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Zero Energy Olive Oil Production Plant Design by Using Waste Valorisation

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Abstract

Olive oil is an ancient food product essential to the daily life, especially in the Mediterranean region. More than six thousand years old olive oil production methods are still in use today. However, as a result of the Industrial Revolution's influences, there are contemporary methods discovered for the mass production and these methods have increased the carbon emissions that trigger the global warming. In a typical olive oil production plant, there are two parts of the space use; the management and the production line. The management part requires thermal comfort conditions; heating, ventilation and cooling. Second part; the production line's energy requirement based on the capacity of the process, and there is not any requirement for human thermal comfort. The proposed model will provide energy for the production line and also the heating/ cooling requirements of the management part. In the considered system, the briquettes will be made from the waste of the olive oil process. Later, these briquettes can be used as an energy resource for the olive oil plant. The architectural design of the oil plant planned according to the local climate conditions. The results show that the waste of the olive oil extraction is more than enough to provide necessary energy requirement of the olive oil factory. By considering the 2500 kg/h olive flow rate of the olive oil production process, 990.1 kg/h briquettes can be obtained and only 400 kg/h of these briquettes is enough to achieve the aim of zero energy olive oil production plant.

Keywords: olive oil production, zero energy building, valorisation, sustainability

1. Introduction

There is a growing concern about the increase in non-renewable energy production and its adverse effects on the environment. The contemporary construction methods of the new and existing buildings increase the amount of global energy consumption and overall greenhouse gas emissions. Environment and energy are both globally important problems that need immediate actions. The utilization of these contemporary methods has ignored their negative effects on the environment and energy issues. The second problem is the demand for non-renewable resources like fossil fuel usage increases each day. The current assumptions emphasize that the fossil fuel resources will not be enough for the near future. The studies show that next generation's development should be related to the sustainable models. Sustainable models provide strategies to protect the environment and increase the use of renewable clean energies. Formulating new design and strategies play an important role in Sustainable Development. The performance of buildings largely affected by the design of efficient energy uses or adopting renewable energy systems.

Bioenergy is a renewable and clean energy source that is derived from biomass. The chemical energy stored in biomass can be extracted through combustion to produce energy that can be used as heat or power. Sustainable managed biomass resources are considered green because they are renewable and do not contribute to global warming. Carbon dioxide generated from the combustion of biomass is consumed as plants regrow, so that as long as the resource is sustainable managed, the net contribution of carbon dioxide to the atmosphere is zero [1].

Agriculture residues constitute the biggest source of biomass. Olive oil is an ancient food product essential to the daily life, especially in the Mediterranean region. More than six thousand years old olive oil production methods are still in use today, however, as a result of the Industrial Revolution's influences, there are contemporary methods discovered for the mass production as well.

Olive oil extraction process produces a large amount of waste which causes serious environmental problems. This waste can be valorised as fertilizer, residual oil recovery, animal feed, fuel, etc. for sustainable development in the olive sector. Among them, generation of energy from olive mill waste is considered as a promising choice for generating heat and electricity to meet the energy requirement of the olive mill and to reduce its environmental impact [2].

Zero Energy Buildings involve two design strategies (1) minimizing the need for energy use in buildings (especially for heating and cooling) through energy-efficient measures and (2) adopting renewable energy and other technologies to meet the remaining energy needs.

In a typical olive oil production plant, there are two parts of the space use. The first part is the management and second part is the production line. The management part requires thermal comfort conditions; heating, ventilation, and cooling. Second part; the production line's energy requirement based on the capacity of the process, and there is not any requirement for human thermal comfort. The proposed model will provide energy for the production line and also the heating/cooling requirements of the management part. In the considered system, the briquettes will be made from the waste of the olive oil process where these briquettes will be used as an energy resource for the olive oil plant. The aim of the study is to achieve zero energy olive oil production plant by using waste valorisation and design implementations.

