A NOVEL TECHNOLOGY FOR DEWATERING AND PASTEURIZATION OF DIGESTED WATER SEWAGE SLUDGE UTILIZING CONCENTRATED SOLAR ENERGY

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ABSTRACT

The disposal of waste sludge, which is a final product of industrial wastewater treatment plants, is an essential process for many industries and municipalities in the world. This sludge contains about 80-85% water and is usually not safe to store in wild disposal areas without any treatment. Safety and health regulations in developed countries require the post processing of the sludge to achieve a certain minimum dry solids percentage. This results in excessive power consumption and greenhouse gas emissions when conventional dewatering operations are applied. In this study, a novel method is presented that utilizes the concentrated solar energy to increase the dry solids ratio in the wet sludge and to achieve sludge pasteurization. This system does not produce any greenhouse gases since no fuels are burned to supply thermal energy in the process. This new approach helps also to stabilize the waste sludge in terms of disinfection prior to use in further applications. Calculations of a sample case are presented for a facility in North Cyprus that processes about 600 kg waste sludge per day.

1. INTRODUCTION

Sewage sludge is the solid matter that is left when sewage is treated by the water industries and/or the wastewater treatment plants. It is mainly human waste but also includes the drainage from industries, animal and vegetable processing, and storm water run-off. In Europe, sludge production varies between 0.1 and 30.8 kg per population equivalent per year **[1]**. Some contents of sewage sludge are good for soil and plants. Others, like the heavy metals, are potentially toxic elements (PTE) which are safe only if they are below set limits. Sewage sludge contains nitrogen, phosphorus and organic matter. It can supply a large part of the nitrogen or phosphorus needed by most crops. But direct use and disposal of sewage sludge involves some risks and problems. High levels of PTEs threaten the health of plants, animals and people. Sludge also contains viruses, bacteria and other disease causing organisms known as pathogens that may cause many environmental problems. The high moisture content of the wet sludge is also undesirable in agricultural land applications for many reasons. When the sewage sludge is abandoned for landfilling in monofills or applied on land as a fertilizer without any pre-treatment processing, the following undesirable situations can arise:

1. The untreated sewage sludge contains pathogens that pose potential human health risks for public health and environmental hazards.
2. If not sufficiently disinfected, the organisms present in the sewage sludge will generate ammonia, methane and hydrogen sulfide gases that are harmful and disturbing.
3. When disposed without any pretreatment, the sludge does not dry up naturally except for the surface and the inner parts of the sludge become a suitable medium for the pathogenic airborne organisms to grow on.
4. The volume of the sludge, when accumulated over the years, is too much to handle near an urban setting and may result in production of unbearable odors.
5. The transportation of the waste sludge with high moisture content is difficult and bears high costs.
6. At a landfill site, the heavy metals may leach into soil with rainfall and contaminate both the soil and the crops grown up on land.
7. The application of wet sewage sludge as a fertilizer on land is difficult since it will not

be homogeneously mixed with soil due to agglomeration problems.

Consequently, the rules and the regulations regarding the disposal of sludge are becoming more and more stringent **[2]** and the sewage sludge needs to be processed in one of the several ways before being used for other purposes. After aerobic and anaerobic degradation processes being conducted in the wastewater treatment plants, the sewage sludge produced may need to be further subjected to either mesophilic or thermophilic digestion process **[3]**. Thermophilic anaerobic digestion of sludge results in destruction of almost all pathogenic organisms but in North Cyprus mesophilic anaerobic digestion is performed which results in partial destruction. The waste sludge, subjected to mesophilic anaerobic digestion, still has a high moisture content even though it might have undergone through some extent of microbial disinfection **[3]**. Thus, the next following step is the mechanical dewatering of wet digested sludge, which reduces water moisture by about 20% **[4]**. Following dewatering, lime stabilization is performed and a final thermal processing is used to bring the dry solids percentage to 50% by weight before final disposal, according to requirements in regulations. A common practice is to use this processed sludge for landfill on a monofill disposal and/or for agriculture as a fertilizer. However, thermal treatment process involves extra fuel and power consumption, which increases the cost and carbon footprint of the disposal process and releases gases that increases global warming on earth.

