Introduction of Solar Drying Technology to Trinidad and Tobago

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ABSTRACT

A review of the existing solids management practices in Trinidad and Tobago and experience elsewhere defined the future needs and identified solar drying as a preferred technology for the subject project. Upon analysis of the local conditions, it was calculated that approximately 19 MJ/m^2 (1886 kWh/m^2) of solar radiation, at 30ºC annual average temperature and 80% relative humidity level is appropriate at the project site and that these parameters are adequate for the solar dryer application. The estimated 7,450 m^2 cell area for drying associated with average electrical power consumption of 18 to 20 kWh/tonne of water extracted will provide an evaporation rate of 2.2 kg water/m^2.day. The solids are expected to be dried from approximately 16-18% dry solids to 70-90% dry solids.

KEYWORDS

solar drying, solids, evaporation, stabilization, greenhouse, vector control.

INTRODUCTION

As the wastewater treatment systems are improving in Trinidad and Tobago, the rapid increase in solids production from these systems is triggering the need for better solids management systems. Due to technical, economical and social factors, a tailored approach to get an optimal solids management solution is required. In most cases, implementing the traditional highly complex solids management solutions with heavy reliance on energy, chemicals and operational expertise is not likely a viable solution.

Solar drying has become a more versatile process with the development of solids mixing equipments, emission control and additional heating systems in recent years (Luboschik, 1998). Since 1994, automated solar drying using greenhouse technology has been successfully applied in Europe. More recently there have been a number of new installations in Australia and the United States. Some of the commercially available solar drying systems are Parkson's Thermo-System™, ist's WendeWolf ™, and Huber's Kult™. The largest installation cited at the time of compilation of this paper is for treating solids from a 150 ML/d wastewater treatment plant.

The basic principal of operation in any solar drying process is based on the fact that water molecules change from liquid into vapour (Figure 1). This requires energy, i.e. solar energy. The driving force is the difference between the partial vapour pressure inside the solids and the ambient air. In order to avoid equilibrium between the vapour pressure inside and outside the solids, the surrounding air is ventilated from the cell area. This is naturally helped by the fact that water vapour is lighter than the dry air. The warmer the air is, the more water vapour can be transported. However the partial vapour pressure in the air rises with the amount of moisture in the air. To assist the overall process, in some colder climatic installations, where temperature, or solar energy, is not favourable year-round, additional heating systems can be installed for colder periods.

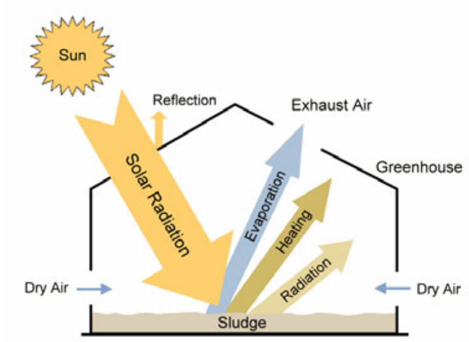

Figure 1. Basic Principal of Solar Dryer

In order to execute the above described process, the common approach in solar dryer systems is to uniformly spread wet solids (either as a liquid or cake) on a concrete slab in a greenhouse building (transparent cover of glass or plastic). The solids are intermittently mixed and the surrounding environment controlled. It generally requires between 15 to 28 days for the solids to proceed from start to finish depending on the number of turns per day. The controlled environment provides a final dried product, or biosolids, that has a reduced mass and pathogen content (Choi and O'Shaughnessy, 2006).

The solar drying technology requires a relatively larger footprint but is somewhat modular. Other technologies, such as thermal dryers, can dry the material more rapidly, but at the cost of additional energy. Advantages of solar drying are reduced energy requirements in a time of energy cost inflation and reduced total mass without the addition of bulking agents, such as in composting or chemicals as in lime stabilization. Depending upon the particular system installed, the solids with initial dry solids concentration between 2 and 35% can be dried up to 90% dry solids which enables this technology to be attractive for small to medium sized plants in moderate climate and for larger sized plants in warm climates (Seginer and Bux, 2005).

Characteristics of the feed solids, such as grease content, temperature, solids content, depth of applied solids, surrounding environmental conditions, and solids turning method are some of the critical parameters for solar dryer design.

