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Research Article

Enhancement of leachate treatment process through integration of flat solar collectors

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ABSTRACT

Within the scope of this study aimed at safeguarding our environment, we utilized an economical apparatus to eliminate the leachate present in the landfill of Khénifra, Morocco. This substance, predominantly composed of organic matter, exerts a detrimental impact on the ecosystem. The solution put forth in this research involves employing a flat solar collector to expedite the evaporation process of the leachate, which occupies three substantial basins within the landfill. The results obtained showcase a remarkable enhancement in evaporation efficiency, with the flat solar collector contributing to an impressive 300% increase, thereby significantly reducing the evaporation timeframe when compared to the traditional method employed in the landfill. In the context of our experiment, we observed a noteworthy reduction of 18 days in evaporation duration compared to the natural evaporation process, thanks to the implementation of this solar collector. This straightforward, efficacious, and notably cost-effective technique yields compelling and promising results.

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INTRODUCTION

Numerous investigations have undertaken the task of evaluating the potential risks to both human well-being and the environment stemming from groundwater contamination caused by leachate [1–3]. Leachate, characterized by a heightened biochemical oxygen demand (BOD) and substantial concentrations of organic carbon, nitrogen, chloride, iron, manganese, and phenols, poses significant ecological

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challenges. The list of potential components extends to include pesticides, solvents, heavy metals, as well as personal care and pharmaceutical chemicals, among others.

The generation of leachate presents a formidable concern within municipal solid waste landfills, casting a substantial shadow over surface and groundwater quality. However, the physico-chemical attributes of pollutants within leachate can vary significantly from one instance to another, influenced by waste composition, site configuration, climatic conditions, and their inherent variability. Notably, leachates feature both emerging and refractory pollutants, necessitating intricate treatment combining biological and physicochemical processes [4–8], showcasing the pressing need for robust strategies to mitigate the environmental hazards linked to leachate presence[1].

In light of this, several research initiatives have scrutinized the efficiency of leachate treatment methodologies under laboratory, pilot, and semi-pilot conditions. These studies have hailed innovative approaches, notably membrane bioreactors and advanced oxidation processes, showcasing robust purification mechanisms [8–10]. Nonetheless, an inherent challenge emerges in the form of potentially toxic byproducts, such as trihalomethanes, haloacetic acids, chlorates, perchlorates, and the like.

The physico-chemical composition of leachate exhibits a wide range of diversity, dictated by variables like waste content, landfill conditions, temperature, moisture, and microbial activity levels[11,12]. To gain comprehensive insights into leachate profiles, one can turn to physico-chemical markers, including COD, BOD5, nitrogen and phosphorus fractions, conductivity, pH, in addition to heavy metal and anion concentrations [1,13–15].

Leachate is classified into distinct categories—namely young, mature, and old—based on the landfill's conditions and duration, reflecting variations in biodegradability [16]. Leachate may encompass elevated metal concentrations, refractory organic substances such as pesticides, and more [8,17].

Traditionally, leachate removal and treatment from operational landfills have been confined to expensive alternatives [1–4,12–14], which, while highly effective, can be excessively intricate. Techniques like vacuum evaporation, reverse osmosis, ultrafiltration, and membrane bioreactors [2,4,6,8,12,18] demand specialized expertise and nearly constant personnel presence.

Consequently, research efforts that identify or propose low cost treatment methodologies, adapted to operators' needs and discharge standards, are of paramount importance. The present study is dedicated to achieving precisely this objective. We have developed an exceptionally efficient technique that is both cost-effective and ecologically sustainable.

This investigation employs a captivating approach—the utilization of a planar solar collector [11,19–27]. While widely employed across various applications and fields such as solar cookers and solar water heaters, our experiment harnesses this flat collector's potential to expedite the evaporation and removal of leachate. The experimental phase has unequivocally showcased the efficacy of this technique, with the leachate evaporation rate by this process being tenfold that of natural evaporation. This acceleration implies that the timeframe for leachate treatment in ponds, which typically spans three months, could be drastically reduced to a mere three or four days, saving a remarkable 90% of the time typically required.

MATERIALS AND METHODS

Study Site

This study was carried out in the Khenifra solid waste burial and recovery center, located in the village of Amehroq, in the commune of El Heri in Khenifra. This city is located between the Meknes city and Beni-Mellal city. The province of Khenifra is part of the region of Béni-Mellal Khénifra in Morocco (Fig. 1). This solid waste landfill and recovery center, created in 2016, is part of a new generation of environmentally friendly projects that contribute to the development of the green economy and the socio-economic integration of professionals in the waste recycling sector. Its objective is to prevent and reduce pollution caused by household waste and to organize its collection, transport, storage and treatment in a way that takes into account the environmental dimension and allows for the recovery and recycling of waste in a rational way.