To overcome some of these problems, new alternative processes have been developed. These new methods are based on the fact that sewage sludge is a material that contains high amounts of organic material that will yield high thermal energy upon combustion. A heating value range between 6 to12 MJ/kg DS can be achieved by direct combustion of dry waste sewage sludge **[5]**. For comparison, the heating value of gasoline is 45 MJ/kg, that of charcoal is 30 MJ/kg, and that of wood is nearly 15 MJ/kg **[6]**. Direct combustion, or incineration, is a method in which sludge is first dried to 80-90 % dry solids percentage by weight, and then combusted in the presence of oxygen **[4]**. The heat produced in the combustion is used for two purposes; part of the heat is recycled to dry the incoming sludge prior to combustion and the other part is used to generate steam, which is run through a gas turbine to generate power. In this way, the net volume of the material to be disposed is reduced dramatically, the net carbon footprint of the entire process is curtailed and due to the high temperatures involved in the combustion process possible pathogens present in the sludge are destroyed. But however, due to excess temperatures in combustion, in the presence of air, highly poisonous and environmentally harmful NO_x gas emissions occur that need to be controlled and minimized **[7]**. Also, heavy metals, if not removed before from the sludge and emitted with the exhaust gases from the sludge combustion, must be filtered before being vented into the atmosphere.

As an alternative method to direct incineration technology, co-incineration of the waste sewage sludge with coal has been developed, which can better accommodate the humidity in the sludge, eliminating the drying step and saving energy **[8]**. The extra calories from the organic material in the sludge increases the overall energy output of the combustion reaction but however, the extra ash due to the increased amount of solid material leads to more NO_x formations and further complicates the post-combustion handling of the process. As a result, the overall energy efficiency of the co-incineration is not much different than the combustion of coal alone. Waste disposal remains as the main benefit of this option.

Another alternative is the gasification, which involves the exposure of the waste sewage sludge to elevated temperatures in a closed system with the presence of only sub-stoichiometric levels of oxygen **[9]**. The incomplete and partial combustion of the dry material helps to keep the temperature high, and in the meantime, a combustible gas called syngas is synthesized. This gas can be used as an energy source to be burned on-site or elsewhere. This process, too, results in NO_x emissions as in direct incineration or co-incineration, but at much lower levels, since the temperatures involved are much lower.

Similar to gasification, which produces a combustible product, there are two other methods leading to a similar end product. Pyrolysis **[10]** and hydrothermal carbonization (HTC) **[11]** are processes that produce solid fuel from the sludge in a closed system at moderate temperatures. The main difference between them is the temperature range for the process. Pyrolysis takes place at a higher temperature range (300-500 ^{o}C) than that of the HTC (180-350 ^{o}C), and pyrolysis requires the sludge to be dried initially, whereas HTC requires the presence of water. Due to its higher carbon retention in the end product, the HTC yields a fuel that has 15-30 MJ/kg of dry solids heating value.

Throughout all these methods, the primary goal remains as the safe disposal of the waste sewage sludge. Reduction in the overall carbon footprint and the probable power generation are considered as secondary objectives. A comparison of these and other methods are presented in the paper by Tyagi and Lo **[12]**. Except for the HTC, all alternative processes require the sludge to be dried up to 80-90% DS by weight before it is used. When accounted for this and other extra processing requirements, the net gain by the energy production or the decrease in the carbon footprint is more or less compromised **[13]**. Therefore, the maximum gain in the whole process of sludge treatment and disposal comes through the disposal technique with the least environmental impact.

To improve the situation, use of renewable energy sources can be incorporated into the sludge thermal processing systems. A straightforward approach is to use the solar energy through a greenhouse setting for the drying of the sludge **[14] [15]**. On top of reducing the carbon footprint, this facility is calculated to reimburse its cost in nearly four years by virtue of the savings it enables in transportation, handling and landfilling. Another similar application, though not in the sludge treatment field, is the seawater desalination using solar energy **[16]** or sludge generation during wastewater recycling using renewable energies **[17]**.

As mentioned above, it is necessary to implement an additional drying process for increasing the dry solids ratio and obtaining higher levels of disinfection prior to discharging dried sludge to the environment and/or using it as a fertilizer in agriculture. Sludge drying is a unit operation that involves reducing water content by vaporization of water into the air. In conventional sludge drying beds, vapour differences and capture of thermal energy at the surface account for evaporation to the atmosphere. In mechanical drying apparatuses, auxiliary heat is provided to increase the temperature of water molecules held by the sludge particles and to provide the latent heat necessary for evaporation **[3]**. The purpose of heat drying is to remove the moisture from the wet sludge so that it can be incinerated efficiently or processed into fertilizer. Drying is necessary in fertilizer manufacturing so as to permit the grinding of the sludge, to reduce its weight and to prevent continued biological activity by disinfection. The moisture content of the dried sludge needs to be less than 10 % **[3]**.

