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Comparative approach to the performance of direct and indirect solar drying of sludge from sewage plants, estimation of rates of organic materials

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Abstract— **The objective of this work is to contribute to the enhancement of sludge of wastewater treatment plants in Algeria. A kinetic comparison was made to the direct and indirect solar driers operated with natural convection. The indirect dryer gives temperatures and high efficiency with the direct drier. Drying curves show that the higher the temperature, the higher the short drying time and the drying speed is fast. Solar dryers have reduced the time needed, a water reduction of 71% which increases the dryness of the mud from 14.47% to 85.53%. According to the results obtained, the use of sludge could be very interesting from an agricultural and energy point of view, because it contains more than 58% of MO and can reach 63% in the three summer months (June, July and August).**

Keywords— **Organic matter, Physic-chemical characterization, Renewable energy, Sludge, Solar drying, Thermal treatment.**

Nomenclature
DM: Dry matter (%)
DSD: Direct solar drier
ISD: Indirect solar dryer
OM: Organic matter (%)
WM: Wet matter (%)
X: Water content at any instant t (Kg eau/Kg DM)
X_0: Initial water content (Kg eau/Kg DM)
X_r: reduced water content (X_r=X/X_0)

I. Introduction

Today more than ever, waste management has become a priority of the environmental policy in the world **[1]**. Wastewater from various urban activities cannot be rejected as such in the environment because they contain various organic and inorganic pollutants. They must undergo before their release into the natural environment, a sewage treatment which leads the production of sludge **[2]**.

The sludge purification plants are considered as waste by several regulations. They are bulky waste (95 to 99% water) whose composition is problematic: highly fermentable substances, high disease burden (viruses, bacteria, parasites ...) **[3]**.

In Algeria the volume of wastewater discharged nationwide is currently estimated at nearly 750 million cubic meters and will exceed 1.5 billion m^3 by 2020. The current situation (operation) number of wastewater treatment plant: 102 (52 PLANTS + 50 lagoons) current installed capacity: 570 hm^3/year (1999: 28 PLANTS to a processing capacity of 98 million m^3 / d) Location of being implemented program: Number of wastewater treatment plant: 176 (87 PLANT+89 lagoons) installed capacity: 355 hm^3/year **[4]**.

The problem of disposal of sludge from sewage treatment plants is more delicate given the increased production of wastewater and regulations that is becoming more demanding. The use of sewage sludge in agriculture has been widely practiced in most developed countries **[5]**. Sludge processing pathways have always had goals, reduction of volume and fermentability namely their stabilization **[6]**. In this perspective, the drying is often a necessary Plant to facilitate subsequent management of sludge as recovery or storage **[7]**.

There are several methods for sludge dewatering, among which mention is mechanical dewatering and thermal drying. The latter will be a development because it is the one that was chosen as part of this work.

Drying is a dewatering method for the extraction of a solid, semi-solid or a liquid by evaporation **[8]**. The dryers are different because of the energy source that can be used as a fossil fuel, gas, electricity or solar power and the nature of the transfer of heat that is transmitted to the product **[9, 10]**.

Energy has always been a vital issue for humans and human societies. Human behavior is strongly induced by the availability or non-availability, abundance or its scarcity. These behaviors will arise new challenges, particularly for the environment and the socio-economic balance **[11, 12]**.

Renewable energy has been a first phase of development on the occasion of the oil shocks of 1973 and 1978 and a downturn after the against-shock of 1986, before finding a second breath in 1998 following the signing of the Kyoto Protocol, a protocol which provides for an 5.2% decrease in gas emissions greenhouse of rich countries over the period 2002 to 2012 compared to 1990 **[12, 13]**. Solar energy is a viable alternative for developing countries such as: Algeria. The use of this renewable energy can meet the drying process in the interests of sustainable development.

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It should indeed know that Algeria belongs to the regions located in the sun belt of northern Africa, southwestern United States of America, Australia; these regions have the highest solar deposits in the world.