Feed solids with a high amount of grease has a higher drying time (Mehrdadi, N., et al. 2007). For systems that are fed with cake, an optimum concentration of feed solids is desired to reduce the proportion of liquor removed by drainage and to allow free flow of solids to all parts of the bed. The depth to which solids is applied can vary between 150 mm and 350 mm with auger type systems. If the applied depth is too shallow, the thickness of the solids layer will be small and more application area will be required for a given volume of solids. Alternatively, if the applied depth is too thick, there is a risk of solids "gluing" and physical damage to the solids turning equipment.

A past study (Mehrdadi, N., et al. 2007) has concluded that the surrounding environmental conditions have the most influence on the evaporation rate hence the performance of the solar dryer. These surrounding environment parameters are (1) outdoor solar radiation (2) outdoor air temperature, and (3) the ventilation flux. Precipitation also has a considerable effect on drying, especially if it occurs before cake cracking. Evaporation rate tends to reduce in overcast conditions because of low solar intensity. Wind has a beneficial effect as it increases the evaporation rate. The dry solids content of the feed solids also of importance, but is less critical than the environmental conditions. Air-mixing (without ventilation) is an order of magnitude less effective than ventilation. (Mehrdadi, N., et al. 2007; Seginer and Bux, 2005).

Assessment of Solar Drying for Trinidad and Tobago
Trinidad and Tobago is striving to improve the overall wastewater management infrastructure. In keeping with the Vision 2020 initiative and as part of the Strategic Plan for the modernization of the water and wastewater infrastructure, the Government of the Republic of Trinidad and Tobago has embarked on a Water Sector Modernization Programme (WSMP). Wastewater treatment and associated solids management has been one key focus of the WSMP. Like many other developing nations, processing and disposal of excess solids is one of the main challenges encountered in the development of wastewater treatment infrastructure. There is a well-recognized need to provide a solids management solution that is practical, environmentally responsible and cost effective and serve as a model for the whole country.

The first major wastewater project launched under the WSMP was to design a new Malabar wastewater treatment plant. The plant, rated for an average flow of 40 ML/d, will service the Borough of Arima and the Malabar area. The wastewater will be treated utilizing a conventional activated sludge process. The waste activated sludge (WAS) from the plant will be dewatered utilizing belt filter press technology to 16 to 18% dry solids concentration. The Malabar wastewater treatment plant is expected to produce approximately 17,600 wet tonnes of dewatered cake each year. The cost of transporting and disposing of this large quantity of unstabilized solids would have resulted in a large transportation cost. In an attempt to reduce the cost of solids disposal and improve the quality of the biosolids to enable greater beneficial reuse, it was necessary to achieve a reduction in mass, pathogens and vector attraction to produce a stabilized product in accordance with the environmental requirements of advanced nations. Therefore, further drying and stabilization of the solids is required before final disposal.

Simultaneous solids stabilization and mass reduction is typically achieved by the application of high temperature thermal reduction processes such as wet air oxidation, multiple hearth incineration etc. However the disadvantages of these processes include high capital and operating costs, and associated air emission and ash. High temperature heat drying processes such as flash dryers and rotary dryers can also be used for mass reduction and stabilization but the energy requirement is also high. The low-temperature solar drying process simultaneously stabilizes and reduces the mass of municipal wastewater solids (Harlan, 2003).

For the Malabar project, various conventional solids management options were evaluated including on-site drying beds, regional drying systems, and mechanical devices. Most of the technologies that incorporate both mass reduction and stabilization required high energy and/or chemical usage; initial high capital investment and high operating cost. In addition, a regional or local solids drying bed approach would not have been feasible due to the site specific conditions, i.e. significant wet weather during the rainy season, and proximity to residential communities. Lack of local technical support and availability of spare parts dictated the rejection of highly mechanized and complex systems, e.g. incineration and thermal dryers.

Solar drying technology has not yet been applied in Trinidad and Tobago, although conventional low rate drying beds have been used in some locations. These drying beds have been prone to failure due to the extended rain events experienced in the region. Based on a desktop analysis including weather data, solids characteristics, available land area, and a survey of other installations in similar climatic conditions, it was concluded that solar drying is an appropriate technology that would meet the required solids management objectives for Malabar wastewater treatment plant.

