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SOLAR RADIATION AS A SOURCE OF ENERGY USED IN DRYING PROCESSES

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drying house, drying, radiation, solar energy

ABSTRACT

The work presents methods of using solar energy in drying processes. The impact of atmospheric conditions on the process of drying is described. The first part of the work contains the description of construction solutions in solar collectors used in agricultural and food processing industry. The second part of the work focuses on solar drying houses used for sewage sludge processing in treatment plants. The work presents the problem of efficiency of solutions of this kind as well as the financial aspect of solar drying houses functioning. The work focuses on solar drying houses, and presents technological solutions used in this kind of plants.

INTRODUCTION

In the past, people dried green material (e.g. grass for animals) to preserve nutritional values of crops and increase the storage period of food products. They dried the material in the open air, which was a lengthy process, and largely depended on atmospheric conditions, in particular, air humidity. Material loses occurred at different stages of drying process:

- during drying: green material loses approximately 50% of its nutritional value during drying;
- in transport: it is impossible to transport 100%dried material to the destination due to its fragility and brittleness; some material will be left in the drying place or on a trailer;
- decay processes: material that has not been dried out properly, stored in the storage room without proper ventilation may begin to decay.

Nowadays, drying is used to preserve green material for farm animals as well as other biological materials and sewage sludge. It is difficult to imagine drying without appropriate technologies in the 21st century. With these technologies, the material is dried using methods that do not allow for losses resulting from decay processes. Moreover, the material retains more nutritional or calorific values due to shorter drying time. In Poland, solar drying houses at sewage processing plants are becoming more popular. In comparison with traditional high-temperature drying houses, drying sewage sludge in solar drying houses requires much less energy.

Due to various applications of solar radiation, as an alternative source of energy in industry, the main goal of the work was to present the potential of using this source of energy in drying processes.

The scope of the work encompasses:

- characteristic of renewable resources of energy,
- methods of drying biological products,
- types of standard drying rooms,
- modern construction solutions using renewable resources of energy (RRE).

SOLAR ENERGY

1.39 kW/m^2 of solar radiation reaches the border of the earth's atmosphere, with only 45% of the total radiation reaching the surface of the earth. Out of the remaining 55%, 22% is absorbed by the atmosphere, 8% is scattered in the atmosphere, 17% is lost by reflection from clouds, another 4% is absorbed by clouds and 6% is reflected from the surface of the earth. As a result, approx. 1 kW/m^{2}of the total solar radiation reaches the surface of the earth [http://www.zielonaenergia.eco.pl/]. The total solar radiation is the total of the reflected, direct and scattered radiation. It depends on the latitude, climate of the geographic region and air pollution. Direct solar radiation is the radiation that reaches the surface of the Earth directly from the Sun through the earth's atmosphere. Reflected radiation is the solar radiation which, on its way to the earth's surface, meets an obstacle such as a cloud or a building and is reflected. Scattered radiation is the radiation deviated in various directions.

Solar radiation is electromagnetic wave, which may be divided into: ultraviolet radiation (wave length of 150-400nm), visible radiation (wave length of 400-750nm), and infrared radiation (wave length of 750-4000nm).

- Solar radiation reaches the surface of the Earth and induces the following reactions:
- photothermic – solar radiation is transformed into heat energy,
- photovoltaic – solar radiation is transformed into electrical energy,
- photosynthetic – solar energy is transformed into chemical compounds energy, which reaction enables plants to produce oxygen from carbon dioxide [Nowicki J.,1980].

Devices, which operate based on the above mentioned reactions are collectors and photovoltaic cells. Collectors use the photothermic reaction to heat up the utility water or the heating system water. We may distinguish the following types of collectors: pipe solar collectors (vacuum), flat-plate solar collectors (gaseous, fluid, two-phase) and concave solar collectors.

The most important part of the collector is the absorber, which is covered by the glass plate. Solar radiation reaching the surface of the Earth penetrates the glass and falls onto the absorber. The absorber absorbs the solar radiation, and heats up heat exchangers, in which the working medium, such as water, glycol or gas, circulates. The temperature of the working medium may increase by a few to more than ten degrees in a single circulation, and the increase of the temperature depends on radiation intensity. In order to reduce heat losses, insulation materials such as mineral wool or expanded polystyrene are used.