For Algeria, the duration of exposure on almost all the national territory exceeds 2000 hours annually and reaches 3,900 h (Highlands and Sahara). The energy gained daily on a horizontal surface of 1 m^2 is about 5 kWh over most of the country, nearly 1700 KWh / m^2 / year in the north and 2263 KWh / m^2 / year in the south **[14, 15, 16]**.

In the solar drying there are two modes according to the bibliographic data or direct drying when the material to be dried directly receives solar energy is indirect drying when solar energy is captured by a device called a solar collector generally allows then preheat the air which is then sent to the products to be dried **[9]**. The main challenge for research is to improve energy efficiency and optimize the design methods and design of these solar drying processes.

Solar drying greenhouse is positioned as an alternative method, which reduces the volume of sludge with minimal energy expenditure and preserves, through better adjusting, the value of the final dryness of the mud.

In Algeria, the solar drying is still at the experimental stage, to that end, our work is a contribution to a better understanding of solar sludge drying by direct and indirect means. The experimental study is to measure various physical parameters such as: temperature, humidity, lost weight ... etc.

II. MATERIALS AND METHODS

Two drying methods have been carried out to develop a dehydrated sludge from a wastewater treatment plant WTP wilaya of Boumerdes. Solar dryers, Fig. 1 (a, b), have been designed and made by (Solar Energy Development Unit BOU ISMAIL). This is a system that converts solar energy into thermal energy by direct way either (DSD) or through a coolant (ISD).

A. *Dryness of fresh mud*

Dryness is the DM rate of dewatered sludge and thickened sludge, this factor provides information on the proper treatment of the sludge. We weigh the empty crucible and there is EW (g). We introduce a quantity of sludge (thickened or dehydrated), is weighed crucible filled mud and we write FW (g).

Dry the crucible at 105 °C for 24 hours, then taken out of the oven and placed in a desiccators. Finally, we weigh the crucible and note WO (g). DM rate is determined according to equation (1)

$$DM(\%) = \frac{WO-EW}{FW-EW} \times 100 \quad (1)$$

1) *Direct solar drying (DSD)*

The sludge is dried in a thin layer: a single product thickness is disposed on one or more racks mesh with an airflow perpendicular. A glass is inclined by 55 °, which allows having a maximum of radiation in the winter periods. . The indirect dryer is shown in Fig. 1 (a). The temperature inside the dryer is measured by the device called "testo" is 50 °C and the ambient air is 20 °C. The air velocity is between 1.2 and 2 m / s.

2) *Indirect solar drying (ISD)*

Solar radiation is collected by the absorbent surfaces (air manifold 2 m^2), which heats up a heat transfer fluid (air) directed into a confined space (drying chamber) in contact with the product to be dried (mud). Several studies have shown that nearly 10 ° as the angle of inclination of the solar sensor gives better results **[17]**. The drying chamber has a cubic shape with 1 m^3 of volume and can hold up to three trays. It is made of sheet steel with a thickness of 2 mm to prevent corrosion. This latter is covered with 4 cm thickness of polystyrene used as insulation. The trays are perforated to allow good air circulation in the mud. The chamber has a fireplace for discharging humidified air as shown in Fig. 3. The drying operation is propagated on the dryer trays. The velocity of the air entering the dryer is measured by an anemometer remains substantially constant throughout the experiment; its value varies between 1.2 and 2 m / s. The indirect dryer is shown in Fig. 1 (b). The drying air temperature is measured by "testo" is 67 °C and that of the ambient air is 20 °C.

(a) (b)

Fig. 1. Solar dryers: (a) DSD ;(b) ISD

B. *Sample preparation*

The sludge was collected in the decanter in March 2015. The samples were stored at 4 °C in a cooler and transported to the laboratory within 24 hours and are then stored in the freezer at -20 °C to avoid any changes in characteristics sludge. Samples are prepared and spread on drying trays. The mass of the sample to be dried is 300 g with a thickness of 2 cm for all test scenarios Fig. 2.

