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Research Article

A Combined System of Ground Well and Composted Olive Cake for Hot Water Production at Olive Mills

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Building a system that consists of a combination of geothermal component (water well (pit)) and heat recovery from aerobic biological fermentation of olive cake for hot water production at an olive mill is examined in this work. Hot water is essential for mill operation and constitutes a main operational cost, and in many countries, including Jordan, it is normally produced using diesel fuel. In this process, treated and untreated olive cake was characterized. Results show that olive cake is rich in crude fiber and NFE, contains moderate amounts of crude protein and fat, and a good amount of ash. The as-received moisture content ranged from 33.3 to 35.6%, while water activity was between 0.93 and 0.96. The total counts, thermophilic bacteria, and the total mold count of fermentation ranged, respectively, from 2.1×10^8 to 2.4×10^8, 1.7×10^4 to 1.9×10^4, and 1.5×10^2 to 1.7×10^2. The temperature results showed that the well and the covered tank led to a rise in water temperature before entering the boiler in the range of 7 to 13°C. The system effected significant raises in water temperature entering the boiler ranging from 19°C up to 25°C, which holds a promising potential for the system to satisfy much of the mills needs at this range of temperature before entering the boiler provided a large enough pile (pile scale up) is used to handle larger flow rates. The exhausted cake may well be utilized as a soil organic fertilizer.

1. Introduction

In most Mediterranean countries including Jordan, olive tree culture goes back to many centuries, and olive trees in the region enjoy a special cultural and economic significance. Due to various social and economic transformations, the region has witnessed substantial expansion in olive trees in the last several decades. In fact, in Jordan alone, there are more than 110 olive mills that process olive fruits for olive oil production. The latter enjoys several proven health advantages [1, 2].

In addition to olive oil, two other materials are produced by olive processing mills, namely, the solid residue and wastewater as by-products, both of which constitute a serious environmental risk if not adequately disposed of or properly utilized [3]. Thus, numerous researches have investigated the olive oil industry by-products and wastes. In particular, the solid waste has attracted attention for its potential as an energy source [4, 5], oil source, and animal feed [6, 7], among other purposes. The wastewater by-product has also been investigated where several researches attempted to improve the quality of wastewater for better utilization in many areas such as crop irrigation and crop fertilization [8, 9].

Recently, a strong correlation was observed between olive oil production and environmental pollution, and researchers became concerned with the basic issue of the wastes produced after extracting oil from the fruits. Aqueous sludge, which makes about 45% to 54% of the total waste, is treated by using different methods such as chemical, biochemical, and electrochemical treatments, supercritical extraction, and separation processes based on membrane technology [10–12]. Olive cake, which is also considered a major solid pollutant, constitutes more than 80% of the consumed olives and depends on olive varieties and the extraction process. Generally, olive cake is utilized as a fuel due to its relatively high energy content [5] and as a raw material for soap making due to its high-quality oil content of about 5% to 8% [13].

However, these application areas require drying of the olive cake from a moisture content of 20% to 45% to approximately 5% to 6%; this process is regarded as energy intensive [14, 15].

During olive oil production, mills need large amounts of hot water that are normally obtained from boilers that operate on diesel fuel. In Jordan, that imports more than 97% of its energy, the annual energy bill averages about JOD 10,000 per mill (equivalent to US$15,000) and is projected to be doubled with the continuous increase in diesel fuel prices. Mills use large amounts of hot water at about 60 to 70°C for about four to five months, which is the length of the annual pressing season. In addition, some mills have on-site olive oil storage facilities for filling and exporting purposes. These storage facilities also require additional large volumes of hot water at 30 to 40°C for oil processing.

Olive processing yields enormous quantities of solid waste after the separation of the aqueous phase. This residue contains 4% to 9% of olive oil, depending on the extraction system used: continuous or discontinuous pressure [16]. Chemically speaking, this solid waste is a lignocellulosic organic material [17]. In different countries, this by-product is burned for heat generation. However, since the enactment of international regulations limits the emission of CO_2, this practice has been prohibited, thus requiring alternative practices.