A vacuum collector consists of two glass pipes, one transparent one with a greater diameter, which is the shell and another one, with a smaller diameter, covered with a layer of selective coating, which absorbs the radiation. Between the two pipes is the vacuum, which allows for the decrease of heat loses. With vacuum collectors, the temperature of the working medium may reach 150^{o}C. This allows for using such collectors for steam production, and is a considerable advantage. [Klugmann-Radziemska E., 2008].

A concave solar collector consists of mirrors that concentrates solar rays at the absorber, which at the same time, acts as a heat exchanger, filled with the working medium. The advantage of this solution is high temperature of the heated working medium. However, for the highest efficiency, the collector must follow the movement of the sun, which increases the cost of the installation.

Photovoltaic cells use photothermic reaction for the production of electrical energy. There are different generations of photovoltaic cells. Cells of the 1st generation are most often used in photovoltaic panels. A monocrystalline cell is a homogeneous silicon crystal, which results in high efficiency (22%) of PV panels using this type of cell. However, the cost of production of a PV panel is very high compared to other solutions. Polycrystalline cell has slightly lower efficiency compared to monocrystalline cell. A single cell is made of crystallized silicon. Photovoltaic panels of the 1st generation are widely available on the market. They are reliable but not resistant to shading [http://www.obud.pl/].

Cells of the 2nd generation have very thin active layer. Production of panels of the 2nd generation is much lower than the 1st generation but it has impact on the efficiency (10%) and price. Devices using 2nd generation cells are more resistant to shading and perform well in tropical conditions, characterized by high insolation. The disadvantage of such solutions is a small number of products available on the market, and very limited choice of panels made from 2nd generation cells.

Cells of the 3rd generation do not have a P-N junction, used in the two previous generations of cells, which distinguishes this generation from the preceding generations. Due to lack of P-N junction, the cell is not capable of working with classical semi-conductors. This cell is produced using the method of overprinting of very thin structure. It is extremely flexible and fully recyclable. The disadvantages are short lifetime and low efficiency.

Uncovered collectors do not have a transparent coating, and they are usually mounted on roofs or walls of buildings. They have lower efficiency and temperature rise than covered collectors. This solution is mainly used by farmers for heating up air in drying rooms. In drying rooms, which use such solutions, green fodder, cereal grain, herbs, wood chips, wicker, grass, energy plants may be dried [Wiśniewski G., Gołębiowski S., Gryciuk M., 1999]. Such a collector may be used as the roofing, preferably painted dark mat colour (e.g. roofing paper, roofing sheet or roofing tile sheets) with a built-in air duct. The heated air is sucked up to the drying chamber by ventilators. The duct is between the roofing and e.g. the plywood or fibreboard, in the appropriate distance from each other [Pabis J., Szeptycki A., 2012].

Axial fun of 1-5kW power, static pressure of 100-300 Pa and air flow rate of 10 000-40 000 m^3/h are most often installed in this type of drying rooms. Depending on the type of material being dried, e.g. cereal grain, it is better to install centrifugal fans, which have the range of operation from low to high static pressure, high power consumption and low air flow rate [Pabis J., Szeptycki A., 2012]. The disadvantage of uncovered collectors is dependence on atmospheric conditions.

Covered collectors, as opposed to uncovered collectors, are equipped with a shell made of glass or a transparent plastic. The most important element is the absorber, which may be made of metals such as steel, aluminium or copper, and the casing is made of insulation material. Ambient air heats at two levels simultaneously, between the transparent coating and the absorber as well as between the absorber and the casing. Due to the transparent shell, the amount of heat flowing to the environment, as opposed to uncovered collectors, is limited. In order to increase the efficiency of the collector, it is necessary to add more transparent coatings.

Such drying rooms are intended for drying small plant-derived materials (herbs, grains, berries and mushrooms). It uses direct heating. Such a construction works like an absorber.

