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Assessment of Recycling Perspectives for Olive Mill Solid Waste in Palestine

Muna Ghannam[1], R. M. Al-Sa`ed[2] and O.R. Zimmo[3]
[1]*Technical Coordinator. GTZ Water and Sanitation Project Office, 15C Sateh Marhaba Street, Albireh, West Bank, Palestine*
Email: muna@gtz-water-palestine.org
[2]*Assistant Professor. Water Studies Institute, Birzeit University, P. O. Box 14, Birzeit, West Bank, Palestine,*
Email: rsaed@birzeit.edu
[3]*Assistant Professor. Birzeit University, Faculty of Engineering, Department of Civil Engineering, P.O. Box 14, Birzeit,West Bank, Palestine,*
E-mail address: ozammo@birzeit.edu

ABSTRACT

Olive mill solid waste (OMSW) or olive cake, locally known as “Jift”, is the major solid waste generated by the olive oil industry in Palestine. It is also known as “olive husk” or “olive pomace” in some other olive oil producing countries. The organic rich by-product is under utilized in Palestine. After simple drying process and without any treatment, farmers in rural areas use only limited amounts of the waste, as a burning material to produce heat, as a fertilizer, or as animal fodder. The remaining quantity is disposed off either in uncontrolled landfill dump sites or discharged into open channels causing environmental problems. OMSW is mainly made of olive stones and pulp for which the heating value makes it attractive to be used as a source of energy. When used as a source of energy, OMSW has the potential to replace to some extent the use of fossil fuel as a burning material and therefore, to reduce the associated emissions of pollutant gases into the atmosphere. OMSW can also be utilized, efficiently, as animal feed, fertilizer, and in manufacturing. The desk study conducted over four months during 2004, aims at perspectives assessment of OMSW recycling in Palestine with special emphasis on characteristics, quantities, present status of reuse and disposal methods. In addition, sustainable utilization techniques of OMSW as a source of energy are presented and discussed with regard to having the potential to be technically adequate, environmentally sound, and economically feasible in Palestine. The quantity of OMSW varies according to the annual yield and the manufacturing process. The characteristics of OMSW, however, vary according to the origin of olives and the type of extraction process used. Utilization techniques of OMSW which have the potential to be feasible in Palestine should be considered. Co-composting and anaerobic digestion of OMSW to produce energy have the potential to be feasible and can be recommended for Palestine. However, the feasibility of the other techniques depends very much on funds availability. Pilot scale studies on such techniques in Palestine should be encouraged and supported. Hence, the farmers, the energy generation industries, and the environment can benefit if such a waste is fully utilized on a sustainable approach.

Keywords: Olive Mill Solid Waste, Characteristics, Utilization, Energy.

1. Introduction

Storage, disposal, and utilization of OMSW are becoming real issues in olive oil producing countries worldwide, especially in the Mediterranean countries. In Palestine, a small olive oil producing country, olive mills produce large amounts of OMSW in a short period of time, which imposes disposal and environmental problems. Utilization of OMSW can solve such problems and the by-product can become of a great value for the benefit of the farmers, energy generation industries, and the environment. OMSW has the potential to be utilized as a source of energy, fertilizer, animal feed, and to some limit in manufacturing.

Olive mills in Palestine produce solid waste which represents 35-45% of processed olives (Schroeder and Luxconsult, 1999). Statistical data published by the Palestinian Central Bureau of Statistics (PCBS) shows that for the agricultural year 2002, the total amount of pressed olives in Palestine was 124,564 tons (PCBS, Olive Presses Survey, 2003) while according to the Palestinian Ministry of Agriculture (PMA), the estimated quantity of pressed olives in Palestine for the agricultural year 2003 was only 45,054 tons (PMA, Annual Report, 2003) which shows that the annual yield varies significantly from one year to another. Based on such information, the amount of OMSW generated by olive mills in Palestine can be roughly estimated to be in the range 43,000-56,000 tons for the year 2002 and 15,000-20,000 tons for the year 2003. However, the quantity of OMSW produced also varies according to the manufacturing process. For example, for the same amount of processed olives (1000 Kg), the traditional and semi-automatic olive mills produce 400 Kg, the full automatic (3-phase decanter) produces 500-600 Kg (EC, 2000), and the 2-phase decanter produces 400 Kg of OMSW (Caputo *et al*., 2003).

In Palestine, 95% of olive presses return OMSW to farmers while the remaining 5% use other disposal methods for the waste (PCBS, Olive Presses Survey, 2003). A survey done by the PCBS in 1998 showed that the percentage of holders who are using OMSW as fertilizer is 0.8%, while it is 1.2% as fodder for animals, and 62.7% of holders are using the waste for heating purposes in the rural areas. The remaining 35.3% of holders do nothing with the waste and it is more likely disposed (PCBS, Olive Season Survey, 1999).

