sustainability of natural systems and the environment. Sustainable development is closely associated with the use of renewable energy resources [33], recycling or reuse of waste, and, when necessary, minimizing the land use for waste disposal.

The main objective of this work is to perform an experimental analysis of the operation of a solar dryer for the industrial waste from the production of steel wires. The influence of solar radiation on the drying process was evaluated. Drying curves and thermal efficiency are presented.

2. Materials and methods

A small-scale solar dryer was designed and built in the Department of Mechanical Engineering of CEFET-MG. The dryer (Fig. 1) consists of a covered glass and a wood structure, internally and externally coated with black galvanized steel sheets, with internal insulation of glass wool. The structure was made in wood for its characteristic low weight and high mechanical resistance. The solar dryer is 1.8 m long, 1.0 m wide. The height is 0.35 m in the heating chamber and 0.5 m in the drying chamber. The drying chamber area is 0.495 m^2 (0.9 m × 0.55 m) and the solar collector area is 0.99 m^2 (0.9 m × 1.1 m). The drying capacity is estimated at approximately 2 kg of wet waste to be dried at a time. The airflow is forced by a fan at the inlet.

In the dryer (Fig. 2), part of the incident solar radiation crosses the glass cover and reaches the absorber (painted matte black to enhance the absorption of the solar radiation). The airflow enters the dryer at room temperature, is heated by the absorber and crosses the drying chamber in which the product to be dried is placed. The hot airflow removes water from the product and leaves

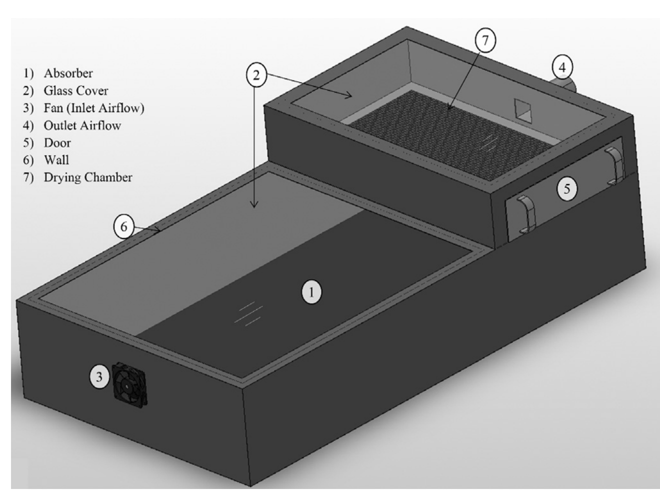

Fig. 1. Schematics of the solar dryer.