The air flowing through vents between the bottom and the holes located at the upper lid is heated up by sun rays penetrating through the transparent material. Green material is put on a net for the purpose of more effective drying from each side. In order to increase the efficiency of the drying room, an additional fan may be installed below the drying chamber to force air flow. In Polish conditions, the roof may be flat or may have 30^{o}pitch [Marks N., 2007].

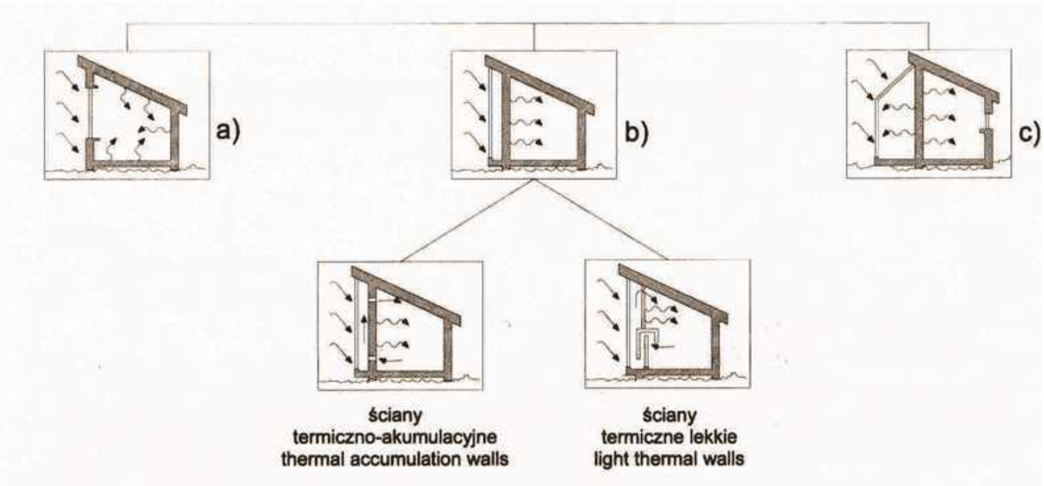

Fig. 1: Solutions related to systems of passive collectors a) direct b) indirect c) complex [Source: Wołoszyn M.A., 1991]

Passive collectors are used in the type of drying rooms presented below, which use the greenhouse effect. Sun rays penetrate through the transparent elements of the drying room, such as windows or glass doors, and are absorbed by the walls inside the drying chamber. The walls releasing heat, heat up the air inside the drier.

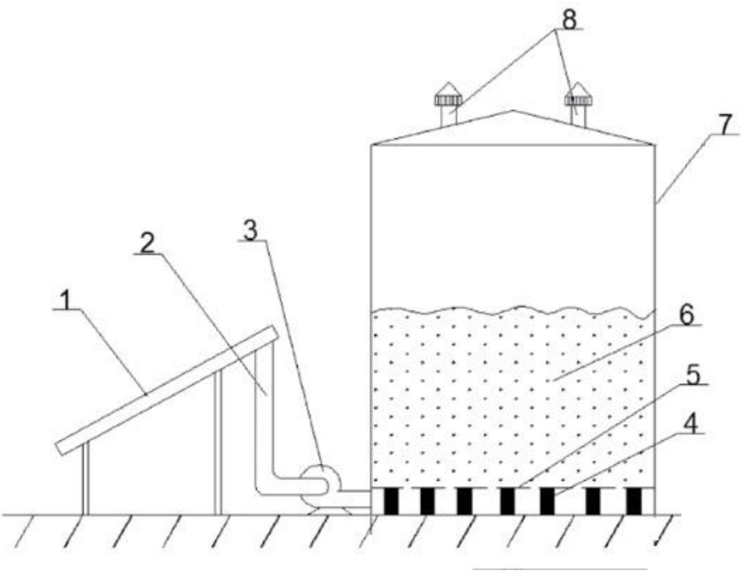

Fig. 2: A diagram of a drying room with an collector. 1 -Collector, 2 - Aggregate channel, 3 – Vent, 4 - perforated sheet floor, 5 - floor support, 6 – Material, 7 – Drying chamber, 8 – Vent [Source: Kopeć A., 2013]