OMSW is often illegally disposed off in the environment causing pollution (Baddi *et al*., 2003). Both the limited storage life and the high transportation costs of OMSW are raising the problem of OMSW disposal. The most common way of OMSW disposal is soil spreading and OMSW is often drained in uncontrolled manner. This causes land, groundwater and surface water contamination, due to the high organic load and to the presence of toxic substances such as polyphenols (Schmidt and Knobloch, 2000).

In Palestine, OMSW is under utilized, and when disposed as a solid waste, suitable and acceptable disposal measures are not taken. Therefore, olive cake makes a potential source of environmental pollution in its raw format and is difficult to handle on a large scale basis. It takes a huge amount of space for storage. Utilization of this by product is significant in terms of saving in energy cost and environmental protection against solid waste pollution (Alkhamis and Kablan, 1999).

OMSW has high calorific value similar to coal and have similar density to that of coal. Therefore, it has the potential to be used as a good source of renewable energy (the biomass is the source of energy). For example, OMSW has the potential of producing 250,000 MWh of electricity per annum in South Australia alone, but when not utilized, OMSW poses an extra expense for storage and disposal since it cost farmers up to 15 dollars a ton to dispose off (Dally and Mullinger, 2002).

Other methods for the utilization of OMSW include using the waste as mulch, animal feed, and high quality fertilizer (which requires post processing to separate the stone from the pulp). The olive stones have also been used to manufacture high resistant bricks and plastic containers or transformed to activated carbon to use in the purification of liquids and gases. Another alternative is to use OMSW for the extraction of anti oxidants for pharmaceutical companies, but this alternative is not likely to have the potential to utilize large quantities of OMSW (Dally and Mullinger, 2002). The objectives of this article are to: discuss the characteristics of OMSW and to investigate the feasibility of utilizing such waste as a source of energy technically and economically in Palestine.

2. Methods of Approach

This study was done based on information gathered from different sources, most of which are up to date. The sources used were websites, technical reports, books, and a variety of up to date scientific journal articles. The authors of such articles used laboratory experiments on samples of OMSW, field experiments on using OMSW as a source of energy, literature review based on scientific and technical reports, and information from experts in the field such as operators and owners of large olive mills as well as energy generation industries.

Since this study deals with OMSW in Palestine, statistical information from the Palestinian Central Bureau of Statistics (PCBS) and the Palestinian Ministry of Agriculture (PMA) were used to review the status of OMSW in terms of quality, quantity, and reuse (utilization). However, for OMSW characteristics and utilization techniques as a source of energy, international studies (Jordan, Australia, Spain, Italy, Tunisia, Greece, and other Mediterranean and olive oil producing countries) were reviewed and studied for their applicability in Palestine technically and economically.

3. Characteristics of Olive Mill Solid Waste

Characteristics of OMSW vary according to the origin of the material (Alkhamis and Kablan, 1999) and the type of extraction process used (Dally and Mullinger, 2002). The physical and chemical characteristics of OMSW produced by pressing techniques and the continuous 3-phase decanter process are shown in Table 3.1. OMSW comprises a significant fraction of the olive fruit (Alkhamis and Kablan, 1999). OMSW produced by pressing techniques in Palestine is of the type crude olive cake which contains the olive kernel shell crushed into fragments, the skin, and the crushed pulp (Sansoucy, 1985). Olive cake is characterized as a material of low biodegradability (Al-Widyan *et al.*, 2002). It is heavily polluted by polyphenols and fats and is constituted by variable quantities of pulp, olive stone, residual oil, and residual water according to the adopted extraction process (Nicoletti *et al.*, 1994; Demibras, 2000).

As shown in Table 3.1, the chemical composition of OMSW varies within very large limits according to the industrial procedures of oil extraction. The fat content of crude olive cake can be a major source of energy (Sansoucy, 1985). OMSW has high calorific value (Dally and Mullinger, 2002). Samples of fresh raw olive cake were taken by Alkhamis and Kablan in 1999 from Jineen (West Bank) and were analyzed within a month of production for their calorific value as a function of grain size (range from 45 to greater than 2360 μm). The study showed that the calorific value of OMSW was not affected by grain size reduction which may indicate that complete combustion can be achieved even for grain sizes greater than 2.3mm. The average calorific value for the samples was calculated to be 31.2 MJ/Kg which is higher than the other reported values as shown in Table 3.1. The presence of volatile matter indicates that certain combustible materials (gases such as methane) can be further processed to produce more energy from the olive cake source. It was observed that, when such volatile matter evolved from the samples, combustion took place instantaneously. The carbon content makes about half the content of the olive cake. Both volatile matter and fixed carbon can be used for energy production. However, the ash content is small and the sulphur content is negligible (Alkhamis and Kablan, 1999). However, inorganic matter present in biomass plays an important role in the various utilization processes of this alternative feedstock as the percentages of calcium, silicon, and potassium in olive cake are high while the percentages of trace elements such as zinc and manganese are low (Garcia *et al*., 2002).