The current practice regarding hot water production for the milling process at the mill under consideration, as well as in most other mills, involves transporting water from nearby springs and storing them in bear (uninsulated) metal tanks on the rooftop of the mill and then feeding this water to the diesel-fired boiler. Given that most of the milling season coincides with the cold winter season when ambient temperatures in most regions including the mill under study are very low and even get close to zero during part of the milling season, large sensible heat is needed to raise the water temperature up to 60 to 70°C needed for olive processing. This fact is reflected in substantial diesel fuel requirements that under current price trends present a heavy toll and a major operational expense of the mill. Based on the above, it may be obvious that the energy bill especially that pertains to hot water makes a major operational cost, and any reductions in energy expenses will effect significant savings in the running costs of operating the mill.

In light of the facts that many families depend on olive oil as an important source of living, the tighter competition among oil producers in available markets, and that Jordan imports almost all its energy needs, this study was set out to explore the possibility of building an alternative novel the on-site system for hot water production. The proposed system which was erected on the mill premises consisted of a combination of geothermal component (water well or pit) and heat recovery from the process heat of the biological fermentation of olive cake that is produced in large quantities at the mill in an attempt to reduce/supplement the diesel fuel consumption at the mill. In fact, heat recovery from the aerobic treatment of organic wastes was investigated although in very limited instances [18].

2. Materials and Methods

2.1. Proximate Chemical Analysis. Proximate analysis was carried out according to the procedures outlined by the AOAC [19].

2.2. Determinations of pH. The regular pH meter was used to determine the pH of fermented and unfermented olive cake. Six measurements were taken for each sample, and the final reported reading was the arithmetic average of the readings.

2.3. Water Activity. The regular water activity instrument was used to determine the water activity of fermented and unfermented olive cake. Three determinations (about 25 grams each) were taken for each measurement, and the final reported reading was the arithmetic average of all readings.

2.4. Microorganism Examinations

2.4.1. Sample Preparation (Dilution Preparation). Twenty-five-gram samples were taken from fermented and unfermented olive cake. Each sample was then added to 250 ml of peptone water to a dilution of 1 : 10.

2.4.2. Total Count (TPC) and Total Thermophilic Bacteria (TTB). From the previous solution (Section 2.4.1), 0.1 and 1 ml were put in Petri dishes and plate count agar that was prepared in standard methods relevant to TPC and TTB was poured onto them. After that, the dishes were put in an incubator for 24 to 48 hrs at 37°C. The colony was counted after the growth.

2.4.3. Total Mold Counts. From the previous solution, 0.1 and 1 ml were put in Petri dishes, and potato dextrose agar that was prepared by standard methods was poured on them. After that, the dishes were put in an incubator for 3 to 5 days at 25°C. The colony was counted after the growth.

2.5. The Hot Water Production System. The system in this work utilized a combination of renewable energy sources for hot water production. The sources included geothermal energy by digging a ground pit (well) with a total capacity of 20 m^3 of water. The well (first station) receives water from tankers that bring water from nearby springs. The water is then pumped to the partially buried tank (second station) that is covered with olive cake for merely thermal insulation purposes and utilizing the possible uncontrolled

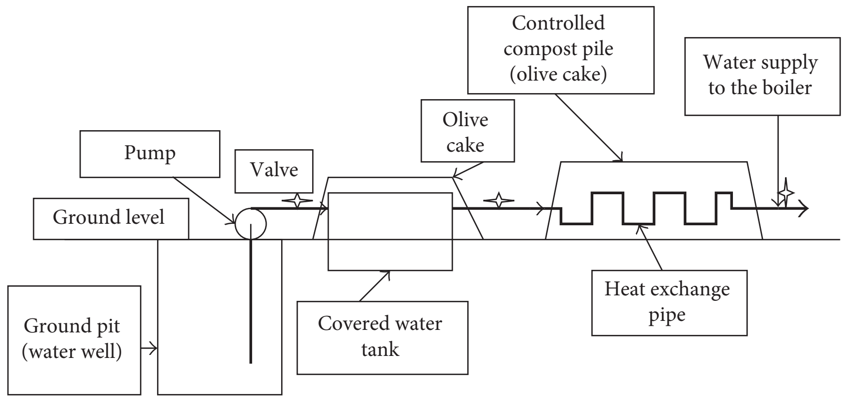

Figure 1: A schematic diagram of the combined system used in this work for hot water production at the olive mill.