It includes a landfill with a system to prevent leachate leakage and waste collection ponds with a storm water drainage system outside the center.

It should be noted that this pioneering project in this region level aims to tackle the problem of anarchic dumps, recalling that this project was set up as part of an integrated vision for a more modern and rational management of waste and its use in the production of energy and raw materials, all in strict compliance with environmental standards. However, to complete this huge project, there are two other points to be achieved, which are the improvement and development of methods for the treatment of leachate at lower costs and the production of biomass energy in order to take advantage of the energy that is produced within the center.

In this study, we will look at the treatment of leachate produced at the center, which is currently treated by natural evaporation, a very old technique that costs nothing but has a major problem in that it is very time consuming, especially during the summer season when leachate production reaches maximum quantities.

Characterization of the Waste of Khénifra City and Its Leachates

The leachates studied were collected from the vehicles in charge of the collection of household waste from the city of Khénifra during transport to the landfill. The household waste from the city of Khenifra has a moisture content of

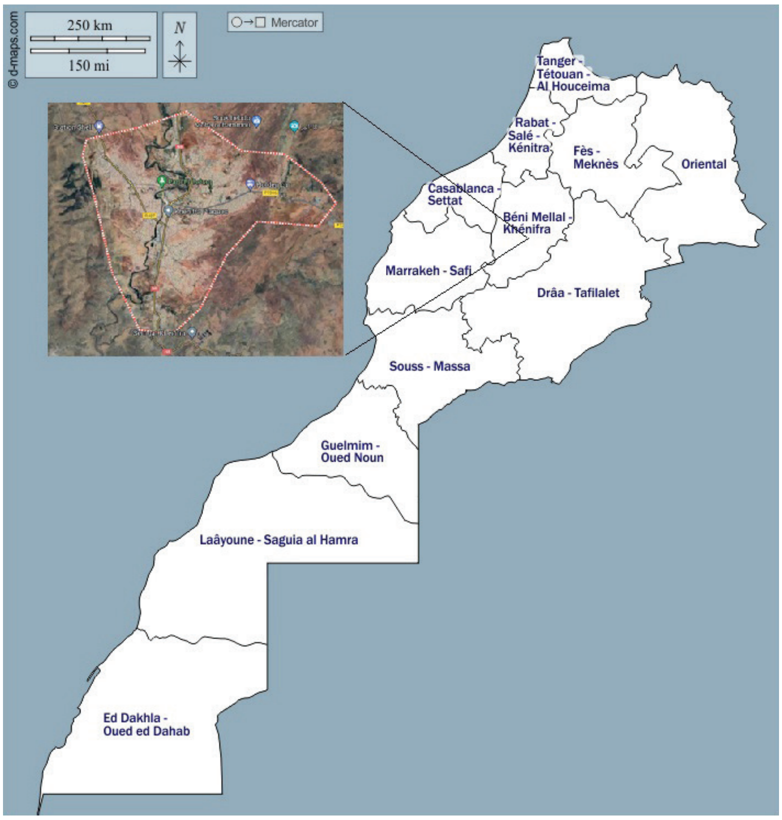

Figure 1. Location of the city of Khénifra (Morocco).

Figure 2. Location of the study site, landfill and waste recovery center.

Table 1. Physicochemical characteristics of the leachate

Parameters	*Values*	*Unit*
Organic compounds	52%	-
pH	4.92	-
COD	22,6	mg/L
Electrical Conductivity (EC)	25,7	µs/cm
Turbidity	2,78	NTU
Total Suspended Solids (TSS)	5,64	mg/L
[NH]$^+$	1,87	mg/L
[Cl]$^-$	2580	mg/L
Heavy Metals	73	mg/L

about [3,28] 64% and is characterized by a high content of organic matter and a high percentage of waste [29]. These types of waste are generally characterized by the presence of a dominant fraction consisting mainly of kitchen and garden waste. This fraction has been estimated, in most landfills, to be more than 50% of the mass of municipal waste. This is justified by a consumption pattern based on fresh products. The waste is still composed of paper, plastics. The quantities of aluminum, iron and glass are very negligible.

The physico-chemical analysis of the young leachate generated by this waste showed an acidic character with a pH of about 5 and a high organic load with a chemical oxygen demand (COD) exceeding 20gO_2/L.