Air collector used in the construction of the drying room, consists of a layer of transparent material (e.g. glass, plexiglass, etc.) and black, insulating material (e.g. black roof paper, foil). In Polish conditions, the absorber should be mounted at the angle of 30° along N-S axis. Material for drying is placed on shelves with perforated (sieve-like) bottom inside the non-transparent drying chamber. Solar radiation falls on the flat-plate air collector. Heated air goes up and through the sieves placed in the chamber and dries the material. Finally, it leaves the drying chamber through the vents in the roof. Such type of the drying house is suitable for drying herbs, mushrooms, berries and fruits [Pabis J., Szeptycki A., 2012].

The principle of operation of a hybrid drying room resembles convective drying rooms. Collectors are not an element of the drying room's construction. The devices are connected by inlet channels which supply heated air directly to drying chambers. Heated air is supplied to drying chambers using ventilators. Ventilators may be supplied by current produced by the photovoltaic panels or from the electrical installation. This drying technology is popular in Poland, and it is used for drying sewage sludge.

The decision regarding the choice of sewage sludge drying method ought to be made based on the location and the size of drying rooms, physical-chemical composition of the material being dried, the final form of the product after drying, final product destination and financial means available.

In Poland, solar drying houses are located in the vicinity of sewage treatment plants. The process of drying sewage sludge is based on renewable resources of energy, thus reducing the outlay for energy.

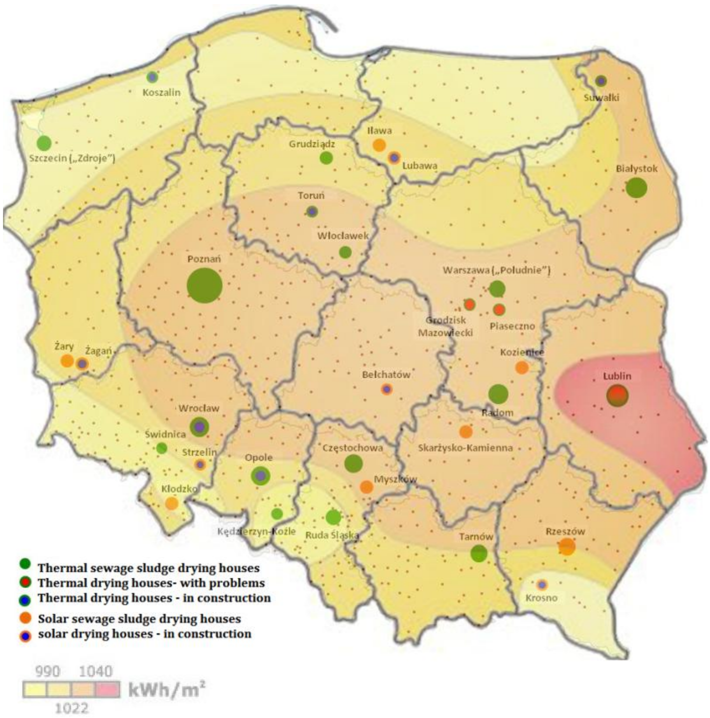

Fig.3: A map of Poland showing the intensity of solar radiation and the location of sewage sludge drying houses [Source:Wójtowicz A., 2012]

The map shows the location of thermal drying houses and solar drying houses and the intensity of solar radiation in Poland. Hybrid drying houses are located, i. a., in Bełchatów, Myszków, Krośno, Kłodzkowo, and solar houses are located in Żary and Lubawa. Poland receives only approx. 1000 - 1100 kWh/m^{2}solar energy [Podogrodzki J., Leszczyński M., 1982]. Solar drying houses operate from spring to autumn. During the winter, they become storage rooms for sludge, as in the winter the insolation is too low, air humidity is too high, and the process of water evaporation takes too long. Summer is the best period for drying, as the insolation is the highest, and the day lasts the longest, thus making sludge drying more intense and cost-effective.