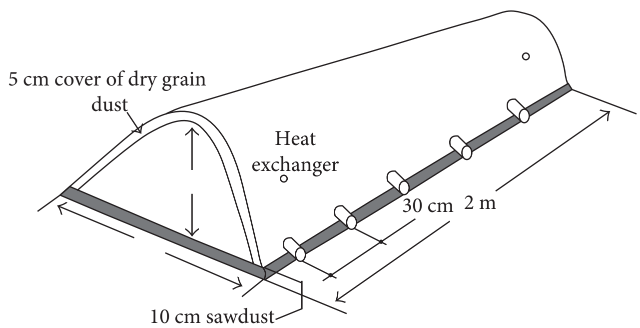

Figure 2: A schematic of the compost pile of olive cake used in this work [20].

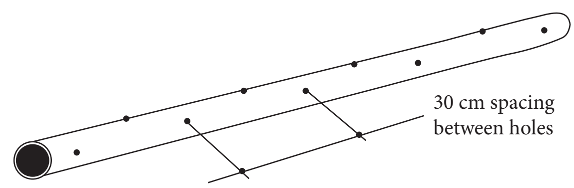

Figure 3: A sketch of the perforated pipes used for aerating the pipe [20].

compost process heat to further heat the water. Water then leaves the tank to a heat exchanger that is completely inserted into a controlled olive cake compost pile (third station) where temperature reaches 60°C to 70°C due to the biological activity. A schematic of the system is shown in Figure 1 [20].

A 100-meter long heat exchanger made of aluminum tubes with an internal diameter of 18 mm was used. The tubes were wound at the Engineering Workshops of Jordan University of Science and Technology to fit within a 13-meter long pile of olive cake. The water flow rate into and out of the heat exchanger at steady-state conditions was measured by a calibrated (graduated) beaker with a stop watch from which the hot water volumetric flow rate was calculated.

As shown in Figure 2, the pile was of the passively aerated type fitted with 12-inch (30 cm) diameter PVC perforated pipes for efficient aeration and air circulation as illustrated in Figure 3. A total of 12 PVC pipes were used. It should be noted that, on one hand, the pile was located in open air next to the mill premises, and on the other hand, the pile management requirements were minimal. Consequently, pile emissions would be substantially diluted, and human exposure to pile emissions would be marginal. As such, no measures of pile emission control were implemented.

A valve was fitted at the exit point of each of the three stations, and numerous measurements of water temperatures were made at these points in addition to the ambient temperature using thermocouples along with a digital multimeter. The water temperature data were averaged for every two weeks (15 days) and reported as a single value. Water temperature measurements were started at the end of January and extended over the following three consecutive months (till the end of April).

2.6. Statistical Analysis. Data are presented as means of three determinations and analyzed using the general linear model procedure with SAS Version 8.2 software package [21]. The LSD analysis was used to compare means. Significant differences were defined at the $p < 0.05$ level.

3. Results and Discussion

3.1. Chemical Analysis. The chemical composition of fermentation periods of olive cake during 90 days of fermentation is shown in Table 1. As may be seen from the results, the unfermented (0 day) and fermented olive cake is rich in crude fiber and NFE and contains moderate amount of crude protein and fat. Also, the results in Table 1 show that olive cake contains a good amount of ash. Table 1 also indicates that the olive oil is rich in the nutrients which helped microorganisms to grow for longer periods of times. That is, these nutrients assist microorganisms to produce heat for longer periods of time, thus enhancing the feasibility of the hot water system. In addition, Table 1 shows the fermentation time for three months. It is shown that no significant differences were found during fermentation. These results indicted that olive cake can be used for long time as a source of fermentation.