Description of the Experimental Set-Up

The tests were carried out in plastic bottles with a capacity of 1 liter each, the first one left in the ambient air with the objective of making a natural evaporation and the second one, the same bottle with the same capacity, is put in

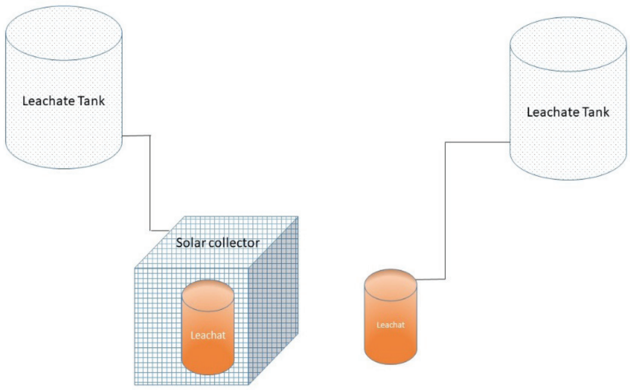

Figure 3. Flat solar collector for evaporation and natural evaporation device.

a flat solar collector. The flat solar collector is made from simple materials, it consists of a box which must be made of an insulating material to prevent heat loss inside and also to minimize the external effects on the internal temperature. The inside of this box is lined with a reflective film, usually aluminum foil or a glass mirror, and the top surface of the box is made like a glass window to let the light rays in and at the same time create the greenhouse effect inside the box. This box, which is 40 cm wide and 70 cm long, must be very well closed to avoid any kind of leakage.

In addition to this we used two thermometers to monitor the temperature of the leachate within each vessel. The amount of leachate we used in each vessel was 800 ml. Figure 3 shows our experimental set-up to be exposed to the sun. Thus, forced evaporation was achieved using the flat solar collector technique.

The experimental device presented in the figure above, is a very simple technique in terms of cost of the necessary elements and also for its realization, that is to say that it does not require special skills in order to carry it out, and this is a strong point of this experiment because it can be carried out easily, from where a broad public can benefit from this device in order to preserve our environment and not to waste money for too complex and too expensive techniques.

RESULTS AND DISCUSSION

Natural and Forced Evaporation of Leachate Through a Solar Collector

The aim of this test is to evaluate the difference in evaporation efficiency between leachate left in the open air i.e. natural evaporation and forced evaporation i.e. using the flat solar collector, all elements must be well exposed to the sun, as the sun plays the most important role in this experiment.

The curves in Figures 4 and 5 show the results of the decrease in the amount of leachate during our experiment and the corresponding temperature values, the experiment is performed during one day in the winter period. We started the experiment at about 10:09 a.m. until 4:00 p.m., so our experiment took 351 minutes in total. First of all we noticed that the maximum ambient temperature was around 22 °C while on average it was around 15 °C, but the maximum temperature in the solar collector reached 61 °C and on average this temperature in the solar collector was around 40 °C, it is to be noted that this day of the experiment was partially cloudy, while in normal conditions in Khenifra city the ambient temperature exceeds 30 °C in

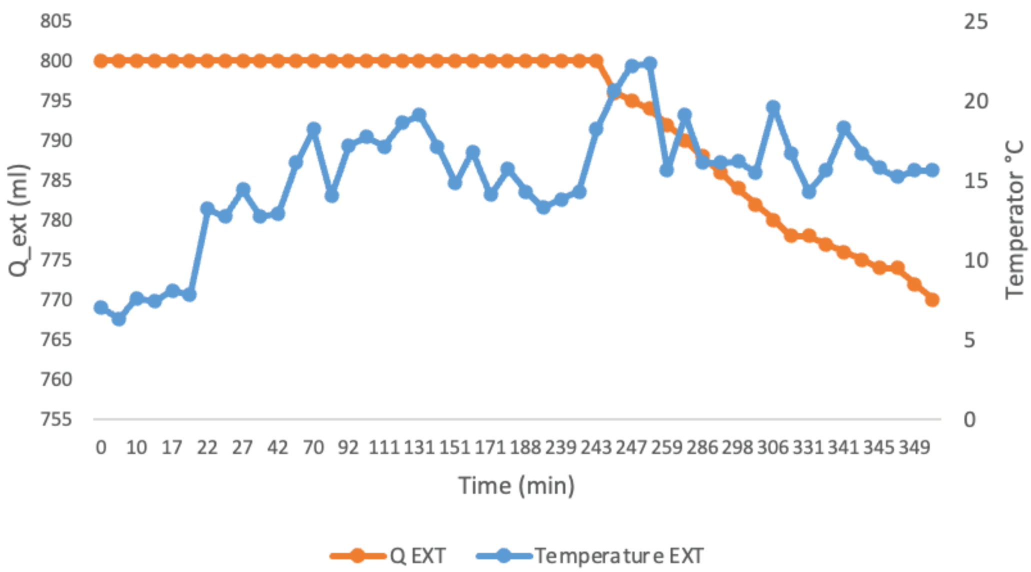

Figure 4. Decrease in the amount of leachate evaporated in the open-air.