Process Sizing

The mass transfer of water is proportional to: (a) the area of wetted surface exposed, (b) the difference between the moisture level of the drying air and the saturation humidity of air at the solids-air interface, and (c) other factors such as velocity and turbulence of drying air expressed as a mass transfer coefficient. Incorporating the above key parameters, a computer modelling analysis was completed to determine the required solar drying area. The model allows one to calculate the air flow of different dryers as a function of the meteorological conditions.

Based on the analysis, it was determined that approximately 19 MJ/m^2 (1886 kWh/m^2) of solar radiation, at 30ºC annual average temperature and 80% relative humidity level was appropriate for the project (Figure 2 and 3).

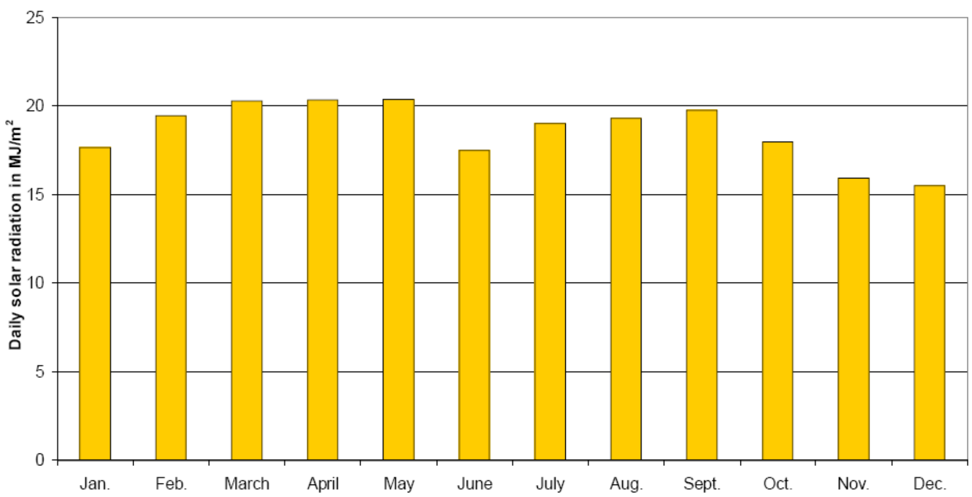

Figure 2. Annual Solar Radiation for Malabar Solar Drying Site

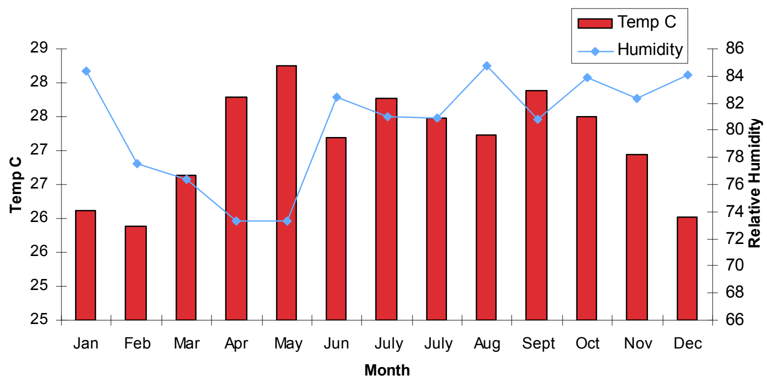

Figure 3. Average Monthly Relative Humidity and Temperature Data Analysis

These conditions are adequate for solar drying. Typically solar drying processes are capable of providing evaporation rates between 1 and 3.3 kg water /m^2.day (Bux and Baumann, 2003). The design for Malabar is based on 2.2 kg water/m^2.day. It was determined that for the current project the solar dryer system will be capable of generating a biosolids product with a solids content of up to 72% (Table 1).