Table 1: Chemical composition of olive cake during 90 days of fermentation.*

Fermentation period (day)	Dry matter	% of dry matter				
		Ash	Crude protein	Crude fiber	Ether extract	NFE**
0	65.3 ± 4.4	4.4 ± 0.2	7.2 ± 0.5	43.6 ± 3.3	11.4 ± 0.8	32.3 ± 2.5
30	66.7 ± 4.5	4.6 ± 0.3	7.1 ± 0.4	44.0 ± 3.8	11.3 ± 0.7	32.3 ± 2.7
60	65.9 ± 4.1	4.2 ± 0.2	7.4 ± 0.5	44.5 ± 3.2	11.5 ± 0.8	32.0 ± 2.4
90	65.3 ± 4.4	4.3 ± 0.3	7.1 ± 0.4	45.5 ± 3.9	11.4 ± 0.7	32.7 ± 2.3

*Means ± SD; **nitrogen-free extract.

Table 2: Moisture contents and water activity of olive cake during 90 days of fermentation.

Fermentation period (day)	Moisture contents (%)	Water activity*
0	34.7 ± 2.2	0.95 ± 0.03
30	33.3 ± 2.1	0.93 ± 0.04
60	34.1 ± 2.5	0.94 ± 0.05
90	35.6 ± 2.1	0.96 ± 0.04

*Means ± SD.

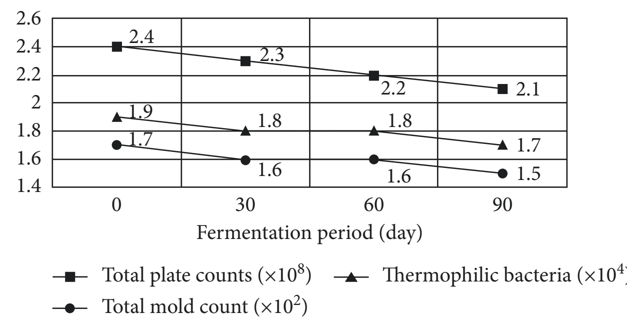

Figure 4: The total counts, the thermophilic bacteria, and the total mold count of olive cake during 90 days of fermentation.

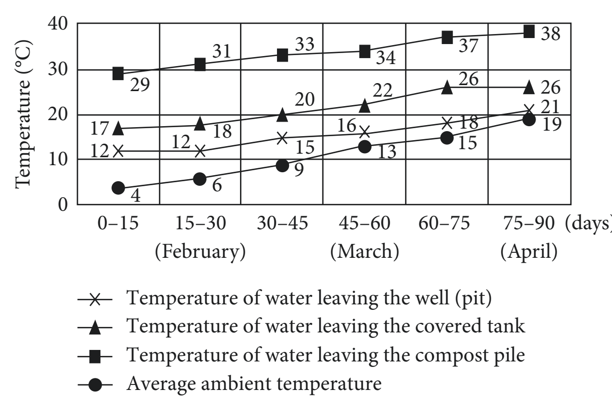

Figure 5: Water temperature data for three months.

3.2. Water Activity and Moisture Content. Moisture content and water activity values of olive cake over 90 days of fermentation are shown in Table 2. It may be noted from the table that moisture contents of the unfermented (0 day) and fermented olive cake ranged from 33.3% to 35.6%, while the corresponding values for water activity were 0.93 and 0.96, respectively. In either case, no statistically significant difference was found during the 90 days of fermentation. The numerically higher water activity could be due to the fat contents that let the water molecules to move easily in the media (olive cake). Also, these results agreed with the microorganism determinations.