Table 3.1: Physical and chemical characteristics of OMSW produced by pressing techniques and the continuous 3-phase decanter process.

Item	**Unit**	**Value**	**Reference**
Density	Kg/m^3	515	(Dally and Mullinger, 2002)
pH	-	5.9 ± 0.26 8.7 ± 0.4	(Baddi *et al*., 2003) (Benitez *et al*., 2000)
Heating value	MJ/Kg dry matter	12.5-21 19-26 31.2	(Atimtay and Topal, 2004) (Abu-Qudais and Okasha, 1996) (Alkhamis and Kablan, 1999)
Water content	%	25-30	(Chiofalo *et al*., 2004)
Moisture content	% % g/Kg fresh weight	30 35-40 340.4 ± 0.2	(Alkhamis and Kablan, 1999) (Al-Widyan *et al*., 2002) (Baddi *et al*., 2003)
Oil content	%	3-8 18-25	(Caputo *et al*., 2003) (Chiofalo *et al*., 2004)
Dried stones	%	20-36	(Caputo *et al*., 2003)
Pulp	%	22-31	(Caputo *et al*., 2003)
Kernels	%	3	(Sansoucy, 1985)
Dry matter	% g/100g fresh matter	75-80 65-90	(Sansoucy, 1985) (Alcaide and Nefzaoui, 1996)
Ash	% % of dry matter g/Kg	1.5 3-5 50.8 ± 0.3	(Alkhamis and Kablan, 1999) (Sansoucy, 1985) (Baddi *et al*., 2003)
Gross cellulose	%	40	(Abu-Qudais and Okasha, 1996)
Organic matter	g/100g dry matter	86.8 91-97.5	(Alcaide *et al*., 2003) (Alcaide and Nefzaoui, 1996)
Crude protein	% of dry matter g/100g dry matter	5-10 3.75-11.9 5.72	(Sansoucy, 1985) (Alcaide and Nefzaoui, 1996) (Alcaide *et al*., 2003)
Crude fat	% g/100g dry matter	4 11.7 2.0-36.0	(Abu-Qudais and Okasha, 1996) (Alcaide *et al*., 2003) (Alcaide and Nefzaoui, 1996)
Crude fibre	% % of dry matter	27-41 35-50	(Chiofalo *et al*., 2004) (Sansoucy, 1985)
Neutral detergent fibre	g/100g dry matter	66.2 51.7-71.8	(Alcaide *et al*., 2003) (Alcaide and Nefzaoui, 1996)
Acid detergent fibre	g/100g dry matter	49.7 40.9-59.6	(Alcaide *et al*., 2003) (Alcaide and Nefzaoui, 1996)
Acid detergent lignin	g/100g dry matter	30.9 24.0-33.0	(Alcaide *et al*., 2003) (Alcaide and Nefzaoui, 1996)
Total extractable polyphenols	g/100g dry matter	0.280 ≤ 1.00	(Alcaide *et al*., 2003) (Alcaide and Nefzaoui, 1996)

Table 3.1(cont'd): Physical and chemical characteristics of OMSW produced by pressing techniques and the continuous 3-phase decanter process.

Item	Unit	Value	Reference
Non-nitrogenated extractable material	%	20	(Abu-Qudais and Okasha, 1996)
Ether extract	% of dry matter	8-15	(Sansoucy, 1985)
Volatile matter	% % by weight, dry basis	20 70.8	(Alkhamis and Kablan, 1999) (Garcia *et al*., 2002)
Fixed carbon	% % % by weight, dry basis	40-46 48.5 52.00	(Hamdan *et al*., 1993) (Alkhamis and Kablan, 1999) (Garcia *et al*., 2002)
Sulphur content	% by weight	0.05-0.1	(Atimtay and Topal, 2004)
Hydrogen	% by weight, dry basis	6.91	(Garcia *et al*., 2002)
Nitrogen	% by weight, dry basis	1.62	(Garcia *et al*., 2002)
Chlorine	% by weight, dry basis	0.20	(Garcia *et al*., 2002)
Oxygen	% by weight, dry basis	29.41	(Garcia *et al*., 2002)
Nitrogenated materials	%	4.4	(Abu-Qudais and Okasha, 1996)
TOC	g/Kg g/kg dry weight	464 ± 21 520 ± 1.4	(Benitez *et al*., 2000) (Baddi *et al*., 2003)
TKN	g/Kg g/kg dry weight	11.2 ± 0.5 6.7 ± 0.3	(Benitez *et al*., 2000) (Baddi *et al*., 2003)
C/N	-	41 ± 2 77.9	(Benitez *et al*., 2000) (Baddi *et al*., 2003)
TP	g/Kg	1.0 ± 0.02	(Benitez *et al*., 2000)
TK	g/Kg	6.5 ± 0.3	(Benitez *et al*., 2000)