Table 1. Projected Solids Drying Efficiency

	Days per Month	Input wet cake			Output dried granulate		
		tons	%DS	tons DS	tons	%DS	tons DS
January	31	1.494,8	16,0%	239,2	234,6	69,2%	162,5
February	28	1.350,1	16,0%	216,0	303,6	71,3%	216,6
March	31	1.494,8	16,0%	239,2	370,3	73,1%	270,8
April	30	1.446,6	16,0%	231,5	436,2	74,5%	324,9
May	31	1.494,8	16,0%	239,2	378,3	71,6%	270,8
June	30	1.446,6	16,0%	231,5	306,3	70,7%	216,6
July	31	1.494,8	16,0%	239,2	309,4	70,0%	216,6
August	31	1.494,8	16,0%	239,2	356,3	76,0%	270,8
September	30	1.446,6	16,0%	231,5	366,4	73,9%	270,8
October	31	1.494,8	16,0%	239,2	303,3	71,4%	216,6
November	30	1.446,6	16,0%	231,5	220,2	73,8%	162,5
December	31	1.494,8	16,0%	239,2	230,4	70,5%	162,5
Sum	365	17.600,0	16,0%	2.816,0	3.815,5	72,4%	2.761,8

It is anticipated that due to the dry season in Trinidad, the evaporation rate will be greater than 2.2 kg water/m^2.day for at least 6 months each year, leading to enhanced dryer performance.

Based on the above calculations, it is estimated that a total of six cells will be required i.e. five for current conditions and one for future expansion. Each cell has a dimension of 112 m x 11.3 m.

System Layout

The solar dryer and the belt filter presses are located in the same building to minimize the transportation of cake during dryer loading (Figure 4).