(a) (b)

Fig. 2. Spreading of the sludge on the trays: (a) DSD ;(b) ISD

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C. *Drying conditions*

The same mass is 300 g of fresh mud, was taken to the two modes of drying (ISD, DSD). The drying was stopped when the difference between three successive weighed is less than 0.1 g. The air blown is not conditioned, it arrives perpendicularly inside to cross the lower face of the samples placed on the perforated grid. Its temperature and relative humidity are those of the ambient air in the case of direct dryer, and those of the coolant in the case of indirect dryer, where the rate was almost constant from 1.2 to 2 m / s, relative humidity ranging between 15.2% and 20.3%, temperature of ambient air and coolant air is 20 °C, 67 °C successively.

D. *Drying kinetics*

The essential purpose of this part is to monitor changes in dried sludge mass losses to determine their drying rates. We determined for each mode of drying, the mass variation, the temperature, the time and the yield.

Is meant by drying curve, the curves X = f (t) representing the variations of the water content X (equation 2) as a function of time t. To determine the dry mass of DM products, sludge samples dried in solar dryers were then placed in an oven set at 105 °C for 24 hours until the mud reaches its maximum dehydration (equation1).

$$X = \frac{WM - DM}{DM} \qquad (2)$$

III. RESULTS AND INTERPRETATIONS

Sludge production was very important during 2014, especially in the months of June and July, with amounts of 3934.37 and 3906.05 m^3 per month, which poses the problem of storage. The percentage of OM varies between 44.99 and 63.91% with a monthly rate equal to 54% and peaks in the months of June, July and August, equivalent to percentage 63.91, 63.66, 62.25% successively (Fig. 3).

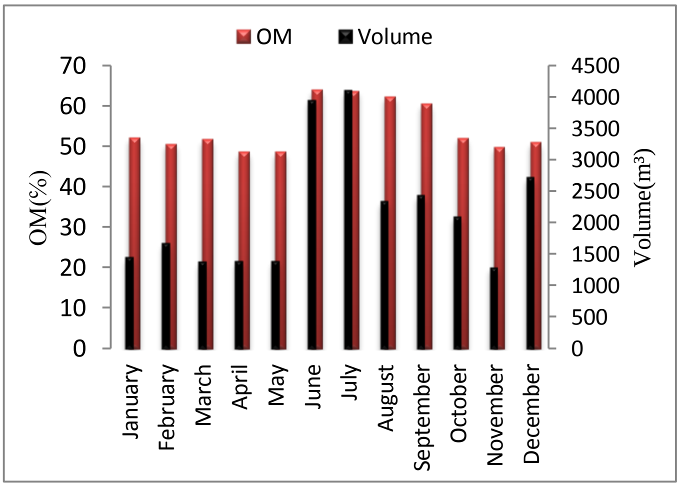

Fig. 3.Volume of sludge produced and its rate OM (Boumerdes station) in 2014.

A. *Temperature measurement*

For indirect dryer selecting three locations to measure temperature, the first thermometer is placed at the entrance of the sensor to measure the temperature of the ambient air, the second to the output of the sensor for measuring the fluid temperature (air) which transfers heat to the drying chamber, and the third level of the key (mud). By against direct dryer is placed only two thermometers, one at the entrance of the chamber and the other at the key (mud). The recorded temperatures are quoted on Fig. 4, 5.

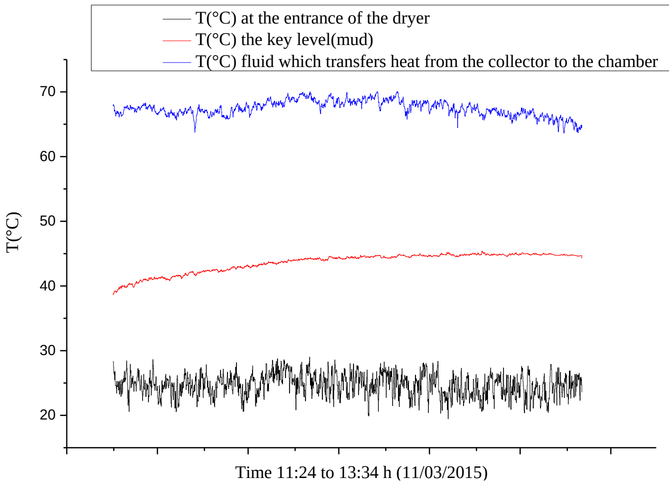

Fig. 4. Temperature evolution in function of time for different measuring points, ISD