Scientific studies were conducted to study the different parameters governing the various drying processes. Zhu et. al. studied the effect of the shape of the sewage sludge sample on thermo-drying efficiency **[18]**. Theoretical calculations of heat transfer coefficients were made for sludge drying in a nara-type paddle dryer using different heat carriers by Deng et. al. **[19]** and they showed that saturated steam was a much more ideal heat carrier than thermal oil and flue gas due to its high thermal capacity and high heat transfer coefficient. Putranto et. al. **[20]** showed that the reaction engineering approach could be implemented for further applications including design and evaluation sludge dryers.

In this paper, the present study proposes a new heat-treatment process that makes use of existing technologies and thermo-mechanical processes in parallel with solar energy utilization. The process significantly lowers the carbon footprint of the drying and pasteurization processes used in wastewater digested sludge treatment. The paper is organized as follows: in section 2, a heuristic description of the process and a concept system design is given; then, thermodynamic and drying efficiency calculations are given in section 3, which is followed by the conclusions in section 4.

2. DESCRIPTION OF THE SYSTEM COMPONENTS AND THE DRYING PROCESS

The wastewater sludge, which is initially completely wet (<10% dry solids), is run through mechanical dewatering processes, bringing it up to 25% in dry solids. One of the prominent usage areas of the digested sludge agriculture, and uncontrolled use of it as a fertilizer is not possible unless some treatment is done prior to use. The chemical analyses performed on the digested sludge output of the EU funded wastewater treatment plant in Haspolat-Lefkoşa in T.R.N.C., showed that there are no heavy metals found in the digested sludge and also that there is no lime-stabilization necessary since the soil has enough calcium content.

According to the suggested solar drying system in this paper, the digested sludge coming from the water treatment plant is directed into a pipeline (Figure 1) where it is exposed to solar heating provided by the surrounding parabolic-through mirrors (Figure 2) that act as solar concentrators. The pipeline acts as an enclosure to helical conveyors that carry the sludge and is composed of a concentric metal and glass tubes with the latter one placed outside. The absorbent metal tube is black-painted to maximize the absorption of solar energy. For optimal heat management, there is a vacuum lining between these tubes with metal to glass insulation elements at the ends. The details of the conveyor enclosure pipes are shown at the inset of the Figure 1. The pipeline is placed at the focus of the parabolic mirrors thereby directing all the sunrays directly onto the absorbent metal pipe. These mirrors are designed to track the sun on one axis to improve the solar heating at the pipeline. Also, solar tracking acts as a means to control the temperature of the sludge depending on the moisture content.

Sludge is transported in the pipes with the help of a helical conveyor driven by asynchronous electrical motors coupled with the helical conveyor below the loading bunkers. In order to convert the extremely long but thin pipeline system to a reasonably long and reasonably wide setting, the system may be designed in parallel pipeline system segments, between which the sludge is transferred to the next by using the conveyor belt and the bunker unit. This process is continued until the desired level of dry solids percentage ratio is obtained. The water vapour evaporated around the sludge inside the pipe equipped with the helical conveyor is collected by a vacuum pump. The use of vacuum pump to suck out the collected water vapours, decreases the operational pressure to less than 1 atm, which allows vaporization to occur at temperatures lower than 100°C. Due to very low levels of microbial activity detected in the digested sludge, no disturbing gases are expected to be produced inside the black painted metallic absorbent pipe and if any produced, will be removed away by the vacuum pump.