4. Utilization Techniques of Olive Mill Solid Waste as a Source of Energy

Efficient use of olive cake in energy production aims at two important issues: clean energy production and acceptable disposal of olive mill wastes (Atimtay and Topal, 2004). The most attractive feature of OMSW is the heating value which is comparable with Leigh Creek coal. It is estimated that approximately 20-25% of the energy available in the olive waste could be realized as electricity (Dally and Mullinger, 2002).

4.1 Drying

In convection drying, heat is transferred to OMSW by means of hot gases. Water contained in OMSW evaporates and is conveyed by the hot gas flow. Examples of this type of dryers are drum dryers, belt dryers, and fluidized-bed dryers. The resulting dried OMSW may be incinerated for energy production, reused in agriculture, or land filled, while the air emission must be treated appropriately (Caputo *et al.*, 2003).

The main drawback is the high energy demand. However, this disadvantage is justifiable against the background that the resulting final product can be reused for energy production. From an economic point of view, high investment and operating costs are associated to drying plants; moreover, to ensure trouble-free operations trained and qualified personnel are required (Caputo *et al.*, 2003).

4.2 Firing or Co-Firing

Direct combustion of OMSW is an attractive method of utilization. OMSW is quite dense (515 Kg/m3 at a moisture content of 5.5%) and have heat release very similar to common coal at around 20 MJ/Kg. This raises the possibility of co-firing of OMSW with coal because it requires minimal modification to existing systems and will not require substantial capital investment by either the farmer or the power generation industry (Dally and Mullinger, 2002).

4.2.1 Direct Combustion of Exhaust OMSW (Firing)

Since exhaust OMSW is characterized by a fairly high heating value (18,000 KJ/Kg) and by low nitrogen and sulfur content (Caputo *et al.*, 2003), direct combustion of exhaust OMSW was carried out in a static furnace of a brick factory in Tunisia to replace No. 2 heavy fuel which contains 4% of sulfur as the crushed solid grains of exhaust OMSW were burned in suspension with the combustion air and the sensible heat of flue gas preheats the brick placed downstream of the combustion zone(Masghouni and Hassairi, 2000). The experiment which lasted one year showed that the resulting temperature (850 ± 10 °C) (Masghouni and Hassairi, 2000) is sufficient for brick production with the clay used in Tunisia (Boubaker, 1994). As for the smoke produced during the process, the Bacharach smoke number was 3-4 (the Bacharach smoke scale has ten levels from zero to nine) (Masghouni and Hassairi, 2000).

The use of the exhaust OMSW instead of No. 2 heavy fuel gives a considerable financial benefit in a very competitive industrial sector. 407 metric tones of No. 2 heavy fuel are equivalent to 1, 073 metric tones of exhaust OMSW, since both quantities produce heat energy of 17,704.5 x 10^6 KJ. In addition, the substitution of No. 2 heavy fuel by exhaust OMSW avoids the cost of not only heavy fuel preheating (this operation is carried out by electrical energy), but also heavy fuel pumping and the systematic maintenance of fuel burners, and the regular cleaning of filters and jets. A financial comparison of the costs of No. 2 fuel and exhaust OMSW shows that the use of the exhaust OMSW instead of No. 2 heavy fuel gives a reduction of 63.8% in the cost of energy, equivalent to some 37,800 USD (Masghouni and Hassairi, 2000).

However, in another study which was done for in situ power generation for Unikom, the refining plant with a capacity of 1 MW of electricity in Turkey, showed that the cost of electricity through incineration was calculated to be about € 0.11/kW h which is more than the price of electricity in turkey (€ 0.087/kW h) (Gurbuz *et al*., 2004). Therefore, from an economic point of view, direct combustion of OMSW to replace expensive fuels in the industry market is more beneficial than using it to generate electricity.