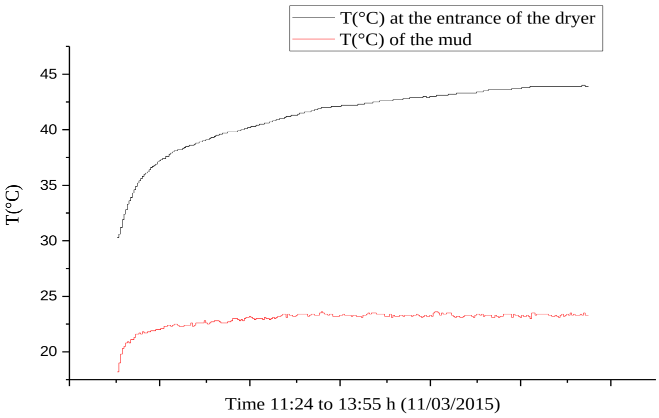

Fig. 5. Temperature evolution in function of time for different measuring points, DSD

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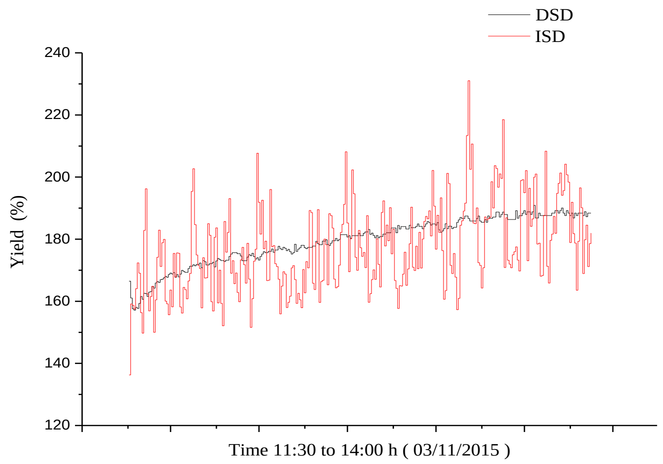

Fig. 6. Yield of the temperature rise for two dryers (ISD, DSD).

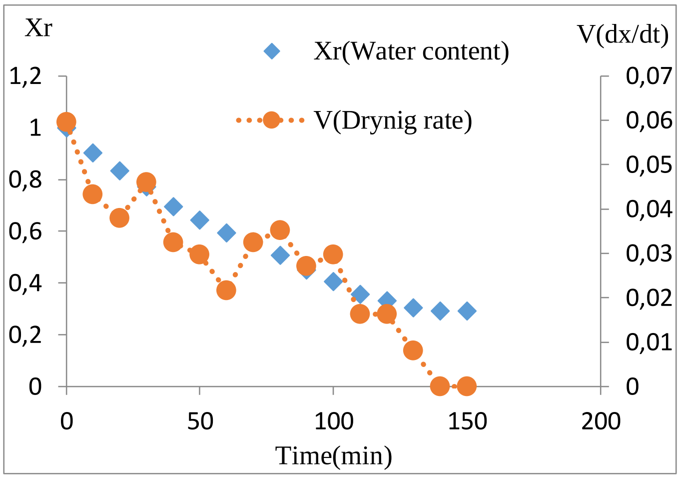

Fig. 7. Evolution of moisture and the drying rate of the sludge, as a function of time, ISD.