3.3. Microorganism Examinations. Figure 4 reports the total counts, the thermophilic bacteria, and the total mold count of olive cake over 90 fermentation days. Figure 4 shows that the total plate count of the unfermented (0 day) and fermented olive cake (during 90 days of fermentation) ranged from 2.1×10^8 to 2.4×10^8, and the corresponding values for the bacteria were 1.7×10^4 to 1.9×10^4, respectively. In either case, no significant difference was found. As for the mold count, Figure 4 indicates that the total mold count of the unfermented (0 day) and fermented olive cake (during 90 days of fermentation) ranged from 1.5×10^2 to 1.7×10^2 with no statistically significant difference. These high values of growth of both types of bacteria could be due to high available nutrients and high amounts of water activity. Also, the type of dominant mold was identified, and the *Aspergillus* spp. was found during the fermentation periods.

3.4. Temperature Measurements. The data that pertain to temperature over the course of the study are reported in Figure 5. Noting that the ambient temperature is the baseline (reference value) that represents the current practice (without the system), the data in Figure 5 indicate that the well alone effected a rise in water temperature in the range of 2 to 8°C, with the lower values being in the warmer weather and the higher values for the cooler period that is more characteristic of the olive milling season.

It should be emphasized here that the well can provide this boost in water temperature at a steady basis with no regard to flow rate. That is, the well can provide the total water requirements of the mill while maintaining this temperature boost. Also, the data indicate that the combination of the well and the covered tank lead to a rise in water temperature before entering the boiler in the range of 7 to 13°C. This rise in water temperature is apparently better (higher) than that by the well alone and could lead to significant fuel savings. It should be emphasized here that, given ample time, the tank, like the well, can provide this boost in water temperature at a steady basis with no regard to flow rate. That is, the tank can provide the total water requirements of the mill while maintaining this temperature boost.

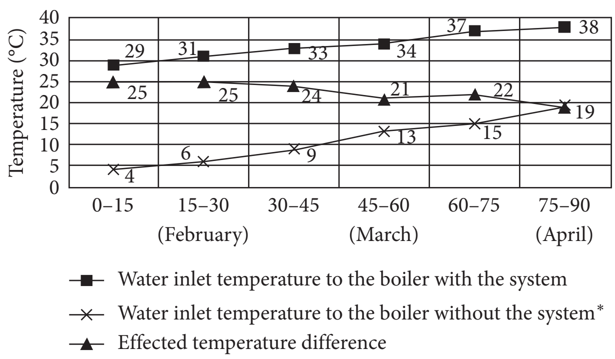

Figure 6: Water temperature entering the boiler with and without the system.

As for the whole system (the three stations), the rise in water temperature relative to the ambient is reported in the last column of Figure 6. It may be readily seen from Figure 6 that, under the flow rate through the heat exchanger in this work (0.4 m^3/h), which is mainly due to limitations of exchanger pipe size and flow speed, the system effected significant raises in water temperature entering the boiler ranging from 19°C up to 25°C, which holds a promising potential for the system to satisfy much of the mill needs at this range of temperature before entering the boiler provided a large enough pile (pile scale up) is used to handle larger flow rates. Note that under steady-state conditions, the temperature of water entering the boiler from the rooftop tanks (without the system) is equal to the ambient.

Given that 1.0 ton of olive fruit requires 200 kg of hot water (a ratio of 5 : 1) and should a scale up system be considered, the current system is sufficient. The 20 m^3 well can process 100 tons of olive fruits, and the 0.4 m^3/h flow rate from the pile is sufficient for 2 tons of olives/h, which is more than the capacity of almost all existing mills. The scenario may involve filling the well in the mill's off time each night which is equivalent to a 4-hour residence time during which water temperature rises by 2 to 8°C above the ambient as was demonstrated during our work.

4. Conclusions

Based on the findings reported herein and the fact that olive milling season in the Mediterranean region coincides with cold winter times, it may be concluded that combining geothermal (well) and on-site aerobic biological treatment of the milling solid by-product (olive cake) holds a promising potential as a simple, low-cost energy source for the needed hot water. This is evidenced by the fact that the system effected significant raises in water temperature entering the boiler to satisfy much of the mill needs at this range of temperature before entering the boiler provided a large enough pile (pile scale up) is used to handle larger flow rates. Consequently, significant savings are possible by implementing the system.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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