Mechanical drying houses do not depend on atmospheric conditions. However, they consume much more electrical energy for drying out 1m^3 of sludge than solar drying houses. The efficiency of solar drying houses depends on relative air humidity, solar radiation, active area of the drying room, temperature inside the drying room [Mehrdadi N., Joshi S.G., Nasrabadi T., Hoveidi H., 2007].

In drying rooms, greenhouse effect may occur. Direct radiation, reaching the surface of the earth, falls on the roof; some of it is reflected by glass panes and the remaining part is absorbed by the sludge. The sludge heats up from solar radiation and emits heat, which circulates inside the heating house, resulting in the increase of the temperature inside the house, and accelerating the process of water evaporation from the sludge.

Drying process in solar drying houses predominantly depends on solar radiation, which, in turn, depends on the time of the year.

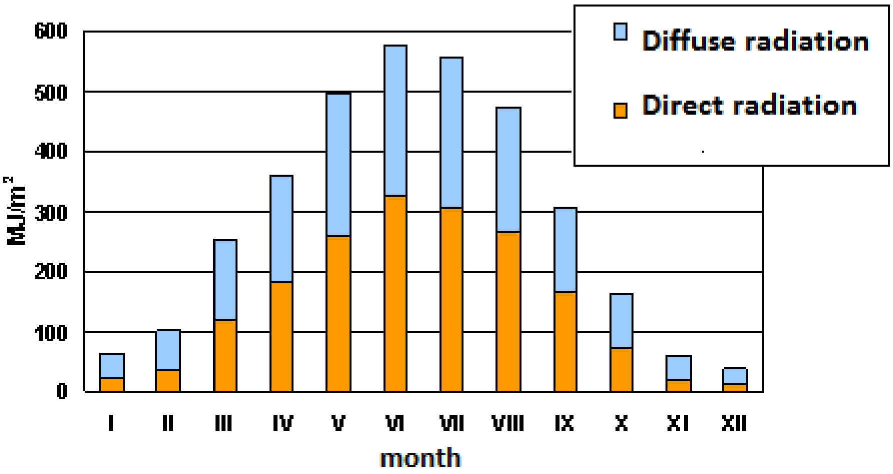

Fig. 4: Monthly amount of radiation received by a flat surface in Warsaw [Source: http://ekologika.pl/]

The graph shows monthly amount of radiation divided into indirect and scattered radiation, which reaches the flat surface in the latitude, in which Warsaw lies. The radiation in various regions of Poland ranges between 3230 MJ/m^2/year and 4310 MJ/m^2/year.

Solar drying houses in the temperate climate zone, in which Poland lies, do not work all the year round. During winter, due to sub-zero temperatures and low insolation, the accumulated sludge may freeze [http://suszarnie.itc.pw.edu.pl/].

Air humidity is a significant parameter that describes the process of drying. Relative humidity of the drying medium depends on air temperature. The potential of humidity reception by the working medium (drying air) is the difference between the dew point and the real relative humidity. In Poland, large diurnal variations in relative humidity may be observed, which do not depend on the season of the year.

High relative humidity during the winter results in lowering the reception of humidity from the sludge by the drying air. In order to increase the reception potential from the sludge, at high air humidity conditions, it is required to heat up the drying medium.

The construction of drying houses is similar to that of a greenhouse, but the house has concrete floor, and is tiled using one-chamber polycarbonate plates (the exception is Strzelin, where the house is built using glass panes). The material used for the construction of the house has good solar radiation transmittance (86%),and low heat transfer coefficient

(3.3W/m^{2}K). The drying process in this type of drying houses involves sun rays penetrating through the roof covered by transparent plates, drawn by the natural colour of sludge [Trojanowska K., 2006].

Sewage sludge technology using solar radiation allows for the continuous work of the drying house. Moist sewage sludge are placed at the entrance to the chamber using loading machines, belt or screw conveyors. At a later stage, a sludge turner gradually transports the sludge to other areas of the drying room. A single passage of this device moves the sludge in the drying room approx. 50 cm, at the same time storing dried out sludge at the far end of the room. Due to the continuous mode of work, the drying house has a higher efficiency in comparison to a drying room with the interrupted drying cycle. [Wójtowicz A., 2012].