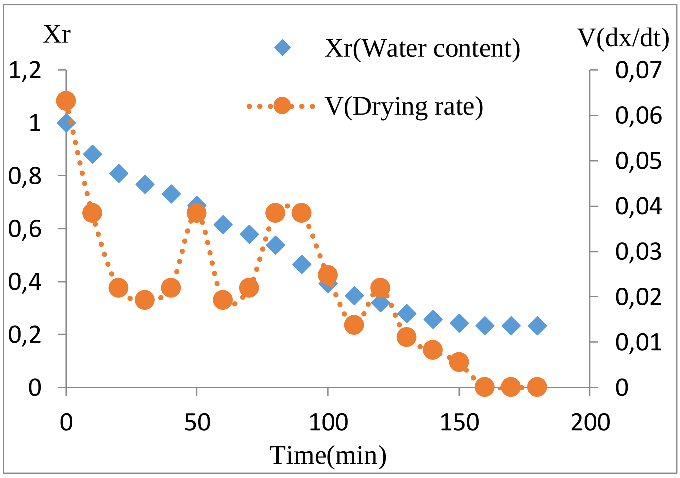

Fig. 8. Evolution of moisture and the drying rate of the sludge, as a function of time, DSD.

According to Fig. 4, 5 the temperature readings are more clear and important in the case of ISD. The outside temperature average is 24 °C. To sensor temperature is 67 °C; the same temperature was obtained with a maximum of 70 °C **[17]**. That is to say an increase of 43 °C. The temperature inside the chamber (mud) is 44 °C, compared with that of the outside; the temperature gain is 20 °C.

Concerning DSD high temperatures are less important compared ISD, with 55 °C for drying air at the drying chamber. The mud the average temperature of 41 °C, compared with that of the outside (24 °C) means a gain of 17 °C. Based on Fig. 6 which give a comparison on performance between the two types of DSD and ISD dryers, the last is most effective views the rate of temperature rise, which saves time of drying following other works **[18, 19, 20]** showing that the temperature increase of the air (or in other words, an increase in energy intake) leads to reduction of the drying time.

In natural convection runs, with ambient temperatures ranging from 22 to 24 °C, the total drying time in the indirect solar dryer was less than in the direct one. By against studies have shown that at higher temperatures vary from 32 to 40 ° C, the total drying time in the direct solar dryer was less than in the indirect one**[21]**, his can be explained by the increase of the greenhouse effect in the solar dryer has high ambient temperatures

B. Drying curves

The initial water content of the sludge is 5.28, 6.15 kg water / kg DM and they were reduced to final water contents of 1.22, 1.78 kg water/kg DM on ISD, DSD respectively. The curves of evolution of the reduced water content versus time ($X/X_0 = f(t)$) and speed are gathered on Fig. 7, 8.

During the drying operation, there is a double transfer: thermal and mass. So that the air at its output has greater moisture, while its dry bulb temperature has dropped. On its side sees the mud decrease its relative moisture and grow its dry temperature. To illustrate these transfer movements, there are several characteristic curves called "drying curves".

The drying curves of the treatment plant sludge wastewater in both cases drying (ISD, DSD) obtained experimentally, describing the evolution of the water content or the absolute moisture with time and the varying the speed of drying are presented in Fig. 7, 8. Recall that in both cases drying the objective was to bring the mud at the minimum water content.

We note the absence of the phases of setting temperature of the sludge (phase 0) and drying to constant pace (phase 1). Only the decreasing speed phase or slowdown (phase 2) is present in both types of drying. This is the slowest step describing the evaporation of water capillaries **[22, 23]**. Bimbenet and al, and Kechaou noted that the first phase of drying was not observed in several biological products **[24, 25]**. The same results were

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found but with vegetable products **[25, 26]**. In fact, Idlimam and al reported that the warm-up period virtually disappears when the product is in leaf and the period at constant speed is not found in the majority of cases when it comes to vegetable product **[27, 28].** This proves that our mud contains important quantity of plant origin (vegetables, fruits, tree leaves ...), and therefore rich in organic matter that can be upgraded later or in agriculture as fertilizer or domain energy to produce biogas through methanation (anaerobic digestion).