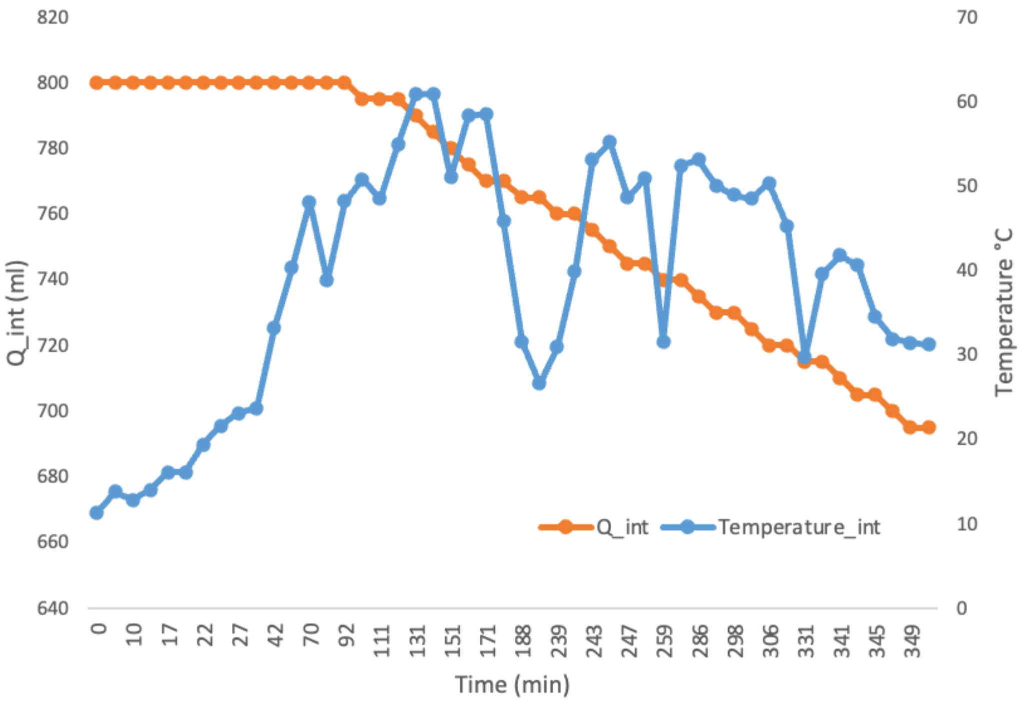

Figure 5. Decrease in the amount of leachate evaporated in the solar collector.

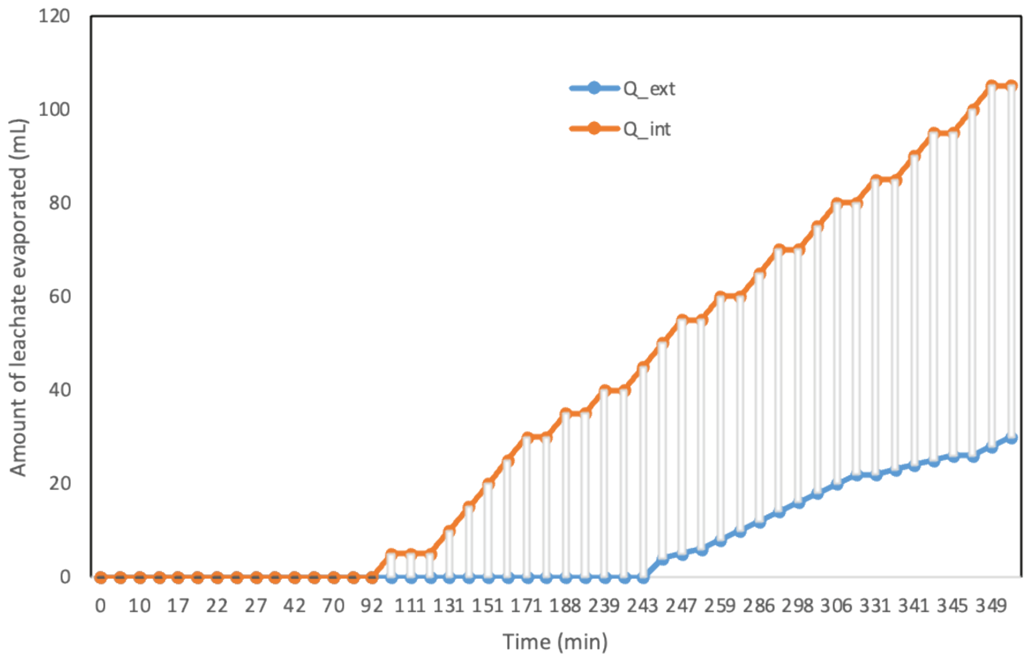

Figure 6. Comparison of leachate evaporation results in the open-air and in the solar collector.