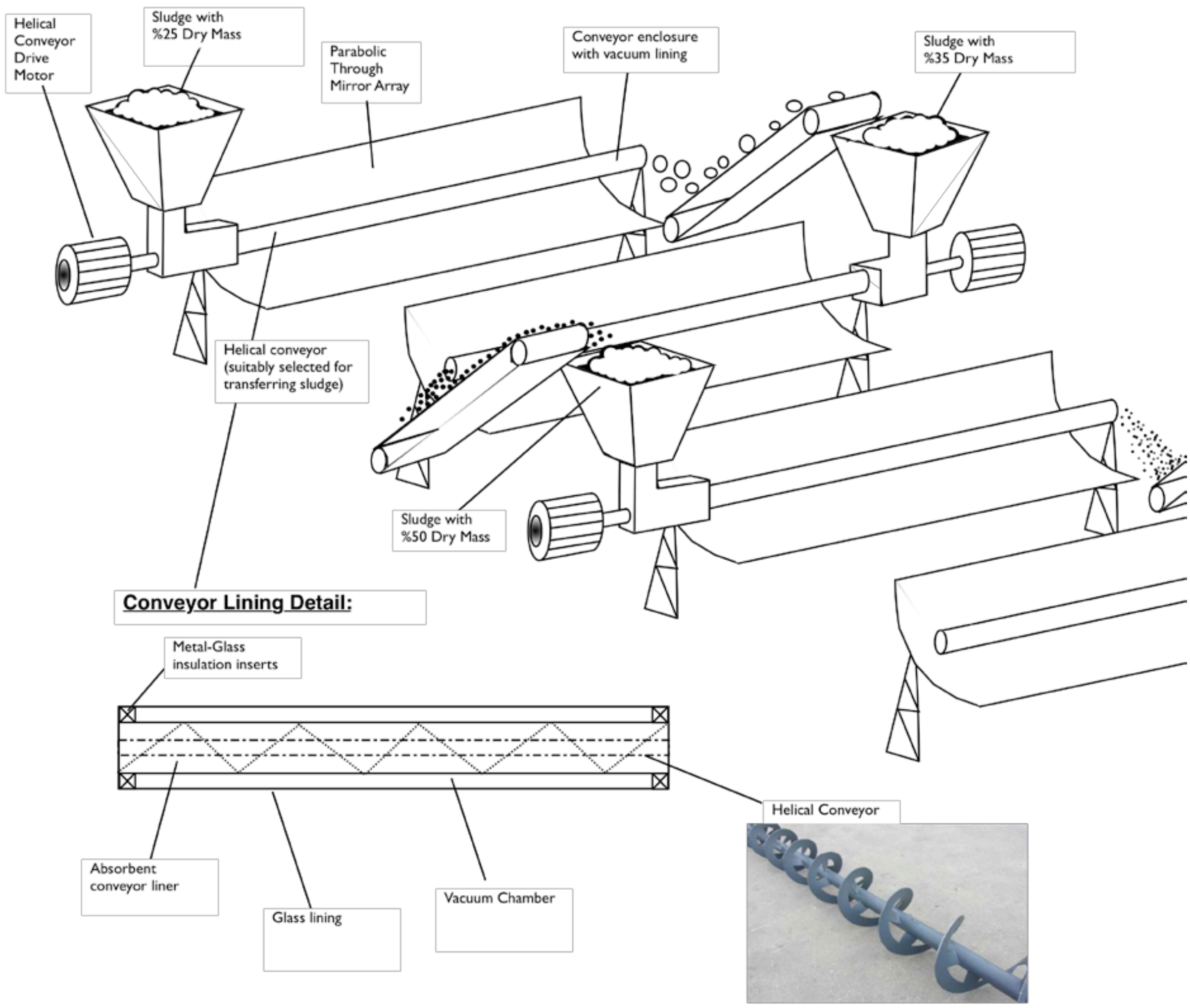

Figure 1 Components of the proposed system for drying and pasteurization of digested sludge.

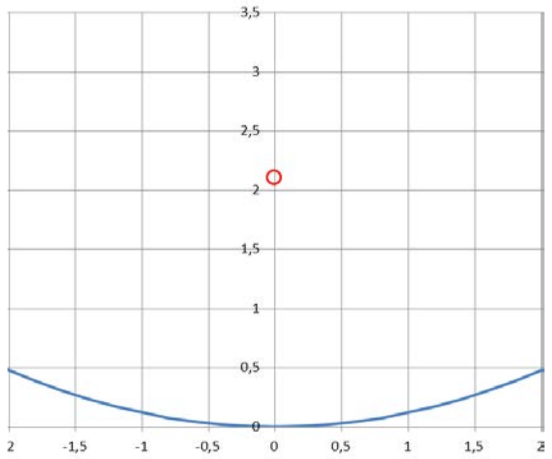

Figure 2 A typical parabolic-through mirror geometry (blue) generated according to the formula $y = 0.12\ x^2$, and the pipeline cross-section overlapping with the focus of the parabola (shown with red circle).

3. DEWATERING EFFICIENCY AND THERMODYNAMIC CALCULATIONS

The main idea of the digested wet sludge processing system is to concentrate the sunlight with the help of parabolic mirrors, and to transfer this energy as directly as possible to the wet sludge to be dried and de-watered. Considering the fact that there is a continuous sludge feed-in to the system, the sludge has to keep moving with the help of the helical conveyor located at the focus of the parabolic mirror, and receive the heat through the surface of the pipe.