2. Description of The System

Figure 1 illustrates a summarized diagram of the integrated system of an olive oil extraction, briquetting and co-generation facilities. The system was designed to produce olive oil and use its waste as a fuel to support the system's energy need. The olive oil extraction and briquetting processes were adopted from a study conducted by Leone *et al*. [3] and Grover and Mishra [4], respectively. In this regard, olive oil extraction process is a 3 phase system and composed of 5 sub-processes namely: olive cleaning, olive crushing, olive paste conditioning, solid-liquid separation and liquid-liquid separation. At the end of the process, the product (olive oil) is bottled and stored to be sold. The by-product, olive pomace is fed to the briquetting process which contains drying and pressing activities to make briquette from olive pomace. Then, the briquettes are used as a fuel for cogeneration plant to produce heat and power to be able to meet the energy requirement of the integrated system (Fig.1). The components of the cogeneration plant are the steam boiler, the steam turbine, the condenser and the pump. In the considered system, the energy required for olive oil extraction and briquetting system is supplied from both electrical and thermal energy. For this reason, a few amount of the fluid at condenser outlet (stream 9) is used for thermal energy requirement of the malaxation process takes place in olive oil extraction.

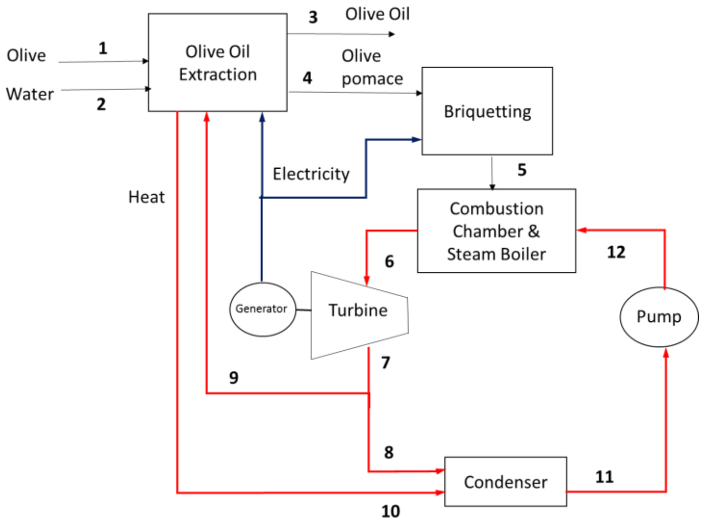

Fig. 1 Schematic representation of the system

3. The Design of The Building

The oil production plant has a double height space with the management part and located in İzmir city (Fig.2). The building is a reinforced concrete structure with brick walls. The plant's machines are placed considering the most efficient layout plan.

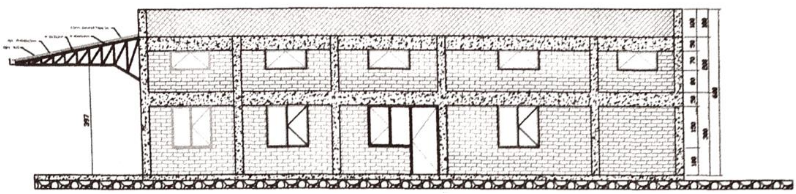

Fig. 2 The long elevation of the oil production building

The management part has three rooms and a toilets area (Fig.3). The manager's room is a place that accommodates the constant circulation of staff and the visitors. The resting room provide comfortable conditions for the staff members during the working hours. The workshop has fixing tools and private lockers. The toilet area has an access from outside because of the hygienic reasons.

The production plan has three parts. The main double-height space has all the necessary machines for the production. The collected oil stored in large containers for distribution in a separate space.