The pace of mud drying kinetics shows that the water content decreases rapidly in the early times of drying, then more and more slowly too long time after evaporating the free water and the adsorbed to the surface. On the contrary, the bound water is chemically attached by strong bonds to bacteria and other particles and can only be removed by thermal drying at temperatures above 105 °C. Indeed, at the beginning of drying, the water moving mechanism by capillarity through the pores of the walls of the solid to the surface is carried out in an accelerated manner reflecting a rather rapid decrease of the activity of water in mud. At the end of the drying process, increasing the temperature at the center of the mud and the decrease of its water content lead to a new equilibrium in the mud, an enthalpy balance in which the temperature difference between the air and the sludge decreases and the water activity of sludge will be in equilibrium with the relative humidity of the air. In this equilibrium, the water therefore migrates more and more difficult in the mud and the internal transfer of matter becomes a limiting phenomenon.

The proportion of water in the mud, and exactly how that water is linked with the complex system, consisting of organic and/or mineral plays a role in relation to the liquid-solid separation. The water connection concept of the solid matrix is still unclear and several classifications have been proposed. The simplest distinguish free water, so-called bound water, and then divide the latter category in various sub-classes according to the intensity of forces of interaction water / solid particles **[29]**. Thus we find **[30]** the interstitial water, surface water and chemically bound water, as shown in Fig. 11. Another phenomenon are added and make the transfer of hard material such as the solute concentration, the development of the phenomenon of crust formation and curing the product surface, reflecting a possible resistance of cell walls **[31]**.

According to Fig. 9, 10 the drying rate is proportional with the water content and the temperature of the drying air and inversely proportional to time. Based on the deceleration stage it may be divided into three parts; the first part where the speed decreases proportionally with the time, because the evaporation of the water surface, i.e. free water. In the second step, the curve becomes sinusoidal with a peak every 20 minutes, this explained by the migration of water from the inside to the surface, and when it becomes in contact with air, it evaporates and consequently the speed rises. The third part is called the partial slowdown begins when the sludge reaches its threshold hygroscopic, that is to say, the remaining water in the mud cannot rise to the surface. The surface drying front has migrated to within the mud. The more this drying front is located away from the outer surface of the mud, the greater the drying rate slows.

The dryness of the mud equal to 14.47 % so the water is about 85.53 %. According to Fig. 9.10 water reduction is almost 71 % in both cases of drying (ISD DSD) which increases the dryness value of 14.47 % to 85 %. According to the literature, this is pasty mud **[32]**, and the maximum target of solar drying is to achieve a dryness of 75-80 %. Higher solids contents of generate new operating constraints (dust). The temperature of the drying air in ISD is 67 °C; however in the DSD chamber is 50 °C, which is why drying in the latter lasts longer than the first with half an hour difference. This confirms that the drying temperature is an important parameter for internal transfers of water in the mud.

Conclusion:

This present work involves the experimental and theoretical study of drying. A first experimental study is carried out on the wastewater treatment plant of the wilaya Boumerdes (Algeria), using two solar dryers; direct and indirect, to study the sludge drying kinetics while determining changes in water content and product drying rate and characteristic drying curve. Analysis of the dryness gave a value of 14.47 % consequently a water content of 85.53 %. The effect of the thickness had much effect on the moisture content of the sludge, which is why the thickness has been set for the different experiences so we can make a comparison of performance between two types of dryers. The sludge dewatering was carried out at temperatures ranging from 38 to 67 °C, noting that the indirect solar dryer gives temperatures and high efficiency with the direct dryer which significantly minimizes drying time.

The study of the kinetics of solar drying of sludge only shows the presence of the deceleration phase, and the absence of warming-up phase and that of the constant rate, as is the case for the majority agricultural products. The pace of mud drying kinetics shows that the water content decreases rapidly in the early time of drying, then more and more slowly to long time after evaporating the free water and the adsorbed to the surface. Drying stops after the complete evaporation of free water and that absorbed at the surface. Bound water is chemically attached by strong bonds to bacteria and other particles and can only be removed by thermal drying at temperatures above 105 °C.

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