4.2.2 Combustion of OMSW with Coal (Co-Firing)

OMSW was co-fired with a lignite coal (widely used in Turkey) in a circulating fluidized bed for which the results showed that OMSW is a good fuel that can be mixed with coal for cleaner energy production in small-scale industries by using circulating fluidized bed (Atimtay and Topal, 2004). Another study done on firing OMSW of 50% moisture content with coal in a fluidized bed showed that a blending ratio of 10% by mass OMSW to 90% coal resulted in 33% reduction in CO emission and a slight drop in Carbon combustion efficiency of less than 5%. It was also found that the bed temperature dropped by 25 °C when compared to 100% coal firing. These effects are probably attributable to the water content of the waste since the evaporating water will tend to gasify some of the carbonaceous material (Cliffe and Patumasawad, 2001).

When the biomass and coal were co-fired in a pulverized coal burner, it was found that there is a potential for reduction in pollutant production, decrease ash deposition, and a decrease in effective CO_2 emissions (Robinson *et al.*, 1998). An experimental study done on co-combustion of OMSW with two different Spanish coals, lignite and anthracite, in a bubbling fluidized bed pilot plant, shows that the combustion of OMSW/lignite or anthracite mixtures is one way to utilize this biomass residue in energy generation. The shares of OMSW in the mixtures used in this experiment are: 10, 15, 20, and 25% (weight percentage as dry basis). The presence of OMSW has not any significant effect on the combustion efficiency. However, the type of coal has a great influence on the combustion efficiency. When lignite coal is used in the mixture, the combustion efficiency is higher than 92% while it is lower than 90% when anthracite is used. This behavior can be explained according to the differences on the volatile matter content for the two coals. SO_2 and NO_x emissions decrease when the amount of OMSW in the mixtures increases, while N_2O emission increases due to the decreasing of the flame temperature caused by high moisture content in OMSW used in the experiment (Armesto *et al*., 2003).

Out of the agricultural residues (wood chips, wheat straws, olive husks, grape residues, and rice husks), char from olive husks have the least nitrogen and sulfur contents, which results in the least emission of air pollutants when burned (Di Blasi *et al.,* 1999a, 1999b, 1999c). Therefore, the potential for direct burning of OMSW is quite possible and a pilot scale trial of co-firing with brown or black coal will help prove that such approach is quite feasible (Dally and Mullinger, 2002).

However, care would need to be taken in the utilization of OMSW in any power station boiler because in the modern electricity market, plant availability is the overriding concern. Furthermore, owing to the ash content of OMSW, it could only be utilized in a boiler designed to handle ash and equipped with dust collectors (Dally and Mullinger, 2002).

Co-combustion is generally viewed as the most cost-effective approach to biomass and wastes utilization by the electric utility industry. The benefits of co-firing are obvious: a low-cost-low-risk renewable energy reduced airborne emissions, diversified fuel sources, and generation of power that can be considered as green power (Armesto *et al*., 2003).

4.3 Briquetting

Briquetting is a technique used to agglomerate a wide range of materials into a more useable form. It has been widely used to upgrade coal dust, mine waste, and Victorian brown coal for use as barbecue fuel. Different biomass products have been considered for Biobriquetting including cotton stalks, tea waste, waste paper, and wheat straw. In such an approach, five main issues have to be considered: Shatter index, compressive strength, water resistance, combustion characteristics, and emission of pollutants. The majority of biomass material needs a binding agent to hold it together and allows handling and transport of the briquettes (Dally and Mullinger, 2002).

OMSW has a low compressive strength and shattering index, even when milled down to 0.25mm diameter particles. Compressive strength decreases with amount of moisture in OMSW. OMSW also has reasonable water resistance when compared to other biomass products. However, this depends on the initial water content and the pressing pressure (Yaman *et al.,* 2000). The properties of briquettes from OMSW can be improved by adding paper waste, which contains fibrous material, and by this, the shatter index increases substantially. In addition, the waste paper has similar combustion characteristics to that of OMSW and will have minimal effect on the burning rate (Dally and Mullinger, 2002).

A study done in Jordan showed that the physical durability and stability of olive cake briquettes made by compressing loose olive cake in a closed -end cylindrical die using hydraulic press under varying maximum pressure, material moisture content, and dwell time was strongly affected by the moisture content at the time of compression. The productions of olive cake briquettes with high quality require material moisture content (30-35%) by weight. At moisture content beyond 35-40%, it was not possible to produce stable units. In addition, the level of stress had significant effect on briquette quality, especially at lower moisture content levels. A stress level of 35 MPa produced the best results and may be considered optimal. Varying dwell time from 5-20 seconds altered neither the briquette durability nor its combinations. Therefore, the maximum dwell time for olive cake compression should not exceed 5 seconds. Under optimal conditions, the briquettes were highly durable and attained a relaxed density of 1,100 to 1,300 Kg/m^3 (Al-Widyan *et al*., 2002).