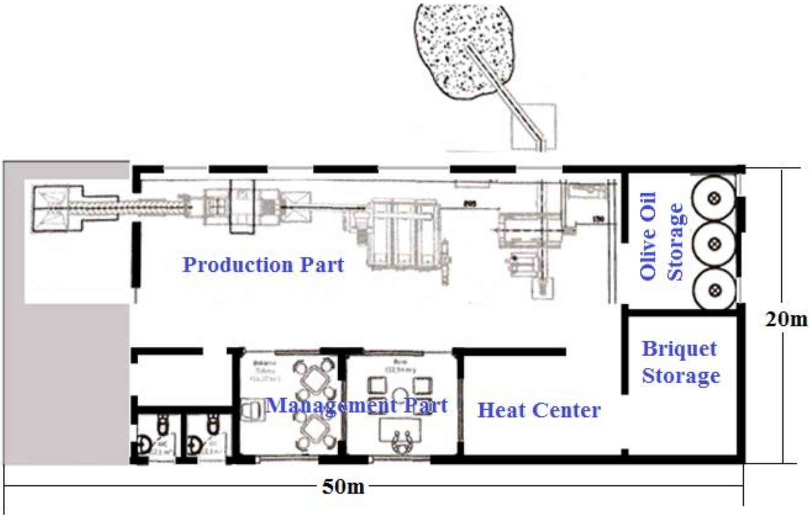

Fig. 3 The plan layout of the oil production building

4. Modeling

The main balance equations, namely, mass and energy balance equations, are applied to the system considered under steady-state conditions. In general, the mass and energy balance equations can be expressed in the rate form as

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$

$$\sum \dot{E}_{in} = \sum \dot{E}_{out} \tag{2}$$

The produced mass flow rate of the oil pomace briquette (B) can be calculated as a function of the moisture content (x_f) and olive pomace mass flowrate (F):

$$B = 1,0297(1 - xf\,)F \tag{3}$$

The mass flowrate of the oil pomace briquette, which is used to provide the thermal energy requirements of the briquetting process is determined by the following equation:

$$P = 500xf - 43 \quad (4)$$

The following assumptions have considered for the analysis of the system of interest:

- All processes are steady state and steady flow with negligible potential and kinetic energy effects.
- Oil production plant is proposed has a capacity of 2500kg olive/h production.
- The olive oil extraction yield is assumed as 14.5% (w/w).
- The initial moisture content of olive pomace is taken as 55%.
- Calorific value of briquette is accepted as 3000 kcal/kg
- The efficiency of the steam boiler is assumed as 75%.
- Isentropic efficiency of the steam turbine and generator are taken as 75% and 90%, respectively.
- The pressure of the steam boiler and the condenser is assumed as 1250kPa and 50kPa, respectively.
- Temperature of the steam at the turbine inlet is assumed as 194 °C.
- The split air conditioner system is selected to provide the thermal comfort of the management part with the COP values as 2.5 for heating and 2 for cooling purpose.
- Heating and cooling design outside temperatures are taken as 0 and 37 °C, respectively.
- Thermal comfort conditions of management part is considered as 22 °C for heating and 24 °C for cooling.
- The unit heating and cooling load of the management part are taken as 70 kW/m^2 and 43,3 kW/m^2, respectively.
- The plant is operated between 9:00 am-18:00 pm during the all year (52 weeks) except the weekends. Therefore, total working hours of the plant are taken as 2600 hours.
- The unit lighting electrical energy requirement is assumed as 5 kWh/m^2.
- The olive extraction and briquetting processes are assumed at the pressure of 1atm and temperature of 25°C.

5. Results

In this study, zero energy olive oil production plant by using olive pomace valorisation was conducted. The heat and power generation by using olive pomace for handling of 2500 kg/h olive was estimated for olive oil extraction process.

For a representative case, the stream fluid, the mass flow rate, temperature, pressure and enthalpy values are shown in Table 1 following the stream numbers specified in Fig.1.

The thermal and electrical energy requirement of olive oil extraction process is 37kW and 100kW, respectively. Briquette machine required 93kW electricity for 1222kg/h briquette production. It is calculated the necessary mass flow rate of the oil pomace briquette for thermal energy requirement of the briquette machine as 232 kg/h with 55% moisture content in oil pomace.

Table 1. Thermodynamic properties of the system

Stream No	**Stream Fluid**	**Mass Flow Rate**		**Temperature (°C)**	**Pressure (kPa)**	**Enthalpy (kJ/kg)**
1	Olive	2500	kg/h	25	101.325	
2	Water	500	kg/h	25	101.325	
3	Olive oil	362,5	kg/h	25	101.325	
4	Oil pomace	2637,5	kg/h	25	101.325	
5	Oil pomace briquetting	990,1	kg/h	25	101.325	
6	Superheated water vapour	1,055	kg/s	194	1250	2797
7	Water liquid& vapour	1,055	kg/s	81,34	50	2401
8	Water liquid& vapour	0,6515	kg/s	81,34	50	2401
9	Water liquid& vapour	0,4032	kg/s	81,34	50	2401
10	Water liquid& vapour	0,4032	kg/s	81,34	50	2334
11	Liquid water	1,055	kg/s	81,34	50	340,5
12	Compressed liquid water	1,055	kg/s	81,41	1250	341,8