To calculate the efficiency and power conversion rates of the solar dewatering system, the following parameters were assumed:

- d = 10 cm (Outer diameter of the concentric pipes)
- l = 100 m (Total length of the solar drying system)
- w= *2 m* (Total linear/planar width of the parabolic mirrors)
- $A_c = \pi(d^2/4) = 0.007854\ m^2$ (Conveyor pipe cross sectional area)
- $\rho_{wet\text{-}sludge}$ = 1.05 tones/m^3 = 1050 kg/ m^3 (wet sludge density)
- $X = m_{water}/\ m_{total} = 0.8$ (i.e., 80% moisture content of the wet sludge)
- η_{mirror}=0.92 (assumed reflectivity of the parabolic mirror ≈ 92%)
- $\eta_{black\text{-}pipe}$=0.98 (assumed absorptivity of the inner black pipe ≈ 98%)
- Q_{sun}= 1900 kWh/m^2.year (Average yearly irradiation for Northern Cyprus)
- v=*5* mm/sec = *0.005* m/sec (operational rate of the helical conveyor)

The solar drying/dewatering system structure is seen Figure 3 and is composed of a parabolic through mirror system made of silver lined glass, chromium or aluminium panels shaped into a parabolic form to direct the sunlight to its focal point. The material, which the mirror is made of, determines its efficiency of reflection and in this paper we assume a reflectivity level of *92%* (η_{mirror}=0.92) that can represent polished chromium panel or aluminium panel as the mirror material. There are concentric dual pipes at the focus of the parabolic through mirror, where the outer liner tube is made of transparent glass or polymeric material, and the inner receiver tube is made of a black painted pipe. The helical conveyor is placed within the black-painted receiver tube.

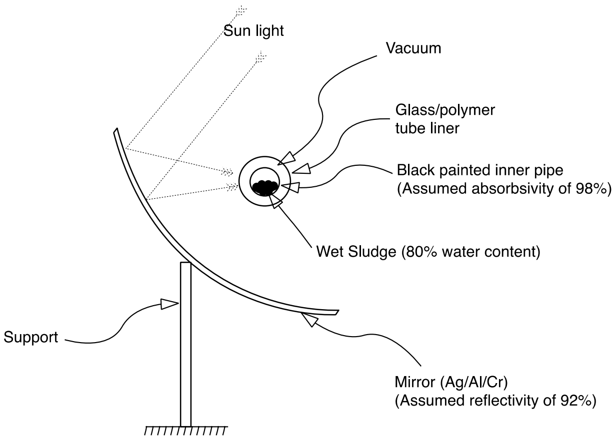

Figure 3 Cross section of the solar drying unit and fundamental descriptions of the components

There is a vacuum in between the concentric tubes to reduce the heat transfer losses by convection. The inner tube is painted black for increasing its heat absorption rate, which is assumed to be *98%* ($\eta_{black\text{-}pipe}$=0.98). The solar drying system is assumed to have the fundamental dimensions seen in Figure 4, which was selected as l=100 m for mirror length, and w=2 m for the mirror width. Also, the conveyor pipe outer diameter was assumed as d=10 cm. The resulting cross-sectional area of the conveyor pipe is A_c = 0.007854 m^2.

The moisture content of the digested wet sludge was assumed as 80% (X=0.8), which is a typical value for sludge outputs of water treatment plants, after mechanical de-watering and digestion processes. Also the density of the digested waste sludge was taken as $\rho_{wet\text{-}sludge}$ = 1050 kg/m^3, as obtained from the literature. For calculations, the heat energy source is the solar radiation, and the typical value for solar irradiation is Q_{sun}= 1900 kWh/m^2.year, which is the yearly solar energy received in Cyprus per m^2 during 1 year period.

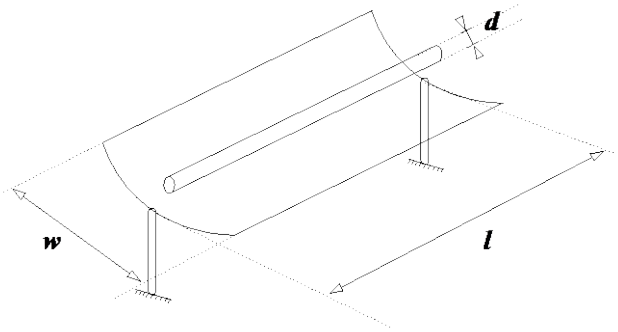

Figure 4 Fundamental dimensions of the parabolic mirror and the conveyor pipe at the focus