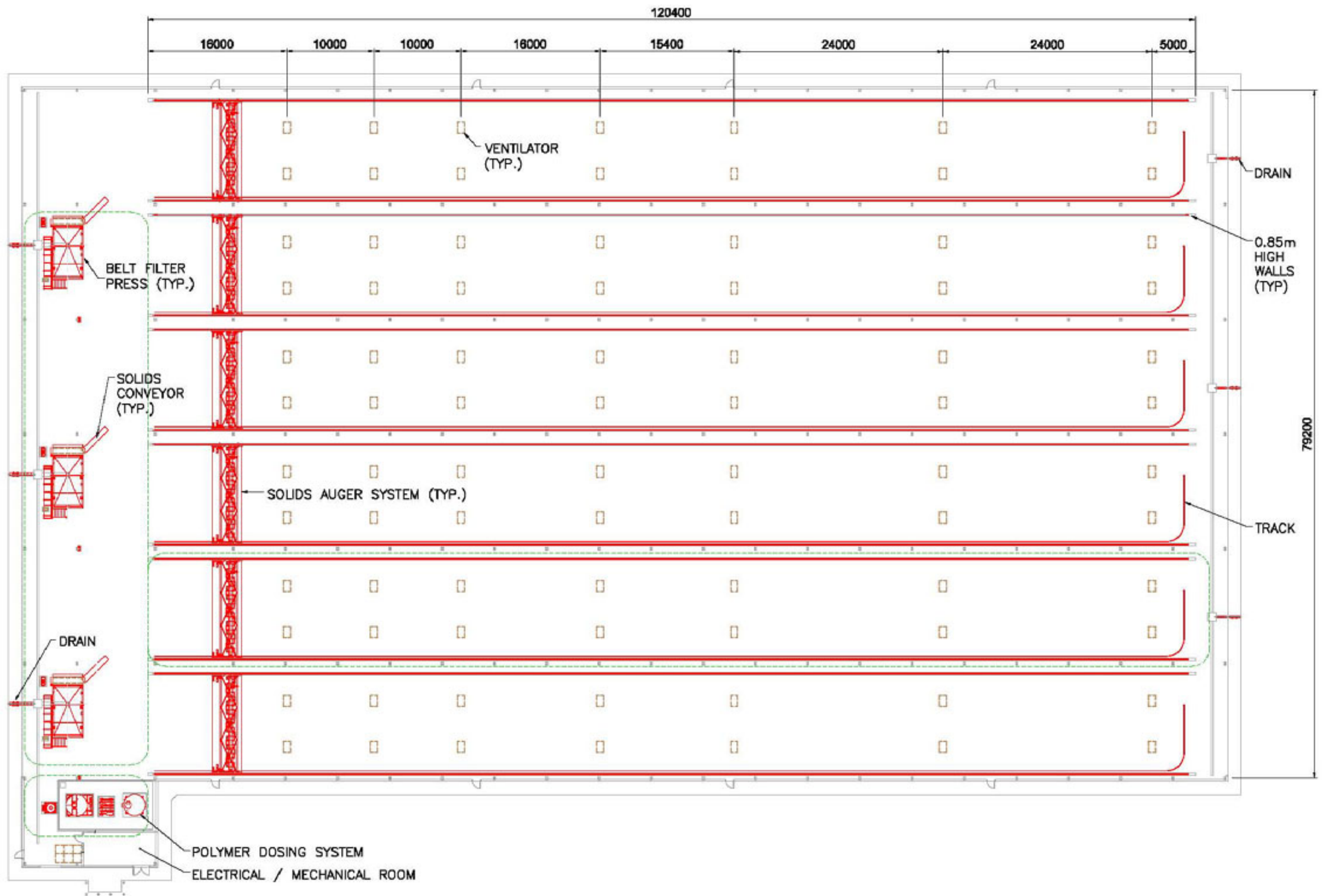

Figure 4. Overall Solar Dryer Cell Layout Plan

The key design elements of the solar dryer system for Malabar wastewater treatment plant are:

- Belt conveyors to transport cake from the belt filter presses to the dryers.
- Six cells each with a 300 mm concrete slab of 120 m x 11.3 m dimension.
- Two parallel walls 11.3 m apart, 0.85 m high and up to 120 m in length in each cell.
- A solids handling rake “Wendewolf ” machine in each cell that progressively turns and moves the solids along the floor.
- Greenhouse drying halls.
- Road access at both ends of the solar drying cells.
- Ventilation system with 14 fans in each cell that control the environmental factors and allow the free exchange of air between outside and inside of the greenhouses.
- Various instrumentation and control systems for process automation. Overall system functionality will be monitored locally and remotely via the central control system.

Figure 5 and 6 illustrate typical system elements and design features of the solar dryer system, similar to the one designed for the Malabar wastewater treatment plant.