The hourly outside air temperature of the İzmir city was used to determine the annual heating and cooling requirement of the management part. Between the hours 9:00 am-18:00 pm during the week day, the annual heating and cooling energy requirement was calculated as 4503 kWh and 2449 kWh, respectively. The annual electrical energy requirement of the olive oil plant for 1222 kg/h oil pomace briquette is summarized in Table 2.

Table 2. The annual electrical energy requirement of the olive oil plant.

Process	**Unit**	**Amount**
Olive oil extraction	kWh	260,000
Briquetting	kWh	242,138
Heating of the management part	kWh	1,801
Cooling of the management part	kWh	1,225
Lighting	kWh	5,000
TOTAL	kWh	510,164

The net power production and the efficiency of the cogeneration plant were calculated as 374,2 kW and 14,45%, respectively. By considering 2600 working hour in a year, annual electricity production is 972,980 kWh.

The electricity usage of the plant is proportional with the olive-oil and oil pomace briquette production. The variation of the annual electricity production and usage with respect to the olive pomace flow rate (in the range between 100-1000 kg/h) is tabulated in Table 3.

Table 3. The variation of the annual electricity production and usage with respect to the olive pomace mass flow rate.

Pomace mass flow rate (kg/h)	Annual Electricity Production (kWh)	Annual Electricity Usage (kWh)
100	98.268	333.801
200	196.537	353.613
300	294.805	373.425
400	393.074	393.237
500	491.342	413.049
600	589.610	432.861
700	687.879	452.673
800	786.147	472.485
900	884.416	492.297
1000	982.684	512.109

It is clearly seen from Fig.4. annual electricity production and usage showed an increasing trend with increasing oil pomace mass flow rate. When olive pomace flow rate is 400kg/h, the electrical energy of the system is totally satisfied and zero energy olive oil production plant can be achieved.

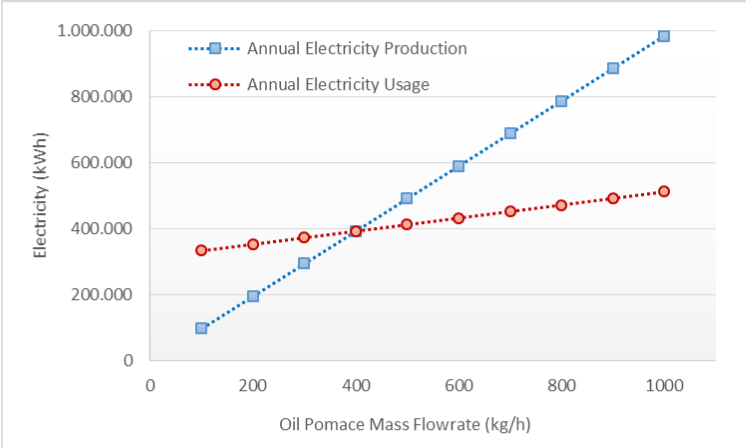

Fig. 4 Effect of the oil pomace mass flow rate on production of electricity.

6. Conclusion

This study presents preliminary results regarding ~~to~~ the Zero energy olive oil production method involving the integrated system composed of olive oil extraction, briquetting and cogeneration facilities.

The annual electrical energy requirement of the olive oil plant to produce 1222 kg/h oil pomace briquette is calculated as 510,164 kWh. By considering 2600 working hour in a year, annual electricity production is 972,980 kWh with the efficiency of the cogeneration as 14.45%.

The analysis results indicate that if 400 kg/h olive pomace is fed to the briquetting machine and then cogeneration plant to produce electricity, respectively, the total energy requirement of the integrated system is met.

As a further study, it is considered to apply thermodynamic optimization assessment to obtain the best performance of the co-generation plant. Additionally, an economic analysis is required for selection of the components in regard to scale up and operational cost of the integrated system.

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