However, burning is usually undertaken in a relatively uncontrolled environment and can be very harmful to the environment. But, considering that the need for alternative fuels will increase in the near future, briquettes offer a substantially better alternative to coal (Dally and Mullinger, 2002).

4.4 Slurry Fuels

Slurry fuels, mixtures of solid particles and a liquid carrier, have received considerable attention recently, primarily owing to their beneficial properties for transportation, handling, and feeding.

Most of the previous studies on slurry-fuel combustion have been concentrated on coal/oil and coal/water slurries (Douglas *et al*., 1988). The quality of fuel atomization is very important to the successful combustion of slurry fuels. Poorly designed atomizer nozzles may lead to clogging or accelerated erosion of the nozzle, causing large droplets which greatly reduce the combustion efficiency (Abu-Qudais and Okasha, 1996).

An experimental study was done on using diesel-olive cake slurry as a source of energy in vertical cylindrical water cooled combustor with jet-blast atomizer, especially designed for slurry-fuel injection. Fine particles (like a powder) of olive cake were added to the diesel fuel, thereby avoiding the clogging of the atomizer holes. Results of the study showed that a stable flame was achieved for up to 20% by weight olive cake in the diesel fuel for the atomizer used in this study. The heat transfer rate to the water jacket rose as the percentage of the olive cake was increased to 7% by weight at which the maximum combustion efficiency was achieved. It may be concluded from this study that OMSW is a very promising source of energy (Abu-Qudais and Okasha, 1996).

4.5 Pyrolysis

Pyrolysis is the thermal degradation of organic waste in the absence of oxygen to produce a carbonaceous char, oils, and combustible gases. Relatively low temperatures are used, in the range 400-800 °C. The process conditions are altered to produce the desired char, gas, or oil end-product, with pyrolysis temperature and heating rate having the most influence on the product distribution. The heat is supplied by indirect heating such as the combustion of the gases or oil, or directly by hot gas transfer. The production of oils from the pyrolysis of waste has been investigated with the aim of using the oils directly in fuel applications or with upgrading to produce refined fuels. The solid char can be used as a solid fuel or as a char-oil (char-water slurry for fuel); alternatively the char can be used as carbon black or upgraded to activated carbon. The gases generated have medium to high calorific values and may contain sufficient energy to supply the energy requirements of a pyrolysis plant (Bridgwater and Bridge, 1991).

The product oil from pyrolysis has the advantage that it can be used in conventional electricity generating systems such as diesel engines and gas turbines. However, the properties of the pyrolysis oil fuel may not match the specifications of a petroleum-derived fuel and may require modifications to the power plant or upgrading of the fuel (Williams, 1998).

The capital cost of power generation equipment for pyrolysis of OMSW is more than € 4,053/kW h, which results in electricity generation being more expensive when compared with gasification and incineration processes (Gurbuz *et al*., 2004).

4.6 Anaerobic Digestion and Co-composting

The main aim of the anaerobic digestion process is to produce a product gas rich in methane, which can be used to provide a fuel or act as a chemical feedstock. The methane is combusted to produce energy (Williams, 1998). An experimental study was done on OMSW batch and semi-continuous anaerobic digesters at 37 °C showed that the methane content of the biogas by volume was in the range of 75-80% for both batch and semi-continuous runs, the remainder being principally carbon dioxide. The maximum methane composition was observed to be around 80% by volume corresponding to a hydraulic retention time of 20 days and 10% total solids during semi-continuous digestion (Tekin and Dalgic, 2000). As far as the fermentation process is concerned, qualified personnel are required for process control and this technology is associated with higher investment costs (Caputo et al., 2003). The advantages are: low energy and space requirements, while biogas production enables energy recovery (Caputo et al., 2003), the economic value of the stabilized sludge which can be used as a fertilizer, and the elimination of environmental problems associated with the uncontrolled and inappropriate OMSW disposal methods (Tekin and Dalgic, 2000).

Paredes *et al.*, (1996) investigated the most suitable conditions for degrading the OMSW through composting and concluded that co-composting with cotton waste appeared to be better, as it generated a more humified organic matter at the end of the process. Recently, the evolution of parameters describing the stabilization and humification of OMSW when co-composted with different agricultural wastes was studied, in order to evaluate the requirements for an adequate composting. It was concluded that composting can be an environment-friendly alternative to OMSW disposal (Paredes *et al.*, 2002).