Based on the above definitions and assumptions, we can calculate the overall efficiency of solar radiation being transferred to the sludge as

$$\eta_{overall} = \eta_{mirror}\eta_{black-pipe} = 0.92 \cdot 0.98 = 0.9016$$

$$\square \quad \eta_{overall} \cong 0.9 \cong 90\% \qquad (1)$$

Assuming that the solar radiation is available all year round at the given average level of 1900 kWh/m^2.year, and that the solar sludge drying/dewatering system has plan-form area of A=200 m^2, we can calculate daily kJ equivalent of solar heat energy reaching on the system as follows;

$$Q_{sun}A = 1900\frac{kW}{m^2\, year}\times 200m^2 = 380{,}000\frac{kWh}{year}$$

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$$= 347\frac{kWh}{8hours}\times\frac{3600kJ}{1kWh} = 1{,}249{,}200\frac{kJ}{8hours}$$

Here it was assumed that the average solar radiation is acting for 8 hours during daytime. Utilizing (1), the net solar heat energy input transferred from mirror to the sludge can be calculated as;

$$Q_{in} = Q_{sun}A\eta_{overall} = (1{,}249{,}200kJ/day)\times(0.9)$$

$$\square \quad Q_{in} = 1{,}124{,}280\frac{kJ}{day} \qquad (2)$$

Now considering the cross-sectional area of the conveyor pipe A_c, and further assuming that only half of this total area is occupied by digested waste sludge, the total volume of the sludge can be obtained as;

$$V_{wet-sludge} = \frac{1}{2}A_c l = \frac{1}{2}\pi(d^2/4)l$$

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which is the total wet sludge volume within the focal tube at any time during the operation of the system. Assuming that the helical conveyor operates at a rate such that the wet sludge travels at a speed of v=5 mm/sec, the volume flow rate of the wet sludge is calculated as;

$$\dot{V}_{wet-sludge} = \frac{1}{2}A_c v = \frac{1}{2}\pi(d^2/4)v$$

$$= (0.003927m^2)\times(0.005m/\sec)$$

$$\square \quad \dot{V}_{wet-sludge} = 1.9635\times10^{-5}\frac{m^3}{\sec} \qquad (4)$$

Note that at the assumed operational helical conveyor speed of v=5 mm/sec, the sludge takes about 5.55 hours to travel 100 m, from the input bunker to the output of the system, which is an important value considering the pasteurization requirement of the wet sludge. With this operational rate, the biological pasteurization and stabilization is therefore guaranteed along with the de-watering and drying functions. Also given this operational rate, one can calculate the total volume and mass of the wet sludge to be treated with the system by assuming average sun-hours of 8 hours/day as follows;

$$V_{total-sludge} = \dot{V}_{wet-sludge}\Delta t$$

$$= (1.9635\times10^{-5}\frac{m^3}{\sec})\times(\frac{8hours}{day}\times\frac{3600\sec}{1hour})$$

$$\square \quad V_{total-sludge} = 0.565488\frac{m^3}{day} \qquad (5)$$

Since $m_{total-sludge} = V_{total-sludge}\rho_{wet-sludge}$, then

$$m_{total-sludge} = 593.7624\frac{kg}{day} \qquad (6)$$

Given that the moisture content of the wet sludge is *80%*, then the dry mass and water mass within the total sludge can be obtained as;

$$m_{dry-mass} = 0.2\times m_{total-sludge} = 118.7525\frac{kg}{day} \qquad (7)$$

$$m_{water-mass} = 0.8 \times m_{total-sludge} = 475.01 \frac{kg}{day} \qquad (8)$$

In order to increase the evaporation rate of the water from the sludge, and also to ensure proper pasteurization conditions, the interior of the concentric tube assembly located at the focus of the parabolic through mirror system was assumed to operate at vacuum environment. For proper pasteurization the absolute pressure was assumed as 0.4 bar, for which the saturation temperature of the water is 75.89°C. For pasteurization, the wet-sludge should be heated to 70°C for at least 30 minutes, which is guaranteed by the suggested drying/de-watering system design. At the vacuum conditions of 0.4 bar, the properties of water is obtained as follows from the property tables;

- P_{sat}=0.4 bar≈0.4 atm (Saturation Pressure)
- T_{sat}=75.89 °C (Saturation Temperature)
- $\Delta H_{vaporization}$=2319.23 kJ/kg (Latent Heat of Evaporation)
- $(Cp)_{wet-sludge}$=1.9506 kJ/kg°K (Specific Heat at P_{sat})