general and even more in the summer period, this shows that our experiment will gain in term of yield during normal conditions and especially in summer.

In Figure 6, it can be seen that the triggering of the natural evaporation needs more than 240 min, while the evaporation in the collector needs only 90 min, which shows that we could reduce this period by more than half, so we can say that it is possible to have an evaporation even with low ambient temperatures and the collector is able to evaporate the liquid in all the conditions because this device also takes advantage of the phenomenon of greenhouse effect. Moreover, we can see that the quantity evaporated at the end of the experiment is 30 mL in the open-air and 105 mL in the collector, which shows that the quantity of leachate evaporated in the collector is three times greater than the quantity evaporated in the open-air, a gain in efficiency that exceeds 300%.

However, the results obtained show that evaporation is largely favored in the solar collector compared to natural evaporation. The estimated time required for complete evaporation under these conditions, considered as bad climate conditions, of 800 mL of leachate at an average temperature of 15 °C during this period is 26 days, while the estimated evaporation period in the collector is about 8 days, i.e. a decrease of 18 days. The average evaporation rate increased by about 351% from the initial evaporation rate of 0.085 mL/min to 0.299 mL/min.

The findings derived from the study unequivocally validate the crucial and highly impactful role played by the solar collector in intensifying the process of evaporation, particularly in comparison to the leachate that remains directly exposed to the ambient air. This substantiates the collector's proficiency in significantly expediting the rate at which leachate transforms from liquid to vapor state.

The detailed analysis of the results underscores a remarkable reduction in the overall evaporation timeframe. Notably, when examining an equivalent quantity of leachate, the utilization of the solar collector precipitates a noteworthy decrease in the temporal span required for the evaporation process to reach completion. This compelling observation emphasizes the remarkable efficiency of the solar collector-driven evaporation mechanism in comparison to the natural dissipation of leachate under standard atmospheric conditions.

CONCLUSION

The culmination of this comprehensive study provides resounding affirmation that the intricate interplay between meteorological nuances and physical parameters governs the intricate process of evaporation. However, the complexity of these factors does not preclude the implementation of pragmatic and astoundingly effective methodologies, as unveiled by the findings of this research. The empirical evidence gleaned from our investigations significantly amplifies the pivotal role of a flat solar collector, shedding light on its profound efficacy as an unassuming yet transformative instrument. The tangible benefits it imparts are indeed striking:

1. A discernible amplification of internal temperature gradients within the collector's confines, a testament to its prowess in harnessing and concentrating solar energy.
2. An impressive acceleration in the rate of evaporation, with the collector propelling the process from a modest 0.085 ml/min to a commendable 0.299 ml/min.
3. Most notably, a remarkable truncation of the once-protracted evaporation period, diminishing from a laborious 26 days to a mere 8 days, all accomplished through the seamless integration of this celebrated device.

These outcomes underscore not only the prowess of the chosen approach but also its ability to revolutionize traditional expectations. The device's multifaceted impact is particularly remarkable when viewed through the lens of enhancing efficiency, with its deployment translating into a staggering efficiency surge of over 300%. Yet, amidst these impressive outcomes, the true gem of this solar collector lies in its inherent simplicity of design and the associated cost-effectiveness.

As we peer into the horizon of possibilities, it becomes increasingly evident that the promise of innovation holds substantial potential. Future explorations might encompass an inquiry into alternative configurations of solar collectors, each poised to further amplify operational efficiency. Moreover, the notion of harmoniously amalgamating disparate techniques kindles intrigue, offering a tantalizing prospect of harnessing green energy in a manner that remains both fiscally prudent and environmentally sagacious.

In this pursuit, the horizon beckons towards a realm where innovative collaborations blend seamlessly with tried-and-true practices, culminating in solutions that propel us closer to safeguarding our environment against the insidious impact of leachate. As the chapters of research and application continue to unfold, this study stands as a beacon, illuminating the path toward a more sustainable and enlightened future.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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