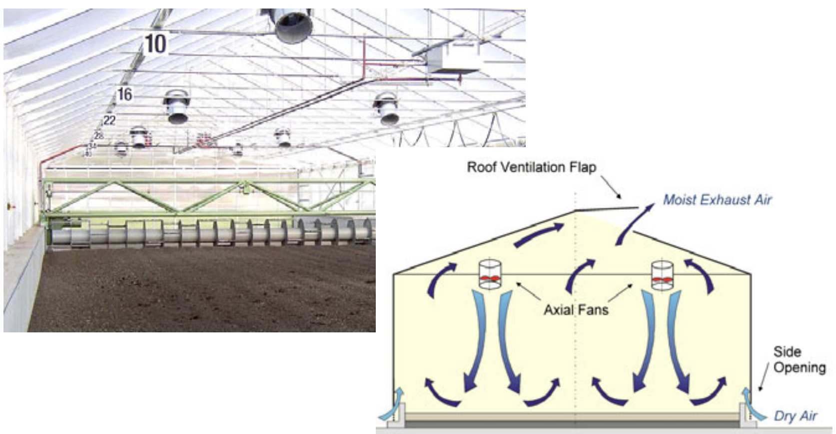

Figure 5. Typical Solar Dryer Setup

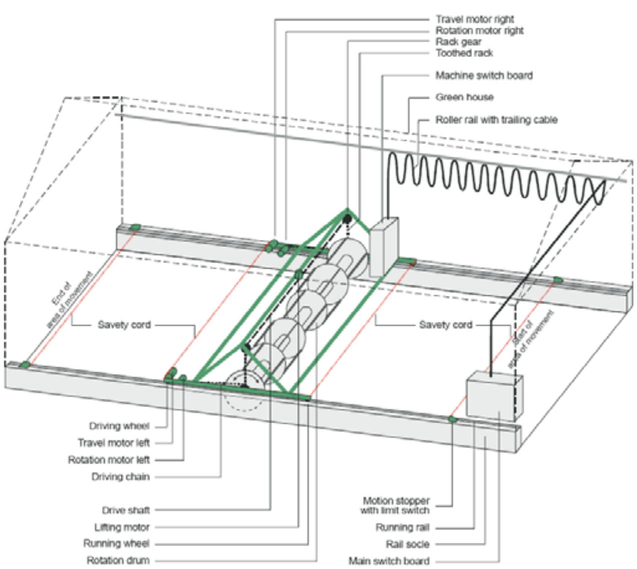

Figure 6. Overall Mechanical System Layout

The main component of the solar dryer system is the WendeWolf™ reversing and conveying machines installed in each of the six drying cells that help in spreading and turning of the solids. In each hall, the machines run on two parallel walls 11.3 m apart, 0.85 m high and 120 m. The central part of the machine is a drum on which combs and paddles are fixed which till the material's surface and assist in the aeration of the lower layers of the solids. The drum can be lowered from a free height of 50 cm to the ground with a central motor and two toothed racks which are mechanically linked. The drum turns with a frequency of up to 60 cycles/min and conveys the solids below while slowly moving. Each WendeWolf® unit moves and aerates up to 250 m³/h of solids at a speed of 0.2-0.8 m/minute. The unit has a free wheel speed of 8 m/minute. The unit can move and rotate in both directions and is controlled by frequency driven motors. A number of sensors are provided to control the machine's movement.

System Operation

The first step in the process is to spread the cake over the concrete floors under a greenhouse-like transparent building envelop. The solar radiation warms the cake's surface. The solids get intermittently mixed, while the air under the cover becomes saturated with water vapour. In accordance with the process settings, the air is replaced with unsaturated air above the dryer cell area utilizing the designed ventilation system. The ventilation system and solids mixing operation is automatically controlled. The drying rate, environment characteristics and the associated control system are defined based on the local site-specific modelling.

Due to the frequent turning of the solids, the solids is transformed into granules, typically 1-20 mm in diameter. The dried granular material is removed from the dryer at the opposite end to the feed. The solar drying process for Malabar wastewater treatment plant does not work as a batch process, but and instead works on a "continual input – continual output" approach.

Once the drying cycle is complete, the dried biosolids are removed using a front-end loader and placed in the biosolids storage area pending removal off-site for land application.

From past experience it is anticipated that the process operation will require that solids turning rates be adjusted in accordance with changing weather conditions and any changes to the upstream process unit performance e.g. less than optimum solids concentration rates from the belt filter presses. From the initial operational experience these parameters can be easily automated for future ease of operation. The auto-turning cycles can be programmed for up to a week ahead. Routine dry solids tests can be conducted once per week and is expected to take one man approximately two to three hours.

The temperature and the relative humidity are automatically monitored outside and inside the each hall using automatic sensors. The Process Logical Control (PLC) calculates the temperature difference and the absolute water content inside and outside of each hall separately. The respective thresholds can be altered. Axial fans are switched on when the temperature inside is five degrees higher than outside. Also roof flaps are opened when the calculated value of the absolute humidity inside exceeds a threshold value.

To improve the amenity of the biosolids product it is necessary to achieve a reduction in pathogens and vector attraction. It is anticipated that the final product from the solar dryer will be in accordance with the US EPA's Class B stabilized product for disposal of biosolids on agricultural land. The current application is expected to provide the volatile solids reduction within the typical literature suggested range. A typical overall process electrical energy consumption has been reported in the literature to be about 30 to 100 kWh/tonne of water evaporated (Bux et al. 2001). Due to site specific conditions, the average electrical power consumption of this operation is expected to be in the range of 18 to 20 kWh/tonne of water extracted, which is at the lower end of the literature values and is also significantly lower than the electrical demand of most conventional thermal drying processes.

In summary, the proposed technology utilizes the traditional principals of air drying biosolids and is expected to enhance the process to produce a consistent, quality controlled product with minimal operational complexity.

CONCLUSION

Sustainable wastewater solids management constitutes a serious challenge to the overall initiative of improvement of the wastewater systems by the local authorities in Trinidad and Tobago. The solids treatment approaches must be focused on the effectiveness of the processes and its durability. The selected approach must also integrate local and regional settings, as well as current and future environmental limiting conditions. It is concluded that the proposed process of solar drying will allow measurable scientific, environmental and economic benefits.

Based on the analysis of the local weather conditions and estimated solids production rate of 17,600 tonnes per year, a total of 6 solar dryer cells covering an area of 7,450 m^2 are required. The biosolids produced from the process is expected to have a minimum solids content of 70% and to have a significant vector attraction reduction. This fully automated and simple technology will enable minimum operator's attention.

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