If all of the incoming heat energy was transferred to the wet sludge without any evaporation taking place, the temperature change of the wet sludge can be calculated from the equation $\Delta E_{heating} = Q_{in} = m_{wet-sludge}(C_p)_{wet-sludge}\Delta T$

$$\Delta T = \frac{Q_{in}}{m_{wet-sludge}(C_p)_{wet-sludge}}$$

$$= \frac{1{,}124{,}200 kJ/day}{(593.7624 kg/day) \times (1.9506 kJ/kg \circ K)}$$

$$\Rightarrow \quad \Delta T = 970.72^{\circ} K \qquad (9)$$

So if all of the heat is transferred to the sludge without any vaporization, the temperature must rise by about 970°K or equally 970°C. But instead we want the water to evaporate so that we get rid of the moisture in the sludge. In order to calculate energy used for evaporation, we need to first calculate the energy required to raise the temperature of the wet sludge to the vaporization/pasteurization temperature. The remaining heat is to be used for vaporization. Mathematically, this can be expressed as;

$$Q_{in} = \Delta E_{heating} + \Delta E_{vaporization} \qquad (10)$$

Assuming the initial temperature of the wet sludge as T_o = 22°C, the energy required for rising the temperature of the wet sludge is computed as;

$$\Delta E_{heating} = m_{wet-sludge}(C_p)_{wet-sludge}\Delta T$$

$$= (593.7624 kg)(1.9506 kJ/kg^{\circ}K)(75.89 - 22^{\circ}K)$$

$$\Rightarrow \quad \Delta E_{heating} = 62{,}415^{\circ} kJ \qquad (11)$$

Now substituting (11) into (10), and also utilizing (2), we can calculate the total heat available for vaporization of water in the wet sludge as;

$$\Delta E_{vaporization} = Q_{in} - \Delta E_{heating}$$

$$\Rightarrow \quad \Delta E_{vaporization} = 1{,}061{,}864.98 kJ \qquad (12)$$

Now utilizing the latent heat equation

$$\Delta E_{vaporzation} = \Delta H_{vaporization} m$$

where *m* is the amount of water mass being evaporated, we can calculate the vaporization mass of water as follows;

$$m_{\substack{water-mass \\ evaporated}} = \frac{\Delta E_{vaporzation}}{\Delta H_{vaporization}} = \frac{1{,}061{,}864.98 kJ}{2319.23 kJ/kg}$$

$$m_{\substack{water-mass \\ evaporated}} = 457.857 kg \qquad (13)$$

which is the amount of water evaporated during a 1 day (8 hour) operation during the day-time. From (7) and (8), as well as the last value obtained, one can calculate the final remaining water content and the total dry mass ratio as follows;

$$m_{water} = m_{water-mass} - m_{\substack{water-mass \\ evaporated}}$$

$$= 475.01 kg - 457.853 kg = 17.247 kg$$

$$m_{water} = m_{water-mass} - m_{\substack{water-mass \\ evaporated}} = 475.01 kg - 457.853 kg = 17.247 kg \qquad (14)$$

and

$$X_{final} = \frac{m_{water}}{m_{total-sludge}} = \frac{17.247 kg}{118.7525 kg + 17.247 kg} = 0.1268$$

$$\Rightarrow \quad X_{final} = 12.68\% \qquad (15)$$

So the final result indicates that with the suggested process, the moisture or water content of the digested wet sludge is reduced from 80% to just 12.68%. In other words this is equivalent to increasing the dry-solids ratio of the digested wet sludge from 20% to 87.32% at the end of the suggested solar de-watering/pasteurization process.

4. CONCLUSIONS

This study proposes a new combination of existing technologies in order to develop a wastewater sludge heat treatment technology that is environmentally friendly and very low carbon footprint as compared to conventional methods. In the suggested parabolic through solar drying system, solar photovoltaic and solar thermal energy supplies are incorporated into a thermal processing unit. This unit can easily be resized according to the amount of sludge to be processed per day and the amount of drying desired. In the assumed operational parameters, the water content of the digested wet sludge is reduced from 80% to just 12.68% for a waste sludge of approximately 600 kg per day. This is equivalent to increasing the dry-solids ratio of the digested wet sludge of the said quantity, from 20% to 87.32% at the end of the suggested solar de-watering process whereas pasteurization of the digested sludge is already guaranteed since it spends about 5.55 hours inside the system. This overall system ensures the safe use of the digested waste sludge as a safe fertilizer, free of pathogens, that can be easily transported to the application site and homogeneously mixed with soil. The system is considered to be novel since it does not produce gas emissions that will contribute to global warming and allows the environmentally sustainable use of the digested sludge as a fertilizer in agriculture.