4.7 Gasification

In gasification, oxygen in the form of air, steam, or pure oxygen is reacted at high temperature with the available carbon in OMSW to produce a gas product, ash and a tar product. Partial combustion occurs to produce heat, and the reaction proceeds exothermically to produce a low to medium calorific value fuel gas. The operating temperatures are relatively low (800-1100 °C) with air gasification, and higher (1000-1400 °C) with oxygen gasification. Calorific values of the product gas are low for air gasification, in the region of 4-6 MJ/m^3, and medium, about 10-15 MJ/ m^3, for oxygen gasification. Steam gasification is endothermic for the main char-steam reaction and consequently steam is usually added as a supplement to oxygen gasification to control the temperature. Steam gasification under pressure, however, is exothermic, and steam gasification at pressure up to 20 bar and temperatures of between 700 and 900 °C produces a fuel gas (Methane) of medium calorific value, approximately 15-20 MJ/ m^3. The product calorific values can be compared to natural gas at about 37 MJ/ m^3.

Gasification involves the release of hydrocarbon gases from the solid material (the conversion of carbonaceous matter into biogas) and can be achieved by a steaming process. The resulting gas contains mainly methane with some residues of other gases which are released during the process including CO_2 and CO. Such processes commonly occur in large scale residential waste fills. The temperature in the reactor needs to be effectively controlled in order to maximize the gas production from the mix. The time scale for processing a batch is between three to four weeks. If used locally, the mill needs to be modified to accommodate the new fuel. The resulting gas is easily utilized either in boilers, furnaces, or in gas engines (Dally and Mullinger, 2002). The heat energy is used for process heat or to produce steam for electricity generation (Williams, 1998). However, some technology issues regarding the fluctuation in the quality of the gas and change in the gas composition need to be resolved before the gas can be used in combustion systems (Dally and Mullinger, 2002).

The main drawback from such an approach is the high cost associated with initial setup and operation of these facilities. Large scale steam plants are quite expensive to setup and the cost effectiveness of the operation may be questioned due to the seasonal nature of the industry. The problem of disposing the residues remains valid. Such residue can be used as land fills or fertilizer

(Dally and Mullinger, 2002). The raw gas contains tar, char, and hydrocarbon gases, and therefore the boiler or furnace burner system must be able to tolerate these contaminants and not be susceptible to fouling or clogging (Williams, 1998). However, amongst the other appropriate conversion technologies such as combustion and pyrolysis of OMSW, gasification was found to be the most economically profitable process for in situ power generation for Unikom, the refining plant with a capacity of 1 MW in Turkey (Gurbuz *et al*., 2004).

5. Feasibility of OMSW Utilization Techniques in Palestine

From previous discussion on the OMSW utilization techniques, some approaches used to utilize OMSW as a source of energy seems to having the potential to be feasible technically and economically in Palestine. Table 5.1 summarizes such utilization techniques in terms of advantages, disadvantages, and the potential for such techniques to be feasible technically and economically in Palestine. Utilization techniques of OMSW as a source of energy which have the potential to be feasible in Palestine should be considered. Anaerobic Digestion (Fermentation) has the potential to be feasible and can be recommended for Palestine. The other techniques such as direct combustion, briquetting, slurry fuels, and gasification have the potential to be feasible in Palestine to some extent, depending very much on the available funds.

Table 5.1: Summary of utilization techniques of OMSW as a source of energy in Palestine.

Utilization Technique	**Advantages**	**Disadvantages**	**Potential to be Feasible**
Drying	- Resulting dried OMSW may be incinerated for energy production, reused in agriculture, or land filled.	- High energy demand. - Air emission must be treated appropriately. - High investment and operating costs. - For operation, trained and qualified personnel are required.	- Technically has limited feasibility. - Financially has limited feasibility taking into consideration that the product can be used for energy production.
Direct Combustion of Exhaust OMSW (Firing)	- Gives a considerable financial benefit. - Avoids the cost of heavy fuel preheating, heavy fuel pumping and the systematic maintenance of fuel burners, and the regular cleaning of filters and jets. - Reduction of 63.8% in the cost of energy. - Reduces air pollution.	- The cost of electricity through incineration is high.	- Technically feasible. - Financially, feasible and more beneficial if used to replace expensive fuels in the industry market than using it to generate electricity.
Combustion of OMSW with Coal (Co-Firing)	- Reduction in pollutant production. - Decrease ash deposition. - Decrease in CO_2 emissions. - Low cost fuel.	- Plant availability is the overriding concern to generate electricity. - Could only be utilized in a boiler designed to handle ash and equipped with dust collectors.	- Technically, limited feasibility. - Financially, feasible if the appropriate plant and boiler are available.
Briquetting	- Briquettes offer a substantially better alternative to coal.	- Can be harmful to the environment (air emissions).	- Technically, feasible. - Financially, feasible.

Table 5.1 (cont'd): Summary of utilization techniques of OMSW as a source of energy in Palestine.