Ventilators, which enable air flow inside the room, are the indispensable element of solar drying houses. Such a system of mechanical ventilation was installed in drying houses located in Krosno and Wieruszów. The air is held inside until it reaches the point of steam saturation humidity, and it is replaced with the fresh air. In Kozienice and Żary gravitational-mechanical ventilation (hybrid ventilation) is installed. This system of ventilation works in the following way: the system of ventilation works in a natural (gravitational) way for a longer period of time, i.e. the roof windows open and close automatically, and, additionally, a mechanical system starts working when air exchange is insufficient. The mode in which the system works i.e. natural or mechanical depends on air humidity degree detected by moisture detectors connected to the control system. Circulating air speed forced by ventilators amounts to approx. 1m/s [Malicki M., 1977].

Heat energy from additional sources using cheap fuels is used in hybrid drying houses. The heat is distributed using floor heating system, heating up ventilation air or low-temperature radiators (infrared). There are area-related limitations related to difficult lie of the land in order to make solar-based drying cost effective. Also, additional heat sources are used to dry out more sludge in shorter time [Sobczyk R., Sypuła M., 2012].Drying houses in Kozienice, Żary, Żagań and Lubawaonly use heat from sun rays while drying houses in Rzeszów, Skarżysko-Kamienna and Iława use heat from biogas combustion. Additionally, in Iława, heat pumps are installed as in Kłodzko, Myszków or Strzelin, and in Wieruszów the central heating system boiler is coal-fired [Sobczyk R., Sypuła M., 2011].

Additional sources of heat and reduction of loses by low heat transfer coefficient allow for drying sludge in winter. Drying houses use heat installations such as heat pumps, biogas- or coal-fired boilers. Heated air has lower relative humidity than non-heated air, which increases the potential of water reception from deposited sewage sludge [Sobczyk R., Sypuła M., 2010].

The disadvantage of heated air is the loss of heat by the construction of the drying room itself, which is light and open. Heat loses are inevitable when floor heating system is used, the cause being the sludge, which acts as insulator. The most efficient method of drying is using additional sources of energy such as biogas-fired infrared radiators. Radiation emitted by radiators and solar radiation have similar characteristics. Biogas combusted in infrared radiators is transformed into electromagnetic waves, which heat the sludge instead of the heating air. According to the principles of thermodynamics, drying effectiveness is higher when warm surface layer of the sewage sludge is blown through by the cold air [Trojanowska K., 2011].

Solar drying houses that use solar radiation as an alternative source of energy have both advantages and disadvantages. The advantages include low energy consumption, using renewable resources of energy, simple construction, no pollution emission, low cost of drying, shorter drying time in comparison with open-air drying, no additional source of heat such as heat oil or natural gas required, automation. The disadvantages include dependence on atmospheric conditions, lack of a system to regulate the parameters of drying process, very long drying time in comparison to thermal drying houses.

SUMMARY

Poland lies in the temperate climate zone, which is characterized by lower intensity of solar radiation in comparison to the countries in tropical or equatorial climate. In this latitude, various technological solutions allowing for solar energy use are applied, with the most popular being solar collectors, which transform solar energy into heat energy, used for heating utility water, and photovoltaic cells, which allow for the transformation of sun energy into electrical energy. The solutions are not only used in industrial establishments or enterprises but also in individual households or detached houses.

In agriculture, solar collectors are used for drying different kinds of agricultural products such as crop grain, power plants, hay, fruits or mushrooms. Construction of some driers is not very complicated and may be done without hiring professionals. Collectors may be mounted on roofs or south walls of buildings.

Solar energy is used in production plants such as sewage treatment plant for the purpose of drying sewage sludge. Sludge drying may be divided into solar – solely based on solar radiation energy, and hybrid – requiring additional sources of energy, such as heat pumps, biogas or coal. The most effective solution is a hybrid drying house with low-temperature gas-fired radiators.

The cost of such a solar drying house for sewage sludge drying depend on its exclusive reliance on solar energy or use of additional sources of energy.

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