The solar parabolic dewatering process can be reverted to a traditional thermal processing unit at times of insufficient insolation by utilizing additional components, and alternatively, it can be connected to other renewable power supplies, e.g. wind, or heat supplies, e.g. geothermal for continuous and increased processing capacity. Overall, the cities can benefit from this new setup in order to significantly reduce their carbon footprint and improve the quality of their environment.

References

[1] A. Kelessidis, A. S. Stasinakis, *Waste Management*, "Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries", 2013, 33, 1186-1195.

[2] S. Werle, R. K. Wilk, *Renewable Energy*, "A review of methods for the thermal utilization of sewage sludge: The Polish perspective", 2010, 35, 1914-1919

[3] G. Tchobanoglous, F.L. Burton, *Wastewater Engineering Treatment, Disposal and Reuse*, Metcalf and Eddy Inc., Mc-Graw Hill, 3rd edition, 1991,842-891.

[4] A. Cammarota, R. Chirone, P. Salatino, R. Solimene, M. Urciuolo, *Waste Management*, "Particulate and gaseous emissions during fluidized bed combustion of semi-dried sewage sludge: Effect of bed ash accumulation on NOx formation", 2013, 33, 1397-1402.

[5] J. W. Judex, M. Gaiffi, H. C. Burgbacher, *Waste Management*, "Gasification of dried sewage sludge: Status of the demonstration and the pilot plant", 32, 2012, 719-723.

[6] [http://www.jatrofuels.com/170-0-Calorific+Values.html]

[7] M.H. Waldner, R. Halter, A. Sigg, B. Brosch, H.J. Gehrmann, and M. Keunecke, *Waste Management*, "Energy from Waste – Clean, efficient, renewable: Transitions in combustion efficiency and NOx control", 2013, 33, 317-326.

[8] J. Hong, C. Xu, J. Hong, X. Tan, W. Chen, *Waste Management*, "Life cycle assessment of sewage sludge co-incineration in a coal-based power station", 2013, 33, 1843-1852.

[9] L. Lombardi, Ennio Carnevale, Andrea Corti, *Waste Management*, "Analysis of energy recovery potential using innovative technologies of waste gasification", 2012, 32, 640-652.

[10] U. Arena, *Waste Management*, "Process and technological aspects of municipal solid waste gasification. A review", 2012 , 32, 625-639.

[11] X. Lu, B. Jordan, N. D. Berge, *Waste Management*, "Thermal conversion of municipal solid waste via hydrothermal carbonization: Comparison of carbonization products to products from current waste management techniques", 2012, 32, 1353-1365.

[12] V. K. Tyagi, S.L. Lo, *Renewable and Sustainable Energy Reviews*, "Sludge: A waste or renewable source for energy and resources recovery?", 2013, 25, 708-728.

[13] C. Cimpan, H. Wenzel, *Waste Management*, "Energy implications of mechanical and mechanical–biological treatment compared to direct waste-to-energy", 2013, 33, 1648-1658.

[14] N.K. Salihoglu, V. Pinarli, G. Salihoglu, *Renewable Energy*, "Solar drying in sludge management in Turkey", 2007, 32, 1661-1675.

[15] U. Luboschik, *Renewable Energy*, “Solar sludge drying - based on the IST process”, 1999, 16, 785-788.

[16] T. Ayhan, H. Al Madani, *Renewable Energy*, “Feasibilty study of renewable energy powered seawater desalination technology using natural vacuum technique”, 2010, 35, 506-514.

[17] M. Meliβ, A. Neskakis, J. Plettner-Marliani, C. Lange, A. Hövelmann , J. Schumacher, *Renewable Energy* , “Waste Water Recycling Supplied by Renewable Energies – Basic Conditions and Possible Treatment Technologies”, 1998, 14, 325-331.

[18] F. Zhu, Z. Zhang, H. Jiang, L. Zhao, *Procedia Environmental Sciences*, “The Study of Sewage Sludge Thermo-Drying Efficiency”, 2012, 16, 363-367.

[19] W. Deng, Y. Su, W. Yu, *Procedia Environmental Sciences*, “Theoretical calculation of heat transfer coefficient when sludge drying in a nara-type paddle dryer using different heat carriers”, 2013, 18, 709-715.

[20] A. Putranto, X. D. Cheng, *Procedia Chemistry*, “A Simple and Effective Model for Modeling of Convective Drying of Sewage Sludge; the Reaction Engineering Approach (REA)”, 2014, 9, 77-87.