Utilization Technique	**Advantages**	**Disadvantages**	**Potential to be Feasible**
Slurry Fuels	- Beneficial properties for transportation, handling, and feeding.	- Poorly designed atomizer nozzles may lead to clogging or accelerated erosion of the nozzle, causing large droplets which greatly reduce the combustion efficiency.	- Technically, feasible. - Financially, Feasible.
Pyrolysis	- The produced oil can be used in fuel applications or with upgrading to produce refined fuels. - The product oil can be used in conventional electricity generating systems such as diesel engines and gas turbines. - The solid char can be used as a solid fuel. - The char can be used as carbon black or upgraded to activated carbon. - The gases generated may contain energy to supply the energy requirements of a pyrolysis plant.	- The properties of the pyrolysis oil fuel may not match the specifications of a petroleum-derived fuel and may require modifications to the power plant or upgrading of the fuel. - Electricity generation is more expensive when compared with gasification and incineration processes.	- Technically, limited feasibility. - Financially, limited feasibility.
Anaerobic Digestion (Fermentation)	- Solid residue can be used as a fertilizer. - Produces methane which can be used to provide a fuel or act as a chemical feedstock. - Energy and space requirements are very low.	- Qualified personnel are required for process control. - This technology is affected by higher investment costs.	- Technically, is feasible. - Financially, is feasible and can be recommended.
Gasification	- The resulting gas is easily utilized either in boilers, furnaces, or in gas engines. - The heat energy is used for process heat or to produce steam for electricity generation. - Gasification was found to be the most economically profitable process for in situ power generation (electricity). - An attractive approach to increase thermal efficiency. - Reduces emission of pollutant gases.	- Fluctuation in the quality of the gas and change in the gas composition need to be resolved before the gas can be used in combustion systems. - High cost is associated with initial setup and operation of these facilities. - The problem of disposing the residues remains valid. - Boiler or furnace burner system must tolerate contaminants and not be susceptible to fouling.	- Technically, feasible. - Financially, feasible for a small scale operation as set up cost can be small.

The high heating value of OMSW implies that OMSW is an excellent source of renewable energy. In terms of contribution of utilization of OMSW as a source of energy in energy cost savings in Palestine, calculations are carried out as shown in Table 5.2 for the agricultural years 2002 and 2003, using firing- direct combustion of exhaust OMSW as a potential use alternative.

Table 5.2: Energy cost savings in Palestine using firing (direct combustion of exhaust OMSW).

Item	Agricultural Year in Palestine	
	2002	**2003**
1. Quantity of processed olives in metric tones	124,564	45,054
2. Quantity of produced OMSW (35-45% of 1) in metric tones (Schroeder and Luxconsult, 1999)	43,000-56,000	15,000-20,000
3. Equivalent quantity of exhaust OMSW (77% of 2) in metric tones (Sansoucy, 1985)	33,110-43,120	11,550-15,400
4. Price of total quantity of exhaust OMSW produced in USD (cost/metric tone = 20 USD) (Masghouni and Hassairi, 2000)	662,200-862,400	231,000-308,000
5. Equivalent No. 2 Heavy Fuel in metric tones (407 metric tones of No. 2 Heavy Fuel = 1, 073 metric tones of exhaust OMSW) (Masghouni and Hassairi, 2000)	12,560 - 16,356	4,381 - 5,841
6. Price of equivalent No. 2 Heavy fuel in USD (cost/metric tone = 125 USD) (Masghouni and Hassairi, 2000)	1,570,000 – 2,044,500	547,625 – 730,125
7. Percent of energy cost savings when exhaust OMSW is used to replace No. 2 heavy fuel (Firing-direct combustion of exhaust OMSW)	58 %	58 %

6. Conclusions and Recommendations

As found in this study, OMSW makes a potential source of environmental pollution in its raw form. In Palestine, suitable and acceptable OMSW disposal measures are not taken and the by product is under utilized. When utilized to its full potential, OMSW can be used as a source of energy, fertilizer, animal feed, or in manufacturing. Utilizing OMSW helps in environmental protection against solid waste pollution. In addition, farmers and energy generation industries can benefit from utilizing the by product.

The characteristics of OMSW vary according to the origin of olives and the type of extraction process used. However, the characteristics of OMSW show that the by product can be a source of pollution in its raw form. Also, such characteristics show that OMSW has the potential to be utilized as animal feed, fertilizer, or as a source of energy. The most attractive feature of OMSW is its high heating value, which implies that OMSW is an excellent source of renewable energy.

It is recommended to raise the awareness of farmers and power generation industries on the potential of utilizing this by product. Also, experimental studies on utilizing OMSW as a source of energy and fertilizer are recommended in Palestine and such studies should receive the appropriate attention and support. Palestinian laws or regulations are needed to encourage the use of OMSW as a fuel or as